BOOK OF ABSTRACTS

MCLS CONFERENCE 2022

June 1st-3rd 2022 | Belgium

CONTENT

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WEDNESDAY 1 JUNE 2022

List of abstracts
(chronologically in order of the program)

Symposia: 9:00am - 10:30am

Challenges in Mathematical Cognition: Are We Making Progress?

Chair: Matthew Inglis

Loughborough University, United Kingdom

In 2014 a group of sixteen researchers participated in an event that had the aim of identifying and discussing the most important challenges that mathematical cognition faces as a discipline. Based on previous exercises (Sutherland et al., 2006; Sutherland et al., 2012), we identified 26 research questions via a six-stage process (Alcock et al., 2016). The introduction to the symposium outlines the process used in the 2014 exercise. The remainder of the symposium consists of a series of reflections on the extent to which progress has been made towards answering the questions since 2014.

References:

Alcock, L., Ansari, D., Batchelor, S., Bisson, M. J., De Smedt, B., Gilmore, C., ... & Weber, K. (2016). Challenges in mathematical cognition: A collaboratively-derived research agenda. Journal of Numerical Cognition, 2(1), 20-41.

Sutherland, W. J., Bellingan, L., Bellingham, J. R., Blackstock, J. J., Bloomfield, R. M., Bravo, M., ... Zimmern, R. L. (2012). A collaboratively-derived science-policy research agenda. PLOS ONE, 7(3), Article e31824.

Keywords: challenges, research agenda, progress

Presentation 1: Longitudinal predictors of the development of number skills, arithmetic and other aspects of mathematics - have we made progress?

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Ansari, Daniel (Western University); Göbel, Silke* (University of York)*

We will take turns in presenting brief reviews of recent results from studies on several domain specific longitudinal predictors (e.g, nonsymbolic number comparison, transcoding, ordering). Each overview of recent results will be followed by a brief critique. We will also discuss possible interactions between these predictors with domain-general factors and whether we know now more about the direction of associations.

Presentation 2: Is developmental dyscalculia qualitatively different from arithmetic performance at the lower end of the normal distribution?

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De Smedt, Bert (KU Leuven)*

Since its first scientific description, developmental dyscalculia has been defined as a distinct disorder. One outstanding conundrum has been to which extent this condition reflects the lower end of a distribution or whether it represents a qualitatively different entity, and this echoes debates on dimensional vs. categorical perspectives on neurodevelopmental disorders. Are predictors of mathematical performance different from what has been observed in the typical population? Are the functional brain networks supporting arithmetic in dyscalculia different from what has been observed in typically developing children? Are different interventions needed to enhance mathematical performance in dyscalculia as compared to children with low achievement in mathematics? I will discuss the progress we made in answering these questions since 2014 and highlight what additional evidence would be needed to know whether dyscalculia is qualitatively different from the lower end of the distribution or not.

Presentation 3: What are the features (including content of intervention or instruction and characteristics of children) of current successful interventions & instruction?

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Hodgen, Jeremy (University College London); Solstad, Trygve* (NTNU Norwegian University of Science and Technology)*

Over the past decade, there has been a vast expansion of interest in the design, implementation and evaluation interventions and instructional strategies from academics as well as 'What Works' centres like the Education Endowment Foundation in England. Yet, despite this work, the evidence about the efficacy of interventions in normal classroom conditions is at best weak. I (oe we) will suggest how this might be addressed through attention to implementation and replication studies.

Presentation 4: Where hasn’t there been progress?

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Gilmore, Camilla (Loughborough University); Simms, Vic* (Ulster University)*

We will consider areas where limited or no progress has been made in the past ten years. We will identify the conceptual, methodological and practical reasons for this and discuss what the field may need to move forwards.

Registered Reports on Early Mathematics Interventions: Process, Challenges, and Key Considerations

Chair: David Purpura

Purdue University, United States of America

Registered Reports are an important mechanism for dissemination of high-quality research because they have rigorous external review prior to implementation and enable well-conducted null findings to be published in the literature minimizing publication bias. However, registered reports are relatively new for early mathematics interventions. The three studies in this symposium are early mathematics intervention studies that have all been accepted as Stage 1 Registered Reports and are in process of being completed. The symposium objectives are to present the studies, their process, the challenges with designing/implementing registered reports—both in general and in the context of the global pandemic.

Keywords: registered reports, mathematics, numeracy, preschool, intervention

Presentation 1: Mechanisms Underlying Transfer from Domain-Specific and Domain-General Cognitive Training to Children’s Math Skills

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Ribner, Andrew (University of Pittsburgh); Libertus, Melissa (University of Pittsburgh)*

Individual differences in the precision of non-symbolic representations of number and mapping between non-symbolic and symbolic number representations predict math achievement. Furthermore, prior investigations have suggested that honing these representations improves math skills. The goal of this registered report is to disentangle potential mechanisms of transfer. Approximately 324 children aged 4-6 years enrolled in one of about 20 classrooms will be assigned to one of three, 5-week computerized, teacher-facilitated training conditions for a total of 10 training sessions. Children will be randomly assigned to a condition which targets their non-symbolic number processing, mapping between non-symbolic and symbolic number formats, or executive function. We intend to explore three primary mechanisms through which training-related improvements might operate: Improvement in non-symbolic number processing, in mapping between symbolic and non-symbolic number representations, or in attention to number. This investigation has in-principle acceptance; however, due to the COVID-19 pandemic, participant enrollment is not yet complete. At the time of presentation, descriptive characteristics for approximately two-thirds of the proposed sample will be presented. We will discuss the process of proposing and subsequently initiating this research study as a registered report. In particular, we will discuss logistics of coordinating the process of submitting a registered report—which underwent three rounds of revision elapsing 11 months—with beginning in-classroom data collection with a school district and in-person data collection in the uncertain context of the COVID-19 pandemic.

Presentation 2: Assessing the impact of LEGO® construction training on spatial and mathematical skills

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Farran, Emily (University of Surrey); McDougal, Emily (University of Surrey); Silverstein, Priya (University of Surrey); Treleaven, Oscar (University of Surrey); Jerrom, Lewis (University of Surrey); Gilligan-Lee, Katie (University of Surrey); Gilmore, Camilla (Loughborough University)*

There is a known association between LEGO® construction ability, spatial thinking and mathematical abilities. The aim of this study is to determine whether this relationship is causal, by measuring the impact of Lego construction training on Lego construction ability and a range of spatial and mathematical abilities. On account of the digital revolution, we will also compare the impact of physical vs. digital Lego training. Children aged 7 to 9 years will take part in one of three training packages: physical Lego training; digital Lego training; and control training (craft activities). Each training package comprises twelve 30-minute sessions. Pre- and post-test tasks include: Lego construction ability, spatial skills (disembedding, visuo-spatial working memory, spatial scaling, mental rotation, and a number line task) and mathematical abilities (geometry, arithmetic, and mathematical problem solving). We predict improvement in both spatial and mathematical skills for both Lego interventions, relative to the control condition. This study has in principle acceptance as a registered report. Due to the COVID-19 pandemic, data collection is not complete. We will also discuss the pros (and cons) of conducting a pre-registered study during a pandemic. This research will both contribute to the development of theories of mathematical cognition and identify the potential of Lego/block construction training to support mathematics learning.

Presentation 3: Unique and Combined Effects of Quantitative Mathematical Language and Numeracy Instruction Within a Picture Book Intervention

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Purpura, David (Purdue University); O'Rear, Connor (Purdue University); Ellis, Alexa (Purdue University); Logan, Jessica (Ohio State University); Westerberg, Lauren (Purdue University); King, Yemimah (Purdue University); Vander Tuin, Mackenna (Purdue University); Ehrman, Patrick (Purdue University); Cosso, Jimena (Purdue University); Zippert, Erica (Purdue University); Hornburg, Caroline Byrd (Virginia Tech); Schmitt, Sara (Purdue University); Dobbs-Oates, Jennifer (Purdue University)*

Children’s early understanding of mathematics provides a foundation for later success in school. Identifying ways to enhance mathematical instruction is crucial to understanding the ideal ways to promote academic success. Previous work has identified mathematical language (i.e., words and concepts related to early mathematical development such as more, same, or few) as a key mechanism that can be targeted to improve children’s development of early numeracy skills (e.g., counting, cardinality, and addition). Current recommendations suggest a combination of numeracy instruction and quantitative mathematical language instruction to promote numeracy skills. However, there is limited direct support of this recommendation. The goal of this registered report is to compare the unique and combined effects of each type of instruction on children’s numeracy skills. Approximately 240 preschool children (ages 3 to 5) were randomly assigned to one of four conditions: (1) quantitative mathematical language only (e.g., more or fewer), (2) exact numeracy only (e.g., cardinality, addition), (3) a combination of quantitative mathematical language and exact numeracy, or (4) a non-numerical (control) condition. The intervention is currently underway and will be completed in March. Post-testing will be completed in March and April. We will discuss initial findings as well as challenges in designing and implementing registered report studies both generally and in the context of the ongoing pandemic. Notably, we will highlight the importance of documentation, clear detailed decision rules, and collaborative decision making throughout the process.

Discussant

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Hart, Sara (Florida State University)*

The discussant will provide a synthesis of the three talks and generate key questions to lead participation.

Does Everybody? Does Anyone? Do They Always? Within-Subject Prevalence and Stability of Numerical Cognition Effects

Chair: Julia Bahnmueller and Krzysztof Cipora

Loughborough University, United Kingdom

In experimental psychology we generalise a lot. Having tested some participants (a sample) we might observe a group-level effect. Based on that, we typically make, at least implicitly, two types of generalisations: (1) that the group level effect is reliably reflected at the level of individual participants, (2) that the effect is present within an individual in a stable manner across different time points. In this symposium we aim at challenging assumptions underlying these two generalisations and provide an idea on how to look at numerical cognition data from a new perspective.

Keywords: individual variability, individual stability, numerical cognition effects

Presentation 1: On the Individual Prevalence of Cognitive Phenomena: Integrative Reanalysis of Multiple Unit-Decade Compatibility Studies

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Cipora, Krzysztof (Loughborough University, United Kingdom); Thoma, Georges (Loughborough University, United Kingdom); Conolly, Hannah (University of York, UK); Bowman, Kristen (Tarleton State University, Texas, USA); Faulkenberry, Thomas (Tarleton State University, Texas, USA); Moeller, Korbinian (Loughborough University, United Kingdom); Nuerk, Hans-Christoph (University of Tuebingen, Germany); Bahnmueller, Julia (Loughborough University, United Kingdom)*

Cognitive phenomena have typically been studied at the group level, with little consideration of individual differences. The same holds true for many effects in numerical cognition, such as the Unit-Decade Compatibility Effect (UDCE). Despite its replicability at the group level, little is known about its prevalence at the individual level. We leverage existing raw trial-level data from multiple research groups to robustly examine the individual prevalence of UDCE using four different approaches: a psychometric and two bootstrapping methods, as well as hierarchical Bayesian models. This comprehensive framework not only allows to investigate the individual prevalence of the UDCE but can be generalised across several other phenomena across (numerical) cognition, which are expressed as a difference between two experimental conditions (i.e., compatible versus incompatible). It allows for answering the “does everybody” question across cognitive phenomena and for evaluating the robustness of individual prevalence estimates across analytical approaches. Within each method participants can be classified as revealing a reliable effect, revealing a reliable reverse effect, or not revealing a reliable effect. Additionally, the lack of an effect can be directly quantified and supported within the Bayesian approach. Preliminary results indicate that the UDCE is reliably present across a substantial proportion of participants, and that there is a high degree of agreement between different analytical approaches.

Presentation 2: Inter-Individual Variability in the Emergence of Canonical Finger Pattern Recognition

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Bahnmueller, Julia (Loughborough University, United Kingdom); Barrocas, Roberta (Leibniz-Institut für Wissensmedien, Tuebinge, Germany); Moeller, Korbinian (Loughborough University, United Kingdom); Roesch, Stephanie (Hector Research Institute of Education Sciences and Psychology, University of Tuebingen, Germany)*

Through repeated use of fingers for counting and representing numerical magnitudes in early childhood, specific finger patterns become associated with mental representations of specific quantities. Although children as young as three years of age already use their fingers for representing numerical quantities, evidence on advantageous recognition of such canonical compared to non-canonical finger patterns as well as its association with numerical skills in young children is scarce. In this study, we investigated the performance of n=101 children aged around four years in canonical vs. non-canonical finger pattern recognition and its concurrent association with skills tapping into children's' knowledge about quantity-number linkage. Extending previous findings observed for older children, the present results indicate that performance in canonical finger pattern recognition was better compared to non-canonical finger pattern recognition on the group level. However, the observed canonicity advantage on the group level seemed to be driven by a subset of children. These inter-individual differences in the emergence of canonical finger-based representations of number magnitude in young children support the idea of a comparably early but also developmentally scattered emergence of the canonicity advantage in finger-pattern recognition. On a more general level, our findings highlight the importance of also considering the individual level, especially in the context of onset and developmental trajectories of (early numerical) skills.

Presentation 3: Kindergartners' Intra-Individual Variability in Performance Across Foundational Numeracy Skills: A Micro-Genetic Study of Log-File Process Data

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Grimes, Rene (Tennessee Technological University); Chitiyo, George (Tennessee Technological University)*

Researchers agree that students need many opportunities to practice yet how much practice is necessary to master specific concepts is virtually silent (e.g., Brinums et al., 2018). Moreover, deliberate practice (e.g., Ericsson, 2020) appears necessary to master skills. One potential vehicle for providing deliberate practice is an intelligent tutoring system (ITS) which provides instruction in tandem with dynamic assessment. Grimes et al. (2021) included an ITS for numeracy in a recent conceptual replication study incorporating a wait-control design with a small sample of kindergarten students. Both groups significantly increased their numeracy skills only after using the ITS. Between group variance was not significant at pre-test, nor post-test after treatment. Interestingly, the outcome measure included concepts that were not part of the instruction provided by the ITS, thus the purpose of the current study was to identify specific tasks that may have contributed to the growth. The hypothesis was that micro-genetic analysis of the log-file process data could shed light on specific numeracy tasks predictive of the increased outcomes. Contrary to the hypothesis, results did not provide insight into specific tasks, rather, at the individual level, participants varied in the number of practice opportunities they required to reach mastery for different concepts. Implications include warnings for analysis of raw log-file data without background of the context and suggest that instructional pacing schedules based on a perceived norm of performance may hinder mastering foundational numeracy skills.

Presentation 4: The Ironman SNARC: Intra-Individual Stability of the SNARC Effect

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Roth, Lilly (University of Tuebingen, Germany); Knödler, Verena (University of Tuebingen, Germany); Schwarz, Stefania (University of Tuebingen, Germany); van Dijck, Jean-Philippe (Thomas More University of Applied Sciences, Belgium); Willmes, Klaus (RWTH Aachen University, Aachen, Germany); Nuerk, Hans-Christoph (University of Tuebingen, Germany); Cipora, Krzysztof (Loughborough University, United Kingdom)*

In (numerical) cognition, researchers often implicitly assume that the presence of group-level effects reliably reflects performance of individual participants, which is not necessarily the case. On top of that, cognitive psychologists often generalise from single observations of the participants to their typical behaviour. However, studies aimed at showing the test-retest reliability of the phenomena under scrutiny challenge this generalisation by suggesting dramatic variations of scores in the same (numerical) cognition task obtained by the same participants in different sessions. Moreover, the presence and magnitude of typical (numerical) cognition effects such as the SNARC effect (Spatial-Numerical Association of Response Codes, i.e., faster left/right sided responses to small/large number magnitude respectively; Dehaene et al., 1993) might vary within participants or covary with aspects of the participant's current state. In this preregistered study, we aimed at exploring intra-individual stability of the SNARC effect. We took a fairly unique approach by not only looking at two time points, but instead asking our participants (n = 10) to perform the same parity judgment task once a day on 30 within 35 consecutive days. Both the SNARC effect in absolute terms and its intra-individual stability in each session were investigated. We also looked at effects of situated factors, namely sleep duration, tiredness, time of day and consumption of stimulants like coffee.

New empirical insights into students' processing of and dealing with rational numbers

Chair: Katharina Loibl

University of Education Freiburg, Germany

Although rational numbers and their properties are a central topic in primary and secondary school education, students and even adults have severe difficulties acquiring an adequate understanding of this topic.

To illuminate the difficulties that students across different age groups experience and to develop potential approaches to overcome them, in this symposium, we focus on three different aspects of rational numbers: rational number arithmetic, understanding of magnitude, and translation among different representational formats.

The discussant of the symposium will be David Braithwaite (Florida State University) who will also deliver an integrated discussion as the fourth contribution in the symposium.

Keywords: Rational numbers, rational number arithmetic, magnitude, representational formats

Presentation 1: Blocked versus Interleaved practice for rational number arithmetic: Which dimension to interleave?

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Babari, Parvaneh (Schwyz University of Teacher Education); Schalk, Lennart (Schwyz University of Teacher Education)*

Research indicates advantages of interleaved over blocked practice (Rohrer et al., 2020), but in mathematics textbooks blocked practice remains prevalent. With regards to rational number arithmetics, the blocked presentation of tasks can partially explain misleading overgeneralizations of strategies and other errors, whereas interleaved practice may help to diminish such errors (Braithwaite et al., 2017). For the case of rational number arithmetic, however, there are different ways of interleaving tasks. They could be interleaved by operation types (i.e., addition, subtraction, multiplication and division) and/or by representation formats of rational numbers (i.e., fractions and decimals). Across two experiments, we tested different ways of interleaving for practising rational number arithmetic.

In Experiment 1 (N = 79 6th graders), we contrasted blocked with two variations of interleaved practice. Specifically, only arithmetic operations were interleaved, but not the representation format. In Experiment 2 (N = 76 6th graders), we again contrasted blocked with two variations of interleaved practice, but this time interleaving both operation types and representation formats. In both experiments, students practised rational number arithmetics for eight sessions (45 mins each) with a web-based software which provided automatic feedback for all tasks. Students' performance was assessed with a pre-, an intermediate, a post-, and a delayed posttest. Our overarching results showed no advantage of interleaved practice in both experiments; that is, all experimental groups improved significantly but did not differ from each other. We will discuss potential reasons for this null finding.

Presentation 2: Disentangling the roles of magnitude processing, biases, and benchmarking in fraction comparison tasks for sixth grade students

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Reinhold, Frank (University of Education Freiburg); Leuders, Timo (University of Education Freiburg); Loibl, Katharina (University of Education Freiburg)*

Research on fraction comparison shows that students typically follow clear and replicable biased patterns (e.g., natural number bias, i.e., 4/9>2/3, because 4>2 and 9>3, Gómez & Dartnell, 2019; Rinne et al., 2017). However, the role of benchmarking (e.g., 4/9<2/3, because 4/9<1/2 and 1/2<2/3, Obersteiner et al., 2020), the role of fraction magnitude processing (indicated by a distance effect, i.e., the smaller the numerical distance between the fractions, the more difficult the item, DeWolf & Vosniadou, 2015), and whether students rely on biased patterns only in tasks that do not allow for salient benchmarking strategies (e.g., Reinhold et al., 2020), remains unclear.

To further explore these complex relationships, we developed a balanced 2x2-dimensional itemset (congruent vs. incongruent items; benchmarking vs. non-benchmarking items) and a Bayesian classification of students' performance (solution patterns, response time and individual distance effect), which we applied to an assessment of N=191 sixth graders. We could show that the classification of the students' with respect to possible solution strategies matched our hypotheses: We could replicate existing patterns and found additional 'benchmarking or bias'-patterns with a bias only in non-benchmark items. For further analyses we expect to find 'benchmarking or magnitude'-patterns (i.e., distance effect only in non-benchmarking items) in addition.

Our study extends previous knowledge on individual strategies in fraction comparison and proposes a new Bayesian approach to interpret individual student profiles that can validly show existing patterns even with small subsample sizes.

Presentation 3: Adaptive rational number knowledge

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Van Hoof, Jo (University of Turku, Finland); McMullen, Jake (Department of Teacher Education (Turku))*

Rational number knowledge is a core component of mathematical development well into secondary school. An important but under-examined aspect of rational number knowledge is fluently switching between fraction and decimal representations. Fluency with such cross-notation skills may have a variety of applications in tasks involving rational numbers, such as supporting rational number arithmetic skills. Adaptive rational number knowledge involves the integration of procedural and conceptual knowledge in solving novel tasks and has been shown to be supported by cross-notation fluency.

The present study explores 108 9th grade students' ability to work across both fractions and decimals in various tasks, including a measure of adaptive rational number knowledge, the arithmetic sentence production task (i.e. using .5; ½; .25; 1/4; and 4 to come up with as many arithmetic sentences that equal 1 as possible in 2 minutes). Cross-notation solutions on the arithmetic sentence production task was associated with mental conversion fluency (e.g. Write ½ in decimal form) and ordering fractions and decimals together (e.g. Put 0.5; ¼; 5/100; and 0.356 in order from smallest to largest) than fraction and decimal arithmetic skills or ordering only fractions or decimals. These results reveal the value of being able to fluently move between different rational number notations for using rational numbers in flexible and adaptive ways.

An integrated discussion on the symposium

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Braithwaite, David (Florida State University)*

The discussant of the symposium will be David Braithwaite from Florida State University. He will present the fourth contribution in this symposium by giving an introduction on the topic and delivering an integrated discussion on the symposium contributions.

Symposia: 11:00am - 12:30pm

Finger-use and Arithmetic Skills in Children with Typical and Atypical Development

Chair: Laurence Rousselle

Université de Liège, Belgium

Recent findings suggest that the development of numerical and arithmetic skills is deeply rooted in finger-based sensory-motor experience. This symposium will examine the contribution of fingers to arithmetic development in children with typical and atypical development. The first objective is to provide further insight into the way fine motor skills, and finger counting support arithmetic development and should be integrated in education and intervention. The second objectives is to review the present state of knowledge about the nature and the mechanisms underlying finger/arithmetic relationship and to discuss futures directions on this issue.

References:

Barrocas, R., Roesch, S., Dresen, V., Moeller, K., & Pixner, S. (2020). Embodied numerical representations and their association with multi - digit arithmetic performance. Cognitive Processing. 21, 95–103.

Moeller, K., Martignon, L., Wessolowski, S., Engel, J., & Nuerk, H. C. (2011). Effects of finger counting on numerical development the opposing views of neurocognition and mathematics education. Frontiers in Psychology, 2, 1–5.

Soylu, F., Lester, F. K., & Newman, S. D. (2018). You can count on your fingers: The role of fingers in early mathematical development. Journal of Numerical Cognition, 4(1), 107–135.

Keywords: finger-based strategies, fine motor skills, arithmetic development, education, intervention

Presentation 1: Fingers and arithmetic: The selective relation of different components of fine motor skills and basic arithmetic in early childhood

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Roesch, Stephanie (Eberhard Karls University, Hector Research Institute of Education Sciences and Psychology, Tuebingen, Germany); Fischer, Ursula (Department of Sport Science, University of Konstanz, Germany); Suggate, Sebastian (University of Regensburg, Institute of Psychology and Education, Germany); Moeller, Korbinian (Centre for Mathematical Cognition, School of Science, Loughborough University, United Kingdom); Stoeger, Heidrun (University of Regensburg, Institute of Psychology and Education, Germany)*

Fine motor skills (FMS) and numerical skills were repeatedly observed to be associated in early childhood. The functionalist hypothesis accounts for this association by means of children using finger-based strategies (e.g., finger counting) during numerical development (e.g., Butterworth, 1999). Accordingly, we hypothesized components of FMS that are closely related to motor processes involved in finger-based strategies such as finger isolation (i.e., the ability to move single fingers separately) to be more strongly related to basic arithmetic skills than other components of FMS such as graphomotor skills (i.e., the abilities to trace a line). In a sample of 108 children, we evaluated associations of finger isolation, graphomotor skills and basic arithmetic skills both at 5;7 years of age (T1) and 10 months later (T2). Results showed that finger isolation, but not graphomotor skills were significantly associated with children's concurrent and later basic arithmetic skills, when control variables (i.e., general cognitive abilities, age, gender, and maternal level of education) were considered. However, in a cross-lagged-panel analysis considering auto correlations, both cross paths did not turn out to be significant: finger isolation failed to predict basic arithmetic at T2 when basic arithmetic at T1 was considered and basic arithmetic T1 failed to predict finger isolation T2 when finger isolation T1 was considered in the analysis. This suggests that components of fine motor skills are associated selectively with basic arithmetic, although they might not be functionally relevant for basic arithmetic skills in 5- to 6-year-old children.

Presentation 2: Learning arithmetic with and without finger-counting in visually impaired children

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Crollen, Virginie (Institute of Psychology (IPSY) and Institute of Neuroscience (IoNS), Université Catholique de Louvain, Belgium)*

The supremacy of vision in accessing numerical information has led some researchers to assume that number was a fundamental visual attribute. In this talk, I will present data examining counting (especially the use of finger-counting) and arithmetic in sighted and visually impaired children. If visual impairments often prevent the development of the finger-counting strategy, it does not necessarily lead to mathematics disabilities. Indeed, while visually impaired children are at risk of developping arithmetic difficulties, congenitally blind children often outperformed their sighted peers. If these data suggest that finger-counting is not necessary for the development of arithmetic, it nevertheless does not mean that this strategy cannot be useful. I will indeed show that an explicit kinesthetic finger-counting training can improve the mathematical abilities of visually impaired children. Within this context, the study of visually deprived individuals not only represents a unique opportunity to test the intrinsic relation between numerical cognition and vision but also provides important insights into educational practices.

Presentation 3: The evolution of finger counting strategies between kindergarten and grade 2

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Krenger, Marie (University of Lausanne, Institute of Psychology, Switzerland); Poletti, Céline (University of Lausanne, Institute of Psychology, Switzerland); Thevenot, Catherine (University of Lausanne, Institute of Psychology, Switzerland)*

Within this symposium, we will present the results of a longitudinal study that we conducted with 24 kindergarteners aged between 5-to-6-years who used their fingers to solve addition problems. We were interested in determining the evolution of their finger counting strategies towards mental strategies after 2 years (Grade 2). Kindergarteners who were the most proficient in calculating on fingers were the more likely to have abandoned this strategy in Grade 2. These children who had abandoned finger counting in Grade 2 more often resorted to more sophisticated finger counting strategies in Kindergarten, namely count-on strategies, than children who still used their fingers. This suggests that the use of efficient finger counting strategies early during development optimizes the shift to mental strategies later on during school curriculum.

Presentation 4: Finger-use and arithmetic skills in children and adolescents

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Neveu, Maëlle (Research Unit for Life-Course perspective on Health & Education , Faculty of Psychology, Speech and Language Therapy, and Educational Sciences, University of Liège, Liège, Belgium); Geurten, Marie (Research Unit for Life-Course perspective on Health & Education, National Fund for Scientific Research (F.R.S-FNRS), Faculty of Psychology, Speech and Language Therapy, and Educational Sciences, University of Liège, Liège, Belgium); Durieux, Nancy (Research Unit for Life-Course perspective on Health & Education, Faculty of Psychology, Speech and Language Therapy, and Educational Sciences, University of Liège, Liège, Belgium); Rousselle, Laurence* (Research Unit for Life-Course perspective on Health & Education, Faculty of Psychology, Speech and Language Therapy, and Educational Sciences, University of Liège, Liège, Belgium)*

Although the role played by fingers in children's numerical development has been widely investigated, their benefit in arithmetical context is still debated today. Considering the need to have clearer guidelines for teachers and intervention and to identify new research directions, this scoping review present a detailed and systematic synthesis of the reseaches which focused on the relation between fingers and arithmetical skills in children. A systematic search on the PsycINFO and Eric databases was conducted to identify eligible studies using rigorous inclusion criteria applied by two independent reviewers during both stages of selection (i.e., titles and abstracts screening, full-text review). Of the 4707 studies identified in the database, 68 met the inclusion criteria and 7 additional papers were add from the references lists of included studies. A total of 75 studies were finally included. Analyses of data showed that papers came from two main research areas and were conducted with heterogeneous methods. Studies that come from mathematical education (n=30) aimed at determining which finger strategies are used across development and how they support computation skills. The main objective of studies published in cognitive psychology and neuroscience (n=44) was to specified the cognitive processes and neurobiological mechanisms underlying the fingers/arithmetic relation. Only one study combined methods conducted in the both previous research areas. Future studies should focus on determining which finger strategy is the most effective, how finger sensorimotor skills should integrated into educational practices and whether it mediate the finger strategies/arithmetic relation.

Let’s Talk About Math: Math Language Input in Books and Parent-Child Interactions

Chair: Rebecca McGregor

University of Pittsburgh, United States of America

Math language input in books and parent-child interactions is central to young children’s math learning. The first paper examines the occurrence of math language input in both math and non-math picture books, revealing strengths and weaknesses in picture book features. The second paper identifies four parental styles of math language while sharing a picture and relations to children’s math talk. The third paper investigates the factor structure of parental math language and links to children’s math skills. Together, the three papers explore several opportunities for math language input and their role in young children’s math development.

Keywords: math language, books, parent-child

Presentation 1: Mathematical Language Input in Picture Books: A Systematic Analysis

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Splinter, Suzanne Elise (KU Leuven); op ‘t Eynde, Emke (KU Leuven); Wauters, Eveline (KU Leuven); Depaepe, Fien (KU Leuven, ITEC); Verschaffel, Lieven (KU Leuven); Torbeyns, Joke (KU Leuven)*

Cumulative evidence points to the potential of picture book reading (PBR) for stimulating young children’s mathematical development. In contrast to the literacy domain, studies on the mathematical content of picture books, and especially the occurrence of mathematical language, and on its contribution to PBR effectiveness are scarce. We aimed to address this gap by analyzing the mathematical features of picture books, including the presence of quantitative language (i.e., language to describe quantities and comparisons between quantities). We analyzed 100 publicly available picture books written with a mathematical aim and 45 matched picture books written without a mathematical aim in view of their features of numbers, sets and quantitative language (cf. Ward et al., 2017). Results revealed that both mathematical and non-mathematical picture books included quantitative language on at least one page, but with overall low frequency across pages and with limited variety in the terms used. Next, about half of the mathematical picture books included numbers 1-10, most often in an ascending order and represented as Arabic numerals and number words. Counting principles, ordinality, and basic mathematical operations were hardly included in this type of picture books. Non-mathematical picture books were even more limited in their mathematical content. Together, our findings point to both strengths and weaknesses in picture book features to promote mathematical dialogue during PBR, and stress the importance of including extra-textual mathematical input to stimulate mathematical interaction during PBR and as such children’s development.

Presentation 2: Exploring Links Between Styles of Parental Math Language and Children's Math Talk

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McGregor, Rebecca (University of Pittsburgh); Leyva, Diana (University of Pittsburgh); Libertus, Melissa E. (University of Pittsburgh)*

Prior work has investigated the associations between parents' use of individual math language features (e.g., questions, statements) and child math development using a variable-centered approach. However, many of these math language features frequently co-occur, suggesting that perhaps it is the way parents combine these math language features, rather than variability in parents' use of individual features that matters for children's math development. The current study addresses this gap by adopting a person-centered approach, in which styles are identified based on the naturally occurring combinations of math language features used by parents and relations between these styles and preschool children's math talk are examined. Participants were 76 mostly middle-income, White parents and their four-year-old children in the U.S. (M age = 53.32 months; 45% girls). Dyads were videotaped sharing a picture and conversations were transcribed and coded at the utterance level. Hierarchical cluster analysis and k-means cluster analysis revealed four distinctive parental styles of combining math language features (questions, statements, and confirmations). One of these styles was marginally significantly related to the proportion of children's math talk. Parents who adopted a style that equally used all three math language features were more likely to have children who talked more about math compared to parents who adopted the style that focused mostly on math questions. The presence of these styles suggests that certain ways of combining math language features may be more successful in fostering preschool children's math talk than others.

Presentation 3: The Factor Structure of Parents' Math-Related Talk and Its Relation to Children's Early Academic Skills

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*King, Yemimah A. * (Purdue University); Eason, Sarah H. (Purdue University); Duncan, Robert J. (Purdue University); Borovsky, Arielle (Purdue University); Purpura, David J. (Purdue University)*

The present study examines if parents' math language use (e.g., "fewer"), number talk (e.g., "five"), and general talk are distinct factors related to children's early academic skills. We hypothesize a three-factor model for parents' talk with parent math language use positively related to children's math language knowledge and numeracy skills, while number talk will be uniquely related to children's numeracy skills and parent general talk will be uniquely related to children's general vocabulary. Parent-child dyads (N = 120) in the U.S. participated in an observed interaction and children (Mage = 4.25, 52.5% female) completed assessments during a Zoom meeting. Parent and child speech transcriptions are nearly complete. Transcripts will be coded for cumulative instances of parents' number talk, mathematical language talk, and general (non-math) talk that occur during each of the three activities. This coding scheme will result in nine indicator variables that will be used to create the parent talk factors. To test the factor structure of parents' talk, a series of three CFAs will be conducted in Mplus. Next, a structural equation model (SEM) will be used to investigate the relations between the parent talk factors and children's general vocabulary, numeracy skills, and mathematical language. The SEM will include child's age, gender, parent-reported executive function, and parent's education as control variables. Transcription, coding, and analyses will be complete by April 2022. The findings could have significant implications for the development of home-based and center-based interventions to improve math support and school readiness of preschoolers.

Symposium Discussant

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Ramani, Geetha (University of Maryland)*

Dr. Ramani will serve as a discussant for this symposium.

Syntactic Contributors to Multidigit Number Processing

Chair: Michal Pinhas (1), Dror Dotan (2)

1: Ariel University, Israel; 2: Tel Aviv University, Israel

Numerical syntax captures the rules that allow constructing symbols – digits and number words – into meaningful numerical entities. Although numerical syntax presumably plays an important role in the way we perceive and manipulate numerical information, it is not well-understood. This symposium will highlight recent research exploring various aspects of numerical syntax: the connections between digit string length and numerical magnitude, and unique linguistic properties that emerge in multidigit number reading and transcoding in various languages. In doing so, it will shed new light on the contribution of syntactic number representations to the human ability to process multidigit symbolic numbers.

Keywords: numerical syntax, multidigit numbers, number length, numbers & language

Presentation 1: Do we compute the exact number of digits in the string when comparing different-length numbers?

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García-Orza, Javier (Numerical Cognition Lab, Universidad de Málaga, Spain); Gutiérrez-Cordero, Ismael (Numerical Cognition Lab, Universidad de Málaga, Spain); Álvarez-Montesinos, Juan. A. (Numerical Cognition Lab, Universidad de Málaga, Spain)*

Recent studies have shown that, when comparing multidigit numbers that differ in length (e.g., 2384-107), a decision is made considering length but also other attributes like the value of the initial digits (i.e., left-most digit/length congruity effect: faster responses to 2384-107 than to 2675-398). A non-solved issue is whether participants choose the number with more digits by exactly computing the number of digits in the string (e.g., 3 vs. 4) or whether they simply choose the perceptually larger item. In our first study participants were presented with pairs of different length numbers (3 vs. 4-digits) and were requested to decide which multidigit starts with a larger digit. Results showed more difficulties when the smaller digit was in the 4-digit length number, suggesting that length was automatically processed even although it was irrelevant for the task. In a second study, we presented participants with pairs of 3- and 4-digit-length numbers but obscured the processing of perceptual length by including a letter at the end of the 3-digit-length numbers (e.g., 8567-342M). Additionally, we manipulated the left-most-digit/length congruity effect and presented one string in each pair in a larger font than the other. Then we requested participants to do a physical size decision task. Together with an influence of the leftmost digit in the string, no effects of digit-length were observed, thus suggesting that the exact number of digits in the string is not processed automatically. It seems participants rely on perceptual information when comparing multidigit numbers that differ in length.

Presentation 2: The influence of the decimal structure on perceiving multidigit numbers as end-values

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Pinhas, Michal (Quantitative Thinking and Cognition Lab, Department of Psychology, Ariel University, Israel); Lozin, Mariya (Quantitative Thinking and Cognition Lab, Department of Psychology, Ariel University, Israel)*

Little is known about the end effect—faster responses for pairs containing the smallest/largest number in the set compared to non-end pairs—in multidigit numbers. The present study explored the influence of the decimal structure on perceiving multidigit numbers as end-values. In four experiments, participants performed three types of numerical comparisons between numbers from different scales: to a fixed lower end-value, to a fixed upper end-value, and non-end comparisons. In Experiments 1-3, different upper end-values (i.e., 10, 100, 1,000, 10,000, 100,000 or 1,000,000) were manipulated between-groups, while the lower end-value (i.e., 1, 10, or 100) was kept constant for all groups. In Experiment 4, different lower end-values (i.e., 1, 10, 100, 1,000, 10,000, or 100,000) were manipulated between-groups, while the upper end-value was 9,000,000 for all groups. The results revealed two novel syntactic end effects for comparisons of numbers from different scales: (1) a relatively small end effect for comparisons between non-end values and the adjacent scale (lower/upper) end-value (e.g., 700 vs. 1,000), and (2) a larger end effect for comparisons between non-end values and a lower/upper end-value with a gap of two scales or more (e.g., 700 vs. 10,000/1,000,000). These findings demonstrate that comparisons between multidigit numbers rely heavily on differences in the overall numbers' lengths, irrespective of their exact scales. In turn, the findings reflect the internalization of the syntax of the decimal structure, which associates number length and numerical magnitude, and its influence on our perception of multidigit numbers as the "smallest" or the "largest".

Presentation 3: Revisiting the triple-code model: Digit processing is not verbal, but it is linguistic

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Dotan, Dror (Mathematical Thinking Lab, School of Education and School of Neuroscience, Tel Aviv University, Israel)*

The triple code model states that digits and verbal numbers are handled by separate neural and cognitive mechanisms. Here, I show that although the processing of digits is not verbal per-se, it can still be considered as linguistic, because it is affected by several linguistic factors. I analyzed the errors adults made when reading aloud briefly-presented multi-digit numbers. They made fewer errors when the number included 0 or 1, indicating dedicated visual mechanisms to handle these two special digits. Critically, the particularity of 1 is solely linguistic (1 in the decade position yields a teen word). Second, the sensitivity to 1 was "switched on" only when the task required verbal number production, indicating a top-down linguistic effect on the visual analyzer. Third, the order of scanning the digits, measured by comparing the error rates between decimal positions (more errors indicate later processing), depended on language. In Hebrew, participants processed the digits from left to right, congruent with the word order in Hebrew. In Arabic, in which the word order is different (ones-tens, e.g., 32 = "two and thirty"), the digit scanning order was correspondingly different: the unit digit was processed before the decade digit. Last, when numbers were presented with a short delay between the decade and hundred digits, there were more errors compared to a delay between the hundred

and thousand digits – in agreement with the verbal number's triplet structure. Overall, these findings show that the digit-string processing mechanisms are affected by several specific aspects of language.

Presentation 4: Number word syntax is more relevant for transcoding than morphology – a cross-language approach

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de Almeida Gomides, Mariuche Rodrigues (Graduate Program in Psychology; Cognition and Behavior, Universidade Federal de Minas Gerais Belo Horizonte, Brazil); Lopes-Silva, Júlia Beatriz (Graduate Program in Psychology; Cognition and Behavior, Universidade Federal de Minas Gerais Belo Horizonte, Brazil); Moura, Ricardo (2Institute of Psychology, Universidade de Brasília, Brasilia, Brazil); Bahnmueller, Julia (Centre for Mathematical Cognition, School of Science, Loughborough University, United Kingdom, LEAD Graduate School & Research Network, University of Tübingen, Germany); Moeller, Korbinian (Centre for Mathematical Cognition, School of Science, Loughborough University; Leibniz-Institut für Wissensmedien, Tuebingen; LEAD Graduate School & Research Network, University of Tübingen; Individual Development and Adaptive Education Center, Frankfurt); Haase, Vitor Geraldi (Graduate Program in Psychology; Cognition and Behavior, Universidade Federal de Minas Gerais Belo Horizonte, Brazil)*

Number transcoding in languages with intransparent number word formation is more difficult as reflected by both poorer overall performance and specific error patterns. In the present study, we investigated how specificities of number word formation in German and Portuguese (i.e. the syntactic irregularity of unit-decade inversion in German and morphological irregularity of hundred words in Portuguese) differentially affect number transcoding at the beginning of elementary school. We evaluated performance of 148 children speaking Brazilian Portuguese (mean age 6;6 years;months) and 130 German-speaking children (mean age 7;4 years;months) in a transcoding task involving 1- to 4-digit numbers. Results indicated the expected language difference for specific error types due to syntactic irregularities. However, there were no systematic language differences for specific error types driven by morphological irregularities. The present study substantiates and specifies language-related influences on number transcoding by providing converging evidence that syntactic characteristics (such as the inversion property in German number word formation) seem to have a more pronounced impact on children's transcoding performance than morphological aspects (such as specific hundreds number words in Portuguese).

Understanding Cognitive Foundations of Mathematics across Development

Chair: Ilse Elise Johanna Ingrid Coolen

Université de Paris, France

Mathematics is not supported by a single neurocognitive system, but by a network of interrelated cognitive processes. Various cognitive skills have been identified as being part of this interrelated network, but their interactions and mechanisms across development are not fully understood. Spatial skills, executive functions, and domain-specific skills (such as number line estimation or non-symbolic magnitude comparison) have been found to predict mathematics achievement in children from various ages. This symposium aims at bringing together three international studies examining foundational cognitive skills to mathematics across development from the age of 3 years up to 9 years.

Keywords: spatial skills, executive functions, mathematical development

Presentation 1: Predictors of Mathematical Skill in Preschoolers: Does executive function impact the spatial-math link?

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Geer, Elyssa A. (Purdue University); Devlin, Briana L. (Purdue University); Korucu, Irem (Yale School of Medicine); Bryant, Lindsey M. (Purdue University); Purpura, David (Purdue University); Duncan, Robert (Purdue University); Schmitt, Sara (Purdue University)*

Research demonstrates a link between math and spatial skills, with some work suggesting that executive function may play a role in this relation (e.g., Atit et al., 2021). Despite this, more work is needed to examine how executive function uniquely relates to outcomes in math and spatial skills, particularly in young children. We aim to examine if the spatial-math link is impacted by executive function in preschoolers to address if the spatial-math link is moderated by executive function. The data for this ongoing study come from a sample of approximately 230 preschoolers from the Midwest United States. Math skills were measured using the PENS-B (Purpura & Logan, 2015) which assesses children’s early numeracy skills. Spatial skills were assessed using the Test of Spatial Assembly (TOSA; Verdine et al., 2017). Executive function was measured using the Head-Toes-Knees-Shoulders (McClelland & Cameron, 2011), Card Sorting Task (Zelazo, 2006), Day-Night Stroop (Gerstadt et al., 1994) and Hide-and-seek tasks (Garon et al., 2014). The data for this project is currently being collected and entered, as such we can only discuss proposed analyses and expected results. We plan to conduct two regression analyses to examine predictors of math skills and spatial skills. Specifically, we hope to examine if the strength of the relation between math and spatial skills is impacted by including executive function in the model. We expect there to be some difference in the magnitude of the relation between math and spatial skills when we account for executive function skill (Atit et al., 2021).

Presentation 2: Now you see it, now you don't – how the cognitive skills predictive of mathematics evolve across early development

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Coolen, Ilse E.J.I. (Université de Paris); Omont, Sixtine (Université de Paris); Knops, André (Université de Paris)*

Various cognitive skills are thought to be foundational to the development of mathematics. Indeed, both domain-general (such as spatial skills, inhibition and attention) and domain-specific (such as non-symbolic magnitude comparison or arithmetic) skills have been identified as good predictors of mathematics achievement over time. Due to the increasing complexity of mathematics education over time and the associated increase in cognitive demands, it can be assumed that a divergent set of skills is predictive of mathematics achievement at different ages. In addition, foundational cognitive skills are known to develop at various rates, suggesting that they might not be equally predictive of mathematics achievement across a child's development.

This cross-sectional study in children aged 3 years, 5 years and 7 years aims at identifying the differences in predictors of mathematics at the respective ages. Preliminary findings demonstrate an important role for non-symbolic magnitude comparison at the age of 3 years, spatial skills and non-symbolic arithmetic at the age of 5 years and non-symbolic arithmetic at the age of 7 years.

These findings support the notion that mathematics cannot be conceived as a unitary cognitive skill. A fine-grained analysis of the cognitive requirements of the mathematical skills at different ages is required to understand the determining factors.

Presentation 3: Associations and Mediator Effects Between LEGO® Construction and Mathematics Performance

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McDougal, Emily (University of Surrey); Silverstein, Priya (University of Surrey); Treleaven, Oscar (University of Surrey); Jerrom, Lewis (University of Surrey); Gilligan-Lee, Katie (University of Surrey); Gilmore, Camilla (Loughborough University); Farran, Emily K. (University of Surrey)*

There is a known positive relationship between LEGO® construction ability and mathematics skills. Despite this, it is unclear what drives this relationship. That is, which spatial skills mediate the relationship between Lego construction ability and mathematics, and if this differs for different mathematical subdomains. This pre-registered study investigated the mechanisms underlying the relationship between Lego construction abilities and mathematics, and whether this differs for physical vs. digital construction tasks. Children aged 7-9 years (N=358, Mage=8.67 years) completed a battery of spatial skills tasks (disembedding, visuo-spatial working memory (VSWM), spatial scaling, mental rotation, number line estimation) and mathematics performance (arithmetic, geometry, mathematical problem solving). They also completed a Lego construction task, either in a physical format (i.e., with concrete materials) or using our online game, BLOCS. A suite of mediation analyses were conducted to examine the strength of the mediating and direct pathways between Lego construction ability and mathematics, with our spatial skills battery as mediators. Estimated models explained between 8.2% and 26.5% of variance in mathematics. Spatial skills mediated relationships between Lego construction ability and mathematics, although the spatial skills at play differed between models. In the physical Lego condition, the geometry model was strongest (20.5%), partially mediated by disembedding, mental rotation and number line estimation. In the digital condition, the mathematical problem solving model was strongest (26.5%), partially mediated by number line estimation and VSWM. Findings will be discussed in relation to Lego construction as a candidate for spatial training to improve mathematics performance.

Presentation 4: Conclusions and future directions on cognitive foundations of mathematics development

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Gilmore, Camilla (Loughborough University)*

This symposium brings together 3 international studies examining a variety of cognitive foundations of mathematics at different ages. Elyssa Geer will present findings on the relations between spatial skills, executive functions, and mathematics in preschoolers. Next, focusing on 3-, 5-, and 7-year-old children, Ilse Coolen will examine the interactions between different domain-general and domain-specific skills across these age groups. Finally, Emily McDougal investigated the mechanisms underlying LEGO constructions and their link to mathematics through spatial skills in children aged 7-9 years. By gathering research from different age groups, this symposium allows us to get a better understanding of cognitive skills and their relation to mathematics across development from preschool up to the age of 9 years.

During the discussion we will consider the overarching conclusions that can be drawn across these, and other, studies and the next steps needed to build theoretical models of the cognitive foundations of mathematics development.

Poster session 1: 12:30pm - 2:30pm

1. No fingers, no SNARC? Spatial-Numerical Associations and temporal stability of finger counting

Mateusz Hohol* (1), Kinga Wołoszyn (1), Krzysztof Cipora (2)

1: Jagiellonian University, Krakow, Poland; 2: Loughborough University, Loughborough, UK

The SNARC effect is considered as strong evidence for the link between numbers and space. The studies have shown considerable variation in this effect. Among the factors determining individual differences in the SNARC effect is the hand an individual uses to start the finger counting sequence (Fischer, 2008). Left-starters show a stronger and less variable SNARC effect than right-starters. This observation has been used as an argument for the embodied nature of the SNARC effect. For this to be the case, one must assume that the finger counting sequence (especially the starting hand) is stable over time. Subsequent studies challenged the view that the SNARC differs depending on the finger counting starting hand. At the same time, it has been pointed out that the temporal stability of finger counting starting hand should not be taken for granted (Hohol et al., 2018). Thus, in this preregistered study, we aimed to replicate the difference in the SNARC between left- and right-starters and explore the relationship between the temporal stability of finger counting starting hand and the SNARC effect. We expected that higher stability should be associated with a stronger SNARC effect. Results of the preregistered analysis did not show the difference between left- and right-starters. However, further exploratory analysis provided weak evidence that this might be the case. Lastly, we found no evidence for the relationship between finger counting starting hand stability and the SNARC effect. Overall, these results challenge the view on the embodied nature of the SNARC effect.

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Keywords: finger counting, SNARC, embodied cognition, parity judgement task

2. Mathematics in Pre-Term Pre-Schoolers (MIPP)

Colette Duncan*, Victoria Simms

Ulster University, United Kingdom

There are numerous reasons why a child may struggle with mathematics (Harding et al., 2012). A risk factor for poor mathematical attainment is being born very preterm (VP, <32 weeks' gestation; Simms et al., 2015). The time spent learning in the home environment before entering school is a critical period for learning for term-born born children (Fox et al., 2010). Currently there is a lack of research focusing on the underlying mechanisms that may account for the difficulties that VP children experience in mathematics, such as environmental influences (Landry et al., 2003; Wocadlo & Rieger, 2007).

The current study has been informed by a systematic search, secondary data analyses and a pilot study. The overarching aim of the project is to identify if there are any group differences in parent-child interactions, parent's attitudes to education or home environment associated with mathematical skills of 3-4-year-old VP and term-born pre-schoolers (N=90). A novel virtual observation methodology will be used to assess parent-child interactions in the home environment whilst playing with mathematics related toys. These observations will be coded for three major aspects of scaffolding that have been previously shown to predict academic skills in mathematics: parents cognitive, emotional and autonomy support towards their child (Neitzel & Dopkins Stright, 2004; Leerkes et al. 2011). Measures will also include child responsiveness, home environment questionnaire and children's basic mathematics skills. Results to follow.

Keywords: Mathematics; Pre-term, Home Environment, Virtual Observation, Scaffolding

3. Changes in numerical cognition due to aging? A systematic review and meta-analysis

Hannah Dorothea Loenneker*, Hans-Christoph Nuerk, Christina Artemenko

Eberhard Karls University Tuebingen, Germany

Numerical cognition subsumes different components from basic number processing up to arithmetic and mathematics. Developmental research focuses mostly on children up to young adulthood. However, lifespan research on numerical cognition also describes distinct patterns of decline, stability or improvement in the elderly. Therefore, the aim of this systematic review with meta-analysis is (1) to identify differences and similarities in various numerical tasks between younger and older adults, (2) to identify moderators of numerical development, and (3) to find out when and which changes occur during aging.

This review follows the PRISMA criteria. We search for predefined terms in electronic databases of (un)published studies and assess original study quality. Studies are eligible when comparing performance of elderly and younger adults in numerical or arithmetic tasks or using standardized tests of numerical cognition with available age-specific reference norms. Studies not allowing to assess an age effect, only reporting neuro-imaging data and reviews will be excluded. Depending on the resulting data structure, meta-analyses will be conducted with random effects models or two-level models with nested effect sizes. Heterogeneity, moderator variables and potential publication bias will be examined. Subgroup analyses regarding age groups will be conducted using meta-regression.

Results will update existing reviews by systematizing numerical and arithmetic performance deficits and preservations associated with aging in the light of numerical and lifespan theories. The literature search is currently ongoing so that the results will be presented and discussed at the conference.

Keywords: number processing, arithmetic, aging, elderly, lifespan

4. A Review of Study Reporting Quality to Enhance Future Research Focused on Mathematics Interventions Conducted in Informal Learning Environments

Gena Nelson, Hannah Carter*, Peter Boedeker

Boise State University, United States of America

This poster presentation reports on the results of a review of study reporting quality of 23 math interventions conducted in home learning environments with children's parents as interventionists. With the rise in research on early math interventions conducted in home learning environments, researchers can benefit from targeted recommendations for enhancing study reporting to improve generalizability and replicability. We coded intervention studies for quality indicators related to describing: participants, intervention and comparison conditions, outcome measures, and results. Findings from this quality review indicate that studies met an average of 58.6% of the quality indicators, and follow-up analyses revealed that the quality of reporting has improved in recent years. Our analyses also indicated that specific areas of improvement for study reporting include: reporting children's disability and language background, describing the control condition activities and content, collecting and reporting delayed post-test data, and reporting effect size statistics.

Keywords: home math environment, intervention, study quality

5. Neural Translation between Perceptual and Abstract Numerical Representations

Michael Slipenkyj*, Ian M. Lyons

Georgetown University, United States of America

Translating between perception and abstraction is an important part of human cognition. In mathematical cognition, translation is frequently needed to shift between perceptual quantities (e.g. a set of seven objects) and abstract number symbols (e.g. '7'). Behavioral work has shown this translation to be cognitively non-trivial, yet it is unclear how the brain achieves this translation process. In the present fMRI study, fifty-six participants completed mental arithmetic, a verbal working memory task (as a control), and three magnitude-comparison tasks: analog-quantity comparison, symbolic-quantity comparison, and mixed-format comparison. Crucially, in the mixed-comparison task, participants must translate between perceptual and symbolic formats to correctly identify the greater quantity. Fifteen regions across a fronto-parietal network were characterized by increased activity for translation (mixed-comparison), over and above processing the constituent representations (analog- and symbolic-comparison). Within these regions, individual variability in mixed-comparison activity was unrelated to individual differences in working memory or task performance, suggesting analog-symbol translation cannot be explained by factors such as working memory or task demands. An alternative proposal is that the neural capacity to translate between perceptual and abstract representations of number may be a foundational aspect of mathematical thinking. In support of this idea, for a given individual participant, we show that the neural pattern elicited by translation uniquely predicted the pattern associated with arithmetic processing, controlling for both analog- and symbolic-comparison. Broadly, this work identifies the neural basis of analog-symbol translation of numbers and demonstrates that this neural translation may be a core component of more complex mathematical cognition.

Keywords: fMRI, arithmetic, format translation, number comparison

6. Experts in mathematics: Memory capacity for domain-specific material and mathematical creativity

Michaela A. Meier*, Franz Gross, Stephan E. Vogel, Roland H. Grabner

Educational Neuroscience, Institute of Psychology, University of Graz, Austria

The majority of previous expertise research has focused on narrow domains like chess. Much less emphasis has been put on broader, more education-oriented domains like mathematics. A systematic investigation of domain-specific and domain-general cognitive abilities and personality traits showed that when controlled for intelligence, mathematicians had a rather similar profile as non-mathematicians [1]. However, two constructs commonly associated with expertise have not been investigated so far: domain-specific memory capacity and creativity. Experts' superior memory for meaningful domain-specific material has been found consistently across fields of expertise [2], however, no such task exists for mathematics. Further, mathematical creativity is related to mathematical competence [3] and often connected to mathematical giftedness [4]. To date, there is no study comparing these constructs between mathematicians and non-mathematicians. The aims of the present work are to first evaluate the newly constructed memory task, where numerical and figural material is presented only briefly either in a structured, mathematical meaningful way, or unstructured. Second, to compare mathematicians and non-mathematicians in the above-mentioned task and in mathematical creativity. The sample for this online study will consist of a minimum of 60 adult mathematicians (with at least a bachelor degree) and the same number of gender, age, and educational level matched non-mathematicians. Additionally, general creativity, mathematical achievement, and intelligence will be assessed. Data collection will run in March 2022 and analyzed using Frequentist and Bayesian statistics. As shown in other domains, we expect mathematicians to show superior memory capacity as well as a higher mathematical creativity compared to non-mathematicians

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Keywords: mathematics, expertise, memory, creativity

7. Stability in toddlers' number word comprehension between 2 and 3 years

Alex M. Silver, Leanne Elliott, Heather J. Bachman, Elizabeth Votruba-Drzal, Melissa E. Libertus*

University of Pittsburgh, United States of America

Children's early number skills are foundational to later math performance, which in turn predicts school achievement and long-term educational outcomes (1). Previous work has identified a general timeline for children's acquisition of number words, suggesting children acquire the meaning of exact number words very slowly between two and five years of age (2). Additionally, there are individual differences in this process, such that children's own domain-general and domain-specific cognitive abilities are related to their cardinal principle understanding (3). However, little work has examined predictors of variability in children's developing number word knowledge prior to understanding the cardinal principle. Here, we examine the stability of individual differences in toddlers' number word comprehension over the course of one year (N=38, M age at first assessment = 2 years 8 months, range 2-3 years). We tested comprehension of number words via the Point-to-X task, a two-alternative forced-choice task presenting two quantities of identical objects where toddlers were asked to point to a specific quantity. Scores on the Point-to-X task were the percentage of correct responses. Toddlers' Point-to-X performance at the first assessment was significantly correlated with their performance one year later, $r = .42$, $p = .008$, suggesting stability in individual differences of number word comprehension. Moving forward, we will explore how other number skills (i.e., counting, cardinal principle understanding) and general cognitive abilities (i.e., executive functioning, vocabulary) may predict individual differences in toddlers' number word comprehension over time.

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Keywords: number word acquisition, toddlers, individual differences

8. Which Aspects of Fractions Knowledge Support Knowledge of Algebra Concepts, Procedures, and Flexibility?

Alexandria A. Viegut*, Ana C. Stephens, Percival G. Matthews

University of Wisconsin - Madison, United States of America

Fractions skills predict students' success in algebra (e.g., Siegler et al., 2012). However, some studies show that understanding fraction magnitude is most helpful for algebra (e.g., Booth et al., 2014), whereas other studies show that fraction arithmetic skill drives the fractions-algebra relation (e.g., Barbieri et al., 2021). Adding further confusion, "algebra" has been defined and operationalized in multiple ways, and sometimes not clearly defined at all.

Working towards a more nuanced model of the fractions-algebra connection, we investigated whether undergraduates' (n = 53) fraction magnitude knowledge (i.e., an average of their number line estimation and comparison accuracy) or fraction arithmetic was more closely related to three aspects of their algebra knowledge: procedural knowledge, conceptual knowledge, and flexibility (Star & Rittle-Johnson, 2007). We expected that fraction magnitude would relate to conceptual knowledge and problem-solving flexibility, whereas fraction arithmetic would relate to procedural knowledge.

We estimated three separate linear regressions predicting knowledge of algebra procedures, concepts, and flexibility from fraction magnitude knowledge, arithmetic accuracy, and covariates (i.e., math anxiety, working memory, and age). As hypothesized, we found that only fraction magnitude knowledge uniquely predicted conceptual knowledge of algebra (bstd = 0.4, p = .016), and only fraction arithmetic knowledge uniquely predicted procedural knowledge (bstd = 0.5, p = .005). However, algebraic flexibility was not significantly predicted by either component of fractions knowledge (ps > .20). These results highlight the importance of testing relations between specific components of fractions and algebra knowledge. Future research should also test mechanisms by which these relations emerge.

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Keywords: fractions, algebra, measurement, magnitude, arithmetic

9. Longitudinal associations between type of errors on repeating patterning tasks and repeating patterning, growing patterning and numerical ability

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Researchers have recently started to focus on the type of errors young children make while solving repeating patterning tasks (e.g., Borriello et al., 2022). The present study uses data from a longitudinal research project in which repeating patterning, growing patterning and numeracy ability were assessed in 407 children (194 girls) from age four to six (Wijns, Verschaffel, De Smedt, & Torbeyns, 2021). We coded the types of errors that four-year-olds (Mage = 4y10m) made on three repeating patterning tasks (i.e., extending, generalizing and identifying the unit). We analyzed the associations between these errors and children's performances on repeating patterning, growing patterning and numeracy tasks at age four, five and six. We made a distinction was made between structured (e.g., creating a different pattern) and non-structured errors (e.g., making a random arrangement or sorting the blocks on color, cfr. Borriello et al., 2022). Significant positive associations were found between the proportion of structured errors on a repeating patterning task and performance on that task at age four. Moreover, the proportion of structured errors at age four also positively correlated with overall performance on repeating patterning, growing patterning and numerical ability at age four, five and six. These results suggest that children's errors on a repeating patterning task are an indication of their later understanding of repeating patterns, as well as growing patterns and their numerical understanding. The study highlights the informative nature of children's errors on a patterning task, and joins the call for further research on this matter.

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Keywords: repeating patterning, early mathematics, preschool, error analysis

10. Numeracy gender gap in STEM higher education: The role of neuroticism and math anxiety

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The underrepresentation of women in Science, Technology, Engineering and Mathematics (STEM) is as pervasive that understanding its roots is mandatory to guarantee social and economic growth. In the present work, we investigated the contribution of non-cognitive factors on numeracy (Lunardon et al., 2022). Importantly, factors like math anxiety (MA) and neuroticism personality trait are higher in females. STEM undergraduate students, balanced for gender (NF = NM = 70) and IQ, completed online self-report questionnaires and a numeracy cognitive assessment test. With the expectation that Neuroticism would negatively influence the relationship between MA and numeracy, we applied a mediation model, in which the negative relationship between MA and numeracy was partially mediated by Neuroticism level. To this model, we added the moderating effect of gender, to assess differences between males and females in this relationship. Results showed that only for females neuroticism turned out as a significant positive mediator in the negative relationship between MA and numeracy. In subsequent analysises (in progress), we included non-STEM undergraduates (NF = NM = 93) to inspect whether previous results generalized. Results showed that Neuroticism significantly and negatively mediated the relationship between MA and numeracy without gender differences. In conclusion, the indirect effect of MA on numeracy through neuroticism differs in STEM and non-STEM females. Contrary to our expectation, in female STEM students neuroticism seems to benefit numeracy performance, while in non-STEM students its effect is negative regardless of gender. These results suggest that numeracy is differently supported by non-cognitive factors in females and males enrolled in STEM programmes.

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Keywords: mathematics, Big Five, non-cognitive factors, personality, undergraduate students

11. Context effects in numerosity comparison

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In the field of numerical cognition, the numerosity comparison task is considered the eligible method to assess non-symbolic numerical representations. The performance in this task has been related to symbolic numbers learning and more complex mathematical skills, both in children and adults. Traditionally, numerosity comparison has been employed as a pure index of non-symbolic numerical representations. However, in this paper it is demonstrated that the composition of the stimuli sets presented to the participants, something we will refer to as contextual features, influences the way numerosity is processed at the level of the single trial. We present two studies aimed at exploring how contextual features affect the accuracy in a numerosity comparison task. The results of our first study show that the more complex the pattern of covariation is between numerical and non-numerical cues (e.g., convex hull), the more participants will rely on numerical representations to solve the task. In a second study we found that participants' ability to judge numerosity trials differed when respectively more difficult or easier filler trials were included in the experiment. Our results suggests that contextual factors should be taken into account when interpreting the performance in a numerosity comparison task and its relation with mathematical achievement.

Keywords: numerosity comparison, context effects, non-numerical cues

12. Special Education Pre-Service Teacher Professional Mathematical Noticing

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It has been established that teachers play a critical role in student learning and success. It is therefore a cause for concern to learn that many teachers feel unprepared to teach mathematics, particularly to students with a disability (Ernst & Rogers, 2009). One way to improve teacher effectiveness of our teacher's is developing a pre-service teachers' (PST) pedagogical content knowledge (PCK; van Garderen et al., 2021).

To date, only one study has examined the relationship between beliefs, mathematics content knowledge and professional noticing practices using an intervention study (Fisher et al., 2018) but questions remain about mitigating factors (i.e., beliefs for teaching mathematics) and the relationship to professional noticing. Until this study there has yet to be a study that utilized general education and special education PST.

The participants in this study involved 120 PST (67 Special Ed, 53 General Ed) from one US university across three years of the program. Data sources included a mathematics belief scale, a teacher assessment to capture the knowledge teachers, and response activity to measure professional noticing.

The first outcome was the finding there is a relationship between a teacher's content knowledge of mathematics and a heightened sophistication for professional noticing. Further, content knowledge for teaching mathematics was found to be a predictor of professional noticing. The second significant outcome resulting from the study's findings was the link between a teacher's belief score and the professional noticing score; the more student-centered of a belief score, the more sophisticated the professional noticing.

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Keywords: Special Education, Mathematics, Professional Noticing, Pre-Service, disability

13. The Role of Language Modality and Variability on the Neurocognitive Processes Supporting Multiplication Problems

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Sparse research exists on the impact of language modality and age of exposure on arithmetic processing and even less on its underlying neurocognitive processes. Multiplication problems rely on phonological processes in the left-language areas for both hearing and deaf native signers1, with activations being functionally related to proficiency2. Unfortunately, deaf children are at risk for language deprivation3, with consequences for later academic success4. Research shows that deaf children underperform in math5,6,7 and fail to enter STEM careers8. Here, we want to investigate the impact of language variability on the language network recruited during arithmetic problems in deaf adults who use sign language. We hypothesize that a deficit in language-based working memory (LWM), a consequence of language deprivation9,10 will relate to the quality and quantity of neuromodulation observed in the phonological areas while solving multiplication problems. 30 Deaf participants with severe to profound hearing loss who declare using American Sign Language (ASL) as their primary language will be screened based on ASL knowledge and low spoken language access. Behaviorally, participants will be tested on an ASL LWM task and several other tasks. In the fMRI, participants will undertake a single-digit arithmetic task and an ASL phonology localizer task. By independently localizing the ASL phonological areas, we will be able to correlate performance to the ASL LWM task with activations for single-digit multiplication problems. Results will inform on the role of ASL LWM and language deprivation on the neurocognitive processes supporting arithmetic in deaf signers with significant policy implications.

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Keywords: language modality, working memory, neurocognition, arithmetic processing, fMRI

14. Distinct Contributions of the Cerebellum and Basal Ganglia to Arithmetic Procedures

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Humans exhibit complex mathematical skills, often attributed to the exceptionally large neocortex. Using a neuropsychological approach, we report that degeneration within two subcortical structures, the cerebellum and basal ganglia, impairs performance in symbolic arithmetic. Moreover, we identify distinct computational impairments in individuals with cerebellar degeneration (CD) or Parkinson's disease (PD). The CD group exhibited a disproportionate cost when the arithmetic sum increased, suggesting that the cerebellum is critical for iterative procedures required for calculations. The PD group exhibited a disproportionate cost for equations with an increasing number of addends, suggesting that the basal ganglia are critical for the coordination of multiple cognitive operations. In Experiment 2, the two patient groups exhibited intact practice gains for repeated equations at odds with an alternative hypothesis that these impairments were related to memory retrieval. Overall, the results provide a novel demonstration of the contribution of subcortical structures to the computations required for complex cognition.

Keywords: Subcortex, Arithmetic, Parkinson's disease, Ataxia

15. Exploring the link between number and action: an EEG study in preverbal infants

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In the last decades a growing literature has focused the attention on the link between number and action. Indeed, many studies conducted on adult populations have provided evidence for a bidirectional influence between numerosities and grasping/reaching actions (see e.g., Andres et al., 2004; 2008). However, findings about a shared mechanism for both processes in developmental populations are scarce. Here, we tested 33 infants of 3 months of age using the electroencephalography (EEG) method. In line with previous studies (Lunghi et al., 2019; Bettoni et al., 2021), we implemented a cueing paradigm, where infants were presented with images showing congruent (e.g., a large numerosity primed by a large hand opening) and incongruent (e.g., a large numerosity primed by a small hand opening) number-hand couplings. We recorded the EEG signal in both conditions and measured the ERPs responses at the onset of the target image (i.e., numerosity image), which revealed infants' different responses depending on the congruency of the couplings. These findings suggest that the association between number and hand action processing is already functional early in life.

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Keywords: number, action, infant, eeg

16. Developmental Differences in the Predictive Relationship between Fractions and Algebra

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Over the past decade, researchers have established a predictive relationship between students' fraction knowledge and algebra performance (1). For middle school students, fraction magnitude knowledge is predictive of algebra skills (2), however, only fraction computation knowledge predicts algebra performance for college students (3). When do these different facets of fraction knowledge become more or less important for algebra? In the present study, we examine developmental differences in fraction magnitude knowledge, fraction computation knowledge, algebra feature knowledge, algebra equation-solving, and the relationships between these measures for students (N=700) in grades 4-10. Results indicate that fraction skills develop early and are then stable once students hit middle school and beyond, whereas algebra skills consistently improve between late elementary school and high school. Fraction computation skills are consistently predictive of algebra feature knowledge and algebra equation solving skill at all grade levels. In contrast, fraction magnitude knowledge does not often predict algebra equation solving, and predicts algebra feature knowledge as students approach middle school, but becomes less predictive as students reach the grades in which they typically are taking Algebra 1 (i.e., 8th grade and beyond). Collectively, these results suggest that though fraction computation skills develop by middle school, individual differences in those skills may remain important for supporting algebra performance and learning even in high school. However, fraction magnitude knowledge, which develops early, may be particularly important for the development of early algebra skills, but may not play a role in students' learning of core algebra content.

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Keywords: Fractions, Algebra, Development

17. How amodal is the "Approximate Number System"? The role of spatial cues in an approximate cross-modal number matching task.

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The Approximate Number System (ANS) is thought to be an innate cognitive system that allows humans to perceive numbers (> 4) in a fuzzy manner. One assumption of the ANS is that numerosity is represented amodal due to a mechanism, which filters out non-numerical information from stimulus material (Brannon & Merrit, 2011). However, some studies, predominantly in the visual domain, show that non-numerical information (e.g., spatial arrangement of dot patterns) influence the numerosity percept as well (De Wind et al., 2015). The present study investigated if there is a cross-modal transfer of spatial information between the haptic and visual modality in an approximate cross-modal number-matching task. For this purpose, we presented different arrays of dowels (haptic stimuli) to 50 undergraduates (age, M(SD) = 23.22(4.48) years) for a 3.5s and asked them to compare the haptically perceived numerosity to two visually presented dot arrays. The dot arrays, visually presented for 300 ms, were either random patterns (incongruent) or spatially identical to the presented haptic stimulus (congruent). Participants chose which visually presented dot pattern matched the numerosity of the haptic stimulus. We hypothesized that if a "numerosity" percept is solely based on number, spatially congruent patterns would not have any processing advantage. However, results show significant processing advantages for congruent patterns indicating that spatial information is not only extracted from the haptic stimuli but also influences participants' responses. These results challenge the plausibility of the "strong" ANS-assumption that numerosity is represented in a truly abstract manner by filtering out any other stimulus features.

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Keywords: ANS, numerosity, cross-modal, spatial processing

18. How Flexible are Spatial Numerical Associations? A Registered Replication Report.

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Numbers are associated with space on a hypothetical mental number line, but it is unclear how fixed and/or flexible this association is. In the study presented here, we investigate this question using the SNARC effect (Spatial Numerical Association of Response Codes; Dehaene et al., 1993), i.e., faster responses to small/large number magnitude with the left/right hand, respectively. Previously, the SNARC effect has been found to be very flexible: The numbers 4 and 5 were associated with the right-hand side in the range 0-5, where they are the largest numbers, but associated with the left-hand side in the range 4-9, where they are the smallest numbers (Dehaene et al., 1993; Fias et al., 1996). Because relative magnitude, rather than absolute, seemed to play a crucial role, it was assumed that mental number representation flexibly adapts to context. However, closer inspection of the data reveals that absolute magnitude might also matter. Since the important conclusion of the SNARC effect's flexibility was drawn solely from the absence of evidence in underpowered studies, this descriptive observation deserves further investigation. We will therefore conduct direct (number ranges 0-5 and 4-9) and conceptual (number ranges 2-6 and 5-9) online replications of the parity judgment task. Besides traditional null hypothesis testing, we will also take advantage of Bayesian approaches. To achieve a power of > .90 for Cohen's d ≥ 0.20, we will conduct each experiment with 360 participants. We hypothesize that absolute and relative magnitude influence spatial-numerical associations, suggesting that these are both fixed and flexible.

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Keywords: spatial numerical associations, SNARC effect, flexibility, number ranges

19. Estimates of the growth of functions important to computer science

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Understanding the growth of functions plays an important role in computer science. People often have to identify the function which specifies the complexity of an algorithm (e.g., for sorting a list of numbers into ascending order) for a given input (e.g., a list of n numbers). Studies have shown that higher ANS acuity is correlated with better performance on tests of mathematical achievement. However,little is known about people's ability to estimate the growth of functions, and how it impacts performance at computer science. In a preliminary study, we asked forty-nine college students to make estimates of seven common functions in algorithmic analysis: log(n),sqrt(n), nlog(n), n^2, n^3, 2^n, n! where n = {1, 2, 3, 4, 6, 8, 10}. For each function, participants estimates were fit to all seven functions plus a baseline linear function. Estimates roughly followed the correct function, with the correct model (i.e., with the same function) offering either the best or second-best fit. Participants estimated logarithmic functions least accurately, with some appearing to adopt a linear approximation (e.g., 10n). Estimates of sublinear functions were generally best fit by models with sublinear functions,and analogously for superlinear functions and models. These results set the stage for further studies into the importance of understanding the growth of functions in computer science.

Keywords: computational thinking, function estimation, modeling

20. We Have to Use Letters Now?! Motivating Early Algebra Understanding

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Early algebra proficiency is foundational for later mathematics learning. Unfortunately, many U.S. students struggle to understand the purpose of algebraic notation and procedures. We developed modules that use system-of-equations (simultaneous equations) story problems to teach these early algebra concepts. We investigated whether immediate or gradual introduction of formalisms (notation and procedures) resulted in better learning outcomes by comparing two new approaches. The Motivated Concreteness Fading (MCF) condition begins with concrete story problems (e.g., 2 slices of pizza and 1 water cost $5) to motivate understanding of formalisms (2p + 1w = 5). Word equation notation (2 slices of cheese pizza + 1 bottle of water = $5.00) scaffolds concreteness fading and motivates the use of formalisms. Alternatively, the Formalism Contextualizing (FC) condition teaches formalisms first and exemplifies their application across story problems. We randomly assigned 6th- and 7th-grade students from U.S. schools to the MCF, FC, or positive control (Khan Academy) modules. Learning was operationalized as scores on a delayed post-test assessing comprehension of algebraic notation and procedures. Data collection is ongoing this school year (intended n = 100). We will compare learning outcomes resulting from each module against each other and the positive control. Based on prior work on concreteness fading (Fyfe et al., 2014) and purpose (Ainley, 2012), we hypothesize that learning will be highest with MCF, then FC, then control. If findings are as hypothesized, this would support the use of concreteness fading and system-of-equations story problems to better motivate early algebra learning.

Keywords: algebra, motivation, classroom intervention

21. Utilizing Coaching Conversations and the Data-Based Individualization Process to Influence Teachers' Mathematical Practice

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In the United States only 9% of Grade 8 students with disabilities and 37% of Grade 8 students without disabilities score at or above a proficient level in mathematics (National Center for Education Statistics, 2019), suggesting a need for targeted instruction and support, especially for students experiencing mathematics difficulty (MD). This situation increases the demand on middle grade mathematics teachers to improve outcomes prior to students taking algebra in high school. One way to meet this demand is by providing students with intensive intervention which requires an ongoing, data-driven problem-solving process that is individualized based on their needs, rather than a single intervention program or package, such as through using the Data-Based Individualization (DBI) Process. Specific to mathematics, the DBI process has been shown to be effective for improving the understandings and skills of students with mathematical difficulties (Bryant et al., 2016; Jung et al., 2018).

These data are part of a federally funded project aimed at improving the algebra readiness of middle-school students experiencing MD by supporting teachers to implement a DBI framework and refine their instructional practices through instructional coaching. The goal of this presentation is to provide cumulative findings across three years of coaching conversations and classroom observations focusing on implementation of DBI in the classroom. Findings indicate throughout coaching, teachers' observational scores in instructional practices of modeling, guided practice, planned examples, and independent practice all increased. While coaching on DBI specifically, positively affected teacher assessment practice and student algebraic readiness for those with MD.

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Keywords: Data-Based Individulization, Middle School, Algebra, Disability

22. Empirical validation of an early numeracy learning progression

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Numeric relational reasoning (NRR) is often defined as the ability to mentally analyze relationships between numbers or expressions, often using knowledge of properties of operations, decomposition, and known facts. When students solve problems using NRR, they integrate multiple early numeracy concepts through a "strategic" decision making process based on the relationships between numbers.

As part of a federally funded project, we articulated a learning progression for NRR in grades K-2. Learning progressions describe the development of students' understanding and represent increasingly more sophisticated and complex thinking. Learning progressions reflect a research-based sequence of how students move from novice to advanced thinking. We used an iterative development process that included a thorough analysis of existing literature, input from experts in the field of early numeracy, teachers' perceptions of the developmental appropriateness of specific knowledge and skills, and cognitive interviews with children.

The purpose of this presentation is to describe the theoretical and empirical process we used to empirically validate the NRR learning progression. We report results from an extensive review by experts will be reported. Also described are descriptive and inferential statistical analyses of survey results from approximately 300 teachers in grades K-2. We qualitatively analyzed cognitive interview data from 64 interviews with children in K-2 to identify themes in their reasoning skills. Quantitatively, we also analyzed their correctness data to examine our hypotheses about the progressive ordering of the knowledge and skills. We detail the confirmatory and divergent evidence and how we reconciled these outcomes to define the learning progressions.

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Keywords: numeric relational reasoning, learning progressions, mixed methods, validity, classroom assessment

23. Grey matter volume in the left inferior frontal cortex is associated with children's arithmetic and grammar skills

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Previous studies indicate a connection between various language skills in children and their mathematical achievement. Specifically, the development of grammar skills has been associated with the development of math skills (cf. Chow et al., 2021; Viesel-Nordmeyer et al., 2021). To date, however, the neural mechanisms underlying this relation are unknown. To identify the brain structures involved in both grammar and math abilities in children, we made use of two data sets of brain imaging studies of French children from age 8 to age 12 (n = 42 for sample #1, n = 53 for sample #2). Children underwent structural MRI scanning as well as behavioral testing on a grammar task (sample #1) and an arithmetic calculation task (sample #1 and #2). Using voxel based morphometry (VBM) analyses, we identified the brain regions in which grey matter volume (GMV) was associated with individual differences in grammar and arithmetic skills. Controlling for additional language skills (vocabulary, reading), IQ, sex, and age, we found a positive association between GMV and grammar skills in regions of the left perisylvian areas, including the left inferior frontal gyrus (IFG). Interestingly, our results also point to a positive association between GMV and arithmetic skills in the left IFG. This suggests that the left IFG might underlie the relation between grammar and arithmetic skills in children.

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linguistic skills in children with learning difficulties. Frontiers in Psychology, 12. doi: 10.3389/fpsyg.2021.793796.

Keywords: arithmetic skills, grammar skills, overlap, grey matter volume, VBM analyses

24. Building numeracy skills: Associations between DUPLO® block construction and numeracy in early childhood

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Research shows that children's block construction skills are positively associated with their concurrent and later mathematics performance (e.g., Nath & Szucs, 2014; Verdine et al., 2014). Furthermore, there is evidence that block construction training is particularly beneficial for improving early mathematics skills in children from low-Socio Economic Status (SES) groups (Bower et al. 2020), who are known to have lower maths performance than their peers (Dickerson & Popli, 2016). This study investigates the association between block construction and mathematics in children who are approaching the age of formal education in the UK (4 years). It also investigates whether the relation between block construction and mathematics differs between children from more vs. less affluent families. Participants included 116 children (M = 3 years 11 months, SD = 3 months) who each completed numeracy (Preschool Early Numeracy Skills Screener–Brief; Purpura et al., 2015), block construction, and receptive vocabulary tasks. SES data (parental income and educational level) and demographic information (child age, gender, ethnicity) were obtained from the parents. Regression analysis showed block construction accuracy explained 5.3% of the variation in numeracy after controlling for covariates. When separated by SES group, in children from less affluent families, block construction explained 14.9% of the variation in numeracy after covariates. In children from more affluent families, block construction explained no additional variation in numeracy. These findings highlight one possible intervention target for promoting maths-readiness in children of this age. More specifically, interventions involving block construction skills may help to reduce the poverty-led gap in UK children's mathematics attainment.

Keywords: block construction, mathematical development, socioeconomic status, numeracy, spatial skills

25. Exploring brain responses to division problems of various difficulty in adolescents

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Mathematical operations is one of the basic skills taught in school. Division is considered the most difficult, as it is the decomposition of a sum into equal quantitative parts. Division problems are the least studied mathematical operation in the literature. Functional magnetic resonance imaging (fMRI) studies in adults show that division problems elicit activity in medial frontal gyrus, middle frontal gyrus, inferior frontal gyrus, precuneus and caudate body. The present experiment examined fMRI activity in participants 15-17 years old during division tasks with three difficulty levels.

Participants (n = 15, 7 females; 15–17 years) performed the Parametric Math Task (PMT) while their brain activity was recorded using a magnetic resonance Philips Achieva dStream 3.0T scanner. The PMT contains division tasks with three levels of difficulty each indexed by 1-digit, 2-digit, 3-digit numbers. Tasks appear in 32 second blocks during which participants were asked to give as many correct answers as possible. Both accuracy and reaction time were emphasized. Data processing and analysis of MRI data were carried out using AFNI software.

Results showed that 2-digit and 3-digit division tasks showed more extensive superior parietal lobule and prefrontal activations in comparison to 1-digit division. Specifically, when the task becomes more complex, activation is observed in the right inferior parietal, right precuneus and bilateral inferior parietal. Prefrontal areas include the inferior frontal and middle frontal gyri.

Concluding, brain responses are modulated by task complexity in adolescents. Findings inform theories of cognitive development and mathematical cognition.

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Keywords: math cognition, division, adolescents, arithmetic, neuroimaging

26. Cortical quantity representations of visual numerosity and timing overlap increasingly but remain distinct

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Various quantities, including numerical and temporal quantities, show behavioral interactions. A predominant theory ascribes such interactions to a generalized magnitude system with shared neural responses between the quantities (1). Recently, 7T fMRI and neural model-based analyses have revealed largely overlapping networks of cortical maps with a topographic progression of preferred quantities: both the numerosity of visual objects (2) and the timing (duration and period) of visual events (3). Evidence that such quantity-selective responses are linked to perception of their respective quantity is accumulating. From posterior to anterior brain areas, the neural response preferences within both networks become more specific, more tightly linked to behavior, and more abstracted from sensory stimulus properties. As such, here we ask whether numerosity and event timing are being hierarchically transformed into a common representation that might underlie their behavioral interactions. We find that the cortical overlap between numerosity and timing maps increases in posterior-anterior and inferior-superior hierarchies. However, nowhere in these overlapping networks do we find consistent correlations between numerosity and timing preferences. Therefore, representations of these quantities are brought together in the same brain areas, without transforming them onto a common representation. This suggests that behavioral interactions result from interactions between distinct neural populations responding to different quantities.

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Keywords: Visual event timing, visual numerosity, fMRI, pRF modeling, topographic maps

27. Non-spontaneous finger use: a way to improve calculation in young children regardless of working memory and manual motor imitation skills

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The reduction of inequalities in mathematics learning, especially with young children, requires research on what helps young children to master basic numeracy skills and what may improve mathematics instruction.

Finger counting is known to improve calculation performance in 4-to-7-year-old typically developing children (Jordan et al., 2008). However, research has focused on the spontaneous way in which fingers were used while solving calculations. The present study aims at showing that out of the spontaneous nature of finger use, non-spontaneous finger use leads to better performance in simple calculation than calculation without finger use. More, as working memory and manual motor imitation skills were shown to impact spontaneous finger use (Dupont-Boime & Thevenot, 2018; Bonneton-Botté et al., 2022), measures were added to find out if these skills impact non-spontaneous finger use as well.

Preschoolers and first graders from 4 to 7 years old (N=67) performed 14 simple additions and subtractions once with compulsory finger use, and once without the possibility of finger use. A working memory task (Gimbert et al., 2019), and a manual motor imitation task (Vaivre-Douret, 2010) were also performed.

A model comparison demonstrated that non-spontaneous finger use enhanced calculation performance in all age-group children, even if it differed from group to group. Furthermore, in the non-spontaneous finger use condition, calculation performance increased irrespective of working memory spans or manual motor imitation skills.

Thus, supporting the effectiveness of non-spontaneous finger use in calculation tasks for 4-to-7-year-old children, the present results encourage further investigations of finger use training in young children.

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Keywords: finger use, finger counting, calculation, working memory, manual motor skills

28. Finger skills are linked with early mathematical development: New insights from 3D motion analyses

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Children's ability to use their fingers in numerical contexts is thought to contribute to the development of early mathematical skills (Fayol & Seron, 2005) While some authors argue that finger gnosia are good predictor of arithmetic development (Noël, 2005) , others choose to highlight the relationship between fine motor skills (FMS) and early numerical and arithmetic abilities (Asakawa & Sugimura, 2014). Currently, the contribution of finger coordination and dissociation, two component of FMS, to early mathematical development has been less investigated.

The purpose of this study is to explore how finger coordination and dissociation contribute to mathematical processing using 3D human motion analyses, a technique that provide fine-grained measures of both variables. Thirty-four preschoolers aged to 39 and 63 months were tested in finger dissociation and finger coordination tasks as well as tasks assessing early mathematical development (i.e,. number-word sequence skills, cardinality and computation abilities).

Hierarchical regression analyses were conducted to identify the finger skills most strongly related with the early numerical and arithmetic performance, controlling for age and global motor development. Results showed that counting and arithmetic skills were predicted by finger coordination whereas cardinality abilities were related with finger dissociation. These results outline the relationship between FMS and early mathematical abilities and suggest that finger skills could have decisive influences on the development of early mathematical concepts in young children.

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Keywords: Arithmetical development, Finger skills, 3D motion analyses

29. Impact of deafness on numerical tasks implying visuospatial and verbal processes

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The literature suggests that deaf individuals lag behind their hearing peers in terms of mathematical abilities. However, it is still unknown whether deafness differently affects the performance of numerical tasks depending on whether they rely on visuospatial versus verbal processes. We still do not know either the spatial frame of reference deaf individuals use to map numbers onto space in different numerical tasks. To examine these issues, deaf, hearing signer and hearing control adults were asked to perform a number comparison and a parity judgment task with the hands uncrossed and crossed over the body midline. Deafness appears to selectively affect the performance of the numerical task relying on verbal processes while keeping intact the task relying on visuospatial processes. Indeed, while a classic SNARC effect was found in all groups and in both hand postures of the number comparison task, deaf adults did not show the SNARC effect in both hand postures of the parity judgment task. These results are discussed in light of the spatial component characterizing the counting system used in sign language.

Keywords: deafness, numerical cognition, visuospatial, verbal, SNARC effect

30. Differences in Preschoolers' Use of Spatial and Quantitative Language by Prompt Type During Semi-Structured Block Play

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Knowledge of mathematical language, including quantitative (e.g., more) and spatial (e.g., above) terms, predicts early mathematical skill (Purpura & Logan, 2015). Pilot work found that preschoolers who engaged in semi-structured block play improved in their mathematical language more than a control group (Hedge's g=.37; Schmitt et al., 2018). Five types of prompts were used to structure block play across 14 sessions: a) simple prompts, b) simple prompts with a story, c) prompts to incorporate structural components, d) prompts with models of components, and e) prompts with models of complex structures. The present analysis explored whether the prompt types elicited different frequencies of quantitative and spatial language-use during building for children in the semi-structured condition (n = 24; Mage= 57.29 months, SD =6.29). For each child, quantitative and spatial words were coded from video and divided by the total number of words spoken per session. An average proportion was created for each prompt type.

More spatial language was used overall, and spatial language-use was fairly consistent across prompts (comprising 6.1%-6.9% of total words). However, prompts with models of complex structures elicited more quantitative language (4.5% of total words vs. 2.8%, 3.4%, 3.3%, and 3.6% for simple, story, components, and component model prompts, respectively). Children specifically used more comparing language (e.g., more) and number words. Although past work has demonstrated that block play elicits substantial spatial language (Ferrarra et al., 2011), the present work suggests that play may also be structured to increase use of quantitative language, providing a base for future instructional-design.

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Keywords: math language, quantitative language, spatial language, preschool math

31. Math-failure associations, attentional biases, and avoidance bias: Investigation of the relationship with math anxiety and behaviour in adolescents

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Math anxiety in adolescence negatively affects learning math and careers. The current study investigated whether three cognitive biases, i.e. math-failure associations, attentional biases, and avoidance bias for math, were related to trait and state math anxiety as well as math behavior (selecting difficulty level of math problems, math performance). Also, the relations with math self-concept were examined. A sample of 529 secondary school students performed three cognitive bias tasks, questionnaires and a math performance task, and reported their grades. Only math-failure associations were associated with trait math anxiety and predicted math behavior. However, math-failure associations did not show additive value predicting math behavior on top of trait math anxiety. Math self-concept fully mediated the relation between math-failure associations and math behavior. Although the correlational design of the current study does not permit any causal inferences, the findings suggest that math-failure associations might form a link underlying math self-concept, math anxiety, and math behavior. No evidence was found for attentional and avoidance biases in math anxiety and math behavior. Replication is necessary, and suggestions for future research involve improvement of assessment methods.

Keywords: math anxiety, math self-concept, cognitive bias

32. Uncovering the heterogeneous patterns in preschoolers' early numerical abilities

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Already at preschool age, substantial variability can be seen among children in their early numerical abilities. In this study, we used a person-centered approach to learn more about the different heterogeneous patterns that might exist in children's early numerical development. The study used data from a five-year longitudinal study that ran from preschool until Grade 3. Data from 352 children (178 boys, Mage = 58.26 months, SDage = 3.42) were used. Early numerical ability tasks (e.g., counting, number order, Arabic numeral identification) administered in both preschool year 2 and year 3 were used as profile indicators. A repeated measures Latent Profile Analysis identified four different pathways in children's early numerical development: a low (13%), below-average (29%), above-average (44%), and a high numerical ability pathway (14%). We further examined how general cognitive factors (working memory, spatial visualization ability, and vocabulary) and environmental factors (the home math environment) were related to the obtained pathways. Results indicated that working memory, spatial visualization ability, and vocabulary were significant predictors of pathway membership (but to a different extent). The home math environment was not found to play an important predictive role. The four numerical ability pathways performed differently on standardized mathematics achievement tests in Grade 1 and 3, and most of these differences remained after age, SES, and the abovementioned cognitive factors were taken into account. In all, the current study provided insight into the relevance of heterogeneous patterns in children's early numerical abilities.

Keywords: Numerical abilities, person-centered approach, working memory, vocabulary, spatial visualization

33. Use Them or Lose Them: Are Manipulatives Needed to Assess Numeracy and Geometry Performance in Preschool

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Assessment of children's competence is critical to understand to inform developmentally appropriate instruction. These assessments should be as simple to assemble and administer as possible so that teachers can easily use them to measure student learning and plan course content accordingly (Purpura & Lonigan, 2015). It is unclear whether or not children need concrete objects for thinking mathematically more generally, as many parents of young children assume (Cannon & Ginsburg, 2008), or if only 2D images of those objects are needed to assess children's mathematical knowledge. In two studies, we investigated whether manipulatives during assessment aided performance on a variety of preschool math tasks compared to pictures. On measures of children's understanding of counting and cardinality (N = 103), there was no difference in performance between objects and pictures, with Bayes factors suggesting moderate evidence in favor of the null hypothesis. On a measure of children's shape naming ability (N = 93), there was no difference in performance between objects and pictures, with Bayes factors suggesting moderate evidence in favor of the null hypothesis. These results suggest that pictures or 2D renderings of 3D objects, which can be easily printed and reproduced for assessment and instruction, are sufficient for assessing counting and shape knowledge without the need for more cumbersome concrete manipulatives.

Keywords: Manipulatives, Numeracy, Geometry, Assessment

34. Toddlers’ Math Talk in Response to Parents’ Math-Related Prompts, but not Statements, Predicts Early Numeracy

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Children’s mathematical skills prior to school entry are important predictors of later math achievement and overall educational attainment. However, substantial variation exists in these skills, creating a need to understand potential contributions of the home math environment. Prior investigations show that parental math talk during everyday interactions predicts preschoolers’ mathematical language use and abilities. However, little research has examined whether similar patterns are observed during toddlerhood. In the present study, we transcribed parents’ and toddlers’ (N = 97, Mage = 2.67) conversations during a wordless picture book reading activity. Toddlers’ math-related responses were coded at the exchange level, only if occurring after a parent’s math-related prompt (i.e., question or directive) or after a math-related statement. We then examined whether toddlers’ math-related responses to parent math prompts vs statements would predict toddlers’ number knowledge. We measured toddlers’ number knowledge with an adapted Give-N task. Toddlers received a set of plastic fish and were asked to help a puppet count the correct number of fish (1-6) to eat. Percent accuracy was calculated as a measure of toddlers’ numeracy skills. Controlling for age, toddlers’ Give-N scores were significantly predicted by their math-talk responses to parents’ math-related prompts (b=0.09, SE=0.04, p=.02) but not in response to parents’ math-related statements (b=0.03, SE=0.07, p=.65). Results will be discussed with respect to how parental scaffolding of toddlers’ math talk in response to parents’ math-related prompts (but not statements) may support toddlers’ numeracy and potentially contribute to individual differences observed in these skills in later years.

Keywords: Math Talk, Parental Scaffolding, Numeracy, Toddlerhood

35. Examining Patterns of Network Connectivity Associated with Symbolic and Non-Symbolic Numerical Magnitude Processing for First Graders Using rs-fcMRI

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Early math achievement is an important indicator of future academic success. Understanding how non-symbolic and symbolic numerical skills develop and the neural architecture that supports this development may provide helpful information for understanding struggling learners and informing targeted intervention work. The current study used rs-fcMRI to examine how patterns of network connectivity are associated with individual differences in factors underlying non-symbolic and symbolic numerical magnitude processing in a sample of first grade children (n = 80) with broad numerical abilities. Given the paucity of research using rs-fcMRI to understand numerical magnitude processing, we utilized dual regression to extract subject-specific versions of canonical resting state networks to determine how these networks are associated with non-symbolic and symbolic numerical magnitude processing ability as measured by Panamath and ASPENS Magnitude Comparison. Results show novel correlations between left frontal brain regions and the sensorimotor resting state network associated with differences in symbolic and non-symbolic processing. Implications for screening, instruction, and future research are discussed.

The current study addressed the following research questions:

- To what extent are non-symbolic magnitude comparison skills related to symbolic magnitude comparison skills for first graders?
- To what extent is there evidence of differences in functional connectivity associated with non-symbolic magnitude comparison skills for first graders?
- To what extent is there evidence of differences in functional connectivity associated with symbolic magnitude comparison skills for first graders?
- How do resting state networks differ for symbolic and non-symbolic magnitude comparison tasks?

Keywords: non-symbolic/symbolic numerical processing, fcMRI, functional connectivity, math instruction

36. Does Math Language Targeted Intervention Generalize to Parent and Child Use of Mathematical and Number Words During Joint Book Reading?

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Preschoolers' mathematical language predicts early math performance, and interventions targeting math language can promote numeracy skills. Dialogic reading interventions targeting mathematical language can support preschoolers' mathematical language and numeracy skills. However, it is unknown whether engaging in a dialogic book-reading intervention increases parent-child mathematical language during storybook reading.

Eighty-four dyads of parents and children (3-5 years) participated in a dialogic reading intervention where they read researcher-designed picture books at home for four weeks. Dyads were randomly assigned to receive books either with explicit math language (n=40) or without (n=44). They also read a storybook without explicit math language at three time points: prior to the intervention, following 4 weeks of intervention, and at delayed post-test. We coded parent and child mathematical word use (e.g., more, all) and number word use (e.g., one, three) during storybook reading. We measured both the range of mathematical words used (quality) and the total mathematical words used (quantity).

Although the primary intervention itself (Purpura et.al., 2021) showed significant, sustained impacts on children's numeracy and math language, analyses controlling for parent education; child age and ability; dosage, and math language at pretest indicated no significant effect of intervention on quality or quantity of parent or child math language and number word use during storybook reading at either post-test. In addition to presenting these findings, we will examine how parent and child characteristics may account for variance in math language use. These findings will inform future picture book interventions aimed at enhancing parent-child mathematical language.

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Keywords: mathematical language, picture books, preschool, parents, numeracy

37. Symbolic number ordering strategies and math anxiety

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Math anxiety negatively impacts various math-related skills, including number ordering (Colomé & Núñez-Peña, 2021; Douglas & Lefevre, 2018). In two studies, we investigated whether math anxiety influences the use of strategies and response times in a symbolic number ordering task. In the first study, adult participants completed a symbolic number ordering task (e.g., is 3-4-5 in order or not?) and, after each trial, they selected one of four pre-determined strategies: memory, decomposition, arithmetic, others (Dubinkina et al, 2021). Participants also completed math anxiety and trait anxiety questionnaires. Participants with higher math anxiety reported using the memory strategy less frequently. In the second study, participants completed the same tasks and questionnaires as in the first study. Moreover, we also recorded participants' response time in the symbolic number order task. Higher math anxiety was associated with the frequent use of decomposition and slower response time when using both memory and decomposition strategies. We concluded that individuals with high MA tend to use more procedural (decomposition) than automatised strategies (memory), resulting in slower performance in the number ordering task.

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Keywords: ordinality, strategy selection, math anxiety, metacognition

38. Children's Flexible Attention to Magnitudes in Early Childhood: Associations with Executive Function and Math Skills

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We tested the hypothesis that young children's flexible attention to numerical and spatial magnitudes (FAM) is significantly associated with both their executive function skills and math achievement. There were 103 children who completed the study (Mage = 54 months; SDage = 8 months; 44% female; 43% Black/African American, 28% White, 11% multiple races/ethnicities, 2% Asian American, 16% unknown). We assessed children in two sessions. The first included the Minnesota Executive Function Scale, Woodcock Johnson Picture Vocab (control variable) and Number Sense subtests, and the FAM task (Fuhs et al., 2021). The second session included subitizing, number line estimation, proportional reasoning, and approximate non-symbolic numerical comparison tasks. Partial correlations revealed a significant association between children's FAM task performance and their executive function skills after controlling for demographic covariates ($r = .37$). Children's FAM and executive function task performance were then entered into a regression model predicting math achievement. FAM task performance was a significant predictor of math achievement after controlling for covariates and executive function ($B = .23$, $p = .004$). In the next model, we additionally controlled for other early math skills, including subitizing, number line estimation, proportional reasoning, and approximate non-symbolic numerical comparison skills. Children's FAM task performance remained a significant predictor of math achievement ($B = .15$, $p = .045$). It may be important to better consider children's FAM ability in early math instruction, though future experimental studies are needed to examine FAM's causal role in early math achievement.

Keywords: executive function, spatial magnitudes, preschool

39. The overlap between early arithmetic and early reading in preschoolers correlates with the white matter organization of the IFOF

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Learning to count and read constitute important early milestones of children's academic development. To date, most research has focused on either arithmetic or reading development, resulting in separately identified cognitive correlates and underlying brain networks. This seems counterintuitive as both abilities are highly correlated and disabilities in arithmetic and reading often co-occur. To fill this gap, we examined the association between early arithmetic and reading ability at the level of brain networks. Specifically, we analyzed fractional anisotropy (FA) of multiple white matter tracts in 5-year-old preschoolers (n = 58). Applying both averaged and along-the-tract analyses of white matter organization, our results indicated that the FA in the Inferior Fronto-Occipital Fasciculus (IFOF) was strongly correlated with precursors of both arithmetic (numerical ordering, numerical knowledge) and reading (phonological awareness, letter knowledge) even after controlling for age, motion, verbal- and spatial reasoning. Regression analyses showed that numerical ordering and phonological awareness were the strongest unique predictors of the white matter organization of the IFOF. However, neither of these remained a significant predictor when both were simultaneously added into a model, indicating that their associations with the IFOF reflected overlapping processes between the two. Our results emphasize that there exists great overlap between arithmetic and reading, even before children attend formal education. This is observed both at the level of their cognitive precursors as well as at the level of their underlying white matter networks.

Keywords: Academic development, White matter, Diffusion Tensor Imaging, Automated Fiber Quantification

40. Finger-representations and numerical competence in toddlers: a pilot study

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During development, most children use their fingers for counting and calculating (Butterworth, 2005) and frequently do this spontaneously, without instructions. Several studies have shown that the use of fingers in numerical contexts by preschoolers is a significant predictor of their subsequent numerical (Kreilinger et al, 2021) and arithmetic skills (Fayol, et.al, 1998) in primary school. However, it remains unclear at what point in development the link between finger representations and numerical abilities emerges. The present study explores these interactions in a group of toddlers (1 to 3 years-old).

The participants were 35 monolingual Italian children (male = 49%) aged from 18 to 36 months (M = 29.71 + 5.4). They completed tests of emerging mathematics tapping into One-to-One Correspondence, Ordinality, Arabic knowledge, Cardinality, and Enumeration abilities. The children were also assessed for their ability to represent numbers with their fingers (finger-number knowledge) and to successfully match verbal and finger expressions when telling their age (finger-age).

Pearson correlations indicate that the finger-age is positively associated with Enumeration ($r = .577$, $p<.000$), One-to-One Correspondence ($r = .392$, $p<.02$), and Cardinality ($r = .535$, $p<.01$). No other correlation reached statistical significance.

The results indicate that a relation between finger representations and specific numerical abilities can be observed earlier than previously demonstrated. Therefore, assessing embodied numerical representations can serve as a window into the early numerical abilities of the children and may provide a simple tool for discovering and strengthening what they know about numbers.

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Keywords: Numerical Abilities, Toddlers, Fingers, Enumeration

41. Are Number-Space Associations impacted by both Math Anxiety and Spatial Anxiety? Insights from a new Multi-Directional Number Line paradigm

Sophie J. Leonard*, Flavia H. Santos

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Spatial Numerical Associations are an integral, if somewhat elusive aspect of mathematical cognition and learning. The concept of the Mental Number Line is often applied to the perceived spatial organisation of numbers in the brain, yet its relationship with domain specific emotional components; Mathematics Anxiety and Spatial Anxiety, remain debated. Here, we implement a novel multi-directional number line task utilising several conditions, namely number line direction and stimulus modality, to assess aspects of visuospatial performance in relation to Math Anxiety and Spatial Anxiety scores.

Following pre-registration https://aspredicted.org/is5sn.pdf, the within subjects paradigm was administered online to 195 participants in the United Kingdom who received their primary mathematics education through English. We analysed the domain-specific anxiety scores in relation to accuracy and reaction time on the cognitive task using multivariate multiple regression models. Findings indicated that while both arithmetic and spatial aspects of performance were predicted by Mathematics Anxiety, no relationship was found for Spatial Anxiety across either domain. Furthermore, while no differences in gender were found in task performance, significant gender discrepanices existed in both math and spatial anxieties, emphasising societal influence on perceived gender differences in mathematics learning. Our primary findings yield potential implications for mathematics education and intervention while also offering fresh insight into relationships between spatial and emotional facets of numerical cognition with a novel task paradigm.

Keywords: Spatial-Numerical Association, Math Anxiety, Spatial Anxiety, Number Line

42. The impact of COVID on maths attainment in the early school years: Can Maths Anxiety explain differences between SES groups?

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Pre-covid, research demonstrated that children from different SES backgrounds had divergent maths attainment, low SES children tend to show lower achievement. Attainment is linked to many factors, but one strong predictor is maths anxiety, where high anxiety is associated with lower attainment. This study investigated the effects of school closures on maths attainment and MA of high and low SES children.

Two cohorts (Cohort 1= 205, Cohort 2= 199, Mean age 60 months) were recruited. Participants completed Child Maths Anxiety Questionnaire (CMAQ) (Ramirez et al., 2013) and WIAT-iiiUK numeracy and problem-solving subscales (Wechsler, 2017) during school years 1, 2 and 3. Cohort 1 completed their first two years pre-pandemic and Time 3 post-virtual schooling; Cohort 2 completed Time 1 testing pre-pandemic and Time 2 and 3 following virtual schooling.

At Time 1, both cohorts showed similar findings for MA and attainment: High SES children had higher maths attainment and lower levels of maths anxiety than low SES children. However, pandemic schooling effects were apparent by Time 2. The low SES children in Cohort 2 showed increased MA. At Time 3, low SES children in both cohorts showed increased MA and lower attainment. By Year 3, the attainment gap was twice the Year 1 level. At all time-points, high MA was related to lower maths attainment.

Virtual schooling had a greater impact on low SES children. One explanation is that their increased MA led to poorer maths attainment. This evidence strengthens the link between MA and attainment from a young age.

Keywords: maths anxiety, early years maths achievement, Covid 19, SES

43. Revisiting Bächtold et al.'s (1998) clock-face: Spatial-Numerical Associations are modulated by the salience of the context

Mauro Murgia* (1), Serena Mingolo (1), Eleonora Bilotta (2), Tiziano Agostini (1), Valter Prpic (3)

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The Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993) consists in faster left-key responses to small numbers and faster right-key responses to large ones. In a renowned study, Bächtold et al. (1998) observed a reversed SNARC due to the effect of an atypical context, namely the clock-face (small numbers are displayed on the right and large numbers on the left). In the present study, we investigated whether and how the salience of an atypical spatial-numerical context alters the SNARC effect. The clock-face was used as context and its salience was gradually increased by task demands across three experiments. In Experiment 1 (low salience), participants were required to mentally represent the clock-face before performing both a magnitude classification taks and a parity judgement task. Results showed the occurrence of a regular SNARC effect, suggesting that the context did not alter this effect. In Experiment 2 (medium salience), the same tasks were performed, with the addition of a go/no-go procedure based on the position of numbers on the clock-face. Results showed no SNARC effect, probably due to a moderate interference of the context determined by task demands. Finally, in Experiment 3 (high salience), participants were required to judge numbers based on their position on the clock-face. In line with Bächtold's results, a reversed SNARC emerged. In conclusion, the findings from the present study suggest that the context can alter the SNARC effect only when it is made salient by task demands.

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Keywords: SNARC, context, salience, task demands

44. The Influence of the Place Value System on Symbolic Number Perception in a Ruler Task

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Past research on symbolic number perception has shown that children's estimates in standard ruler tasks (i.e., placing numbers on a ruler in reference to a start point and an endpoint) follow a logarithmic function. This finding can be explained by assuming that numbers are mapped onto a compressed mental analogue representation. However, two sets of findings are not consistent with this explanation: The different shape of compression for symbolic and non-symbolic numbers and the different developmental change in the two formats. To address these inconsistencies, we endorse an alternative explanation for the logarithmic-looking estimates in children: Misunderstanding of the decimal place value system. To investigate this, we placed adult participants (N = 188) in an environment that mimics children's experience with numbers by asking them to estimate positions in a ruler task with unfamiliar base-26 and base-5 scales. A preregistered model comparison (power, linear, logarithmic) revealed that adults showed systematic, logarithmic-looking underestimation on both scales, indicating that the place value system itself can cause the pattern. Additionally, the observed shape of participants' estimates on both scales could be well explained by a simple model that assumes insufficient understanding of exponential growth (i.e., a characteristic of place value systems). Taken together, our results suggest that the logarithmic compression in symbolic number perception does not require the assumption of a compressed shared mental analogue representation but can be explained by the influence of the place value system.

Keywords: Place Value, Symbolic Numbers, Ruler Task, Model Comparison

45. Spatial Thinking in Practice: A snapshot of teachers' spatial activity use in the early years' classroom

Katie Gilligan-Lee (1,2), Alice Bradbury (3), Charlotte Bradley (1), Emily K. Farran (1,2), Jo Van Herwegen (4,5), Dominic Wyse (3), Laura A. Outhwaite* (5)

1: University of Surrey; 2: Centre for Educational Neuroscience; 3: Helen Hamlyn Centre for Pedagogy, IOE UCL's Faculty of Education and Society; 4: Department for Psychology and Human Development, IOE UCL's Faculty of Education and Society; 5: Centre for Education Policy and Equalising Opportunities, IOE UCL's Faculty of Education and Society

Spatial thinking is vital for children's mathematical development, yet it is often underrepresented in educational policy. Here we provide the first benchmarks of reception teachers' usage and perceptions of spatial activities in practice. We conducted a questionnaire study with 104 educational professionals working in the reception classroom (4-5 years) in the 2020-21 academic year during a policy transition in the assessment of mathematical skills in England. The new early learning goals in maths have a reduced focus on spatial thinking, compared to numerical skills. 52% of the sample were early adopters of these new early learning goals (n = 54), the remaining 48% continued using the old framework (non-early adopters, n = 50). We found spatial and numeracy activities were perceived as significantly less important, and were completed significantly less often, than literacy or life skills. No differences were observed between early adopters and non-early adopters. Despite the lack of focus on spatial skills in the new early learning goals, the rates of spatial activity use were encouragingly high and were broadly comparable to those of numeracy. Early adopters implemented slightly more spatial and numeracy activities, compared to non-early adopters, but this difference was not significant. Teachers' anxiety levels, regardless of whether they were early adopters of the new framework, were relatively high for both spatial and mathematics domains. The findings highlight a need to elevate teacher's understanding of the importance of developing children's early spatial and numeracy skills, which may begin with efforts to reduce spatial and mathematics anxiety.

Keywords: spatial thinking, classroom practice, early years

46. Predictors of mathematical ability: a meta-analysis and systematic review

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It is well established that children's early mathematical understanding has implications for individual life outcomes as well as the society as a whole. However, the cognitive components that numeracy skills rely on at different stages of development are yet to be fully mapped out. Accumulated findings from research on cognition and neuroimaging support theories of multiple pathways to mathematics. Specifically, cognitive systems and abilities such as the approximate number system (ANS), early counting skills, language and visuospatial abilities have repeatedly been found to predict mathematical achievement. Nevertheless, the importance of each of these predictors is not clear, nor is their relation to mathematical subdomains. Additionally, we lack knowledge about the strength of the predictions at different ages.

The present work is a meta-analytic investigation aiming to improve our understanding of these relationships. To this end, global research examining relationships between cognitive predictors and mathematical outcomes was consolidated. Specific research questions were:

What are the meta-analytic correlations between mathematical ability and its predictors?

To what extent are these relationships influenced by moderating variables, including types of measures, non-verbal intelligence and age of assessment?

The review was pre-registered in the International Prospective Register of Systematic Reviews in 2018. After searching for studies published between 1988-2018, with participants aged 4 to 16, reporting the correlation between a mathematical outcome and at least one other associated variable, 180 concurrent studies were included for analyses. This poster presentation presents results from initial analyses with the Robumeta package in R, examining meta-analytic bivariate correlations.

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Keywords: meta-analysis, predictors, maths, language, spatial ability

47. Predictors of Plans and Desire to Teach Mathematics Among Pre-Service Special Education Teachers

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The beliefs teachers hold regarding mathematics may either promote or inhibit their learning of mathematics content and instructional skills that are critical for supporting their students' achievement (e.g., Olson & Stoehr, 2019). Studies have explored factors such as mathematics anxiety among general education teachers, but limited research has focused on special education teachers (e.g., Alazemi, 2018). The present study investigates (a) the relationships between mathematics anxiety, efficacy for teaching mathematics (i.e., beliefs in one's ability to teach mathematics effectively), mathematics values (i.e., one's feelings toward mathematics) among pre-service special education teachers (PSTs) and (b) the effects of aforementioned variables, preferred classroom setting (e.g., resource room), and grade level they plan to teach on two dependent variables: the PSTs' plans to teach mathematics (no, unsure, yes) and their desire to teach mathematics (strongly undesirable to strongly desirable). A total of 188 participants enrolled in special education teacher preparation programs across the United States completed an online Qualtrics survey. We will report the relationships between all variables of interest, descriptive information including the concerning preliminary finding that only 54%-57% of the PSTs plan or desire to teach mathematics in their future classroom, and ordinal regression results for the two dependent variables. To expand on the quantitative results, we will also share qualitative data about PSTs' response to "Do you think students in special education should learn mathematics? Why or why not?" Findings can be beneficial for informing teacher preparation programs to better support the development of future leaders of the field.

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Keywords: pre-service teachers, mathematics anxiety, special education

48. Relations Among Sense of Belonging to Math, Math Identity, and Math Achievement in the Late Elementary Grades

Caroline Byrd Hornburg* (1), Tamika L. McElveen (2), Dana Miller-Cotto (3), Eric D. Wilkey (4), Andrew D. Ribner (5), Nydia Prishker (6), Kyoung Whan Choe (7), Amanda S. Mayes (2), Ma Bernadette Andres-Salgarino (8), Sarah R. Powell (9), Sara A. Schmitt (2), David J. Purpura (2)

1: Virginia Tech, United States of America; 2: Purdue University, United States of America; 3: University of Delaware, United States of America; 4: Louisiana State University, United States of America; 5: University of Pittsburgh, United States of America; 6: St. Thomas Aquinas College, United States of America; 7: Enuma Inc., United States of America; 8: Santa Clara County Office of Education, United States of America; 9: The University of Texas at Austin, United States of America

Students' sense of belonging to math is an important predictor of algebra learning, and prior work has found students' math belonging partially explains the relation between under-represented minority (URM) status and lower algebra scores (Barbieri & Miller-Cotto, 2021). This study modified the Sense of Belonging to Mathematics scale for use in upper elementary grades and examined its relation to math identity measures and math achievement. The survey, containing items adapted from prior work with middle-school students, was piloted with 89 students (3rd-5th grades; 50 girls, 37 boys, 2 not reported). Standardized math test scores were also obtained. Internal consistency for the math belonging measure was acceptable (α=.79). The math identity measures (adapted from Cribbs et al. [2015]) exhibited good internal consistency, including factors of recognition (i.e., identification as a "math person", α=.86) and competence (α=.84). Math belonging was highly correlated with recognition (r=.71) and competence (r=.66), but of the three scales only competence was significantly correlated with math achievement (r=.35, p=.002). Exploratory analyses revealed that this correlation was significant in 4th and 5th grades but not in 3rd grade. It was also significant for non-URM students (n=44) only, even when controlling for socioeconomic status. Overall, although each measure had decent reliability, only competence was related to math achievement. Future research is needed with larger samples to examine the directionality of these relations, as well as how children's math belonging and math identity may relate to their progression to more advanced mathematics in middle school and beyond.

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Keywords: math identity, sense of belonging to math, math achievement, middle childhood

49. Domain General Cognitive Skills as Predictors of Math Achievement in Emergent Bilingual Kindergartners

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The study explores the degree to which emergent bilingual kindergartners demonstrate differences in response to intervention based on initial math skill and domain general skills. Participants (n=126) were at-risk for mathematics difficulty and identified as emergent bilingual from six school districts in the USA. The Tier II intervention was provided through a partially nested design within classrooms. Participants were assigned: (1) ROOTS with a 2:1 student teacher ratio, (2) ROOTS with a 5:1 ratio, or (3) business-as-usual, no treatment condition. Math assessments were conducted at pre and posttest using: RAENS, ASPENS, NSB, and TEMA. Working memory and phonological processing were assessed at pretest using: CTOPP-DM, CTOPP-NR, & Digit Span Backward. Additional analyses will be conducted using the WPPSI-III subtests of block design and matrix reasoning to incorporate visual spatial skills and fluid reasoning within the analysis. To assess intervention effects on the outcome measures, we used a mixed model (multilevel) Time x Condition analysis (Murray, 1998) which tests differences between conditions on changes from fall to spring. Statistically significant correlations were found between pretest math scores, domain general skills, and English proficiency. Participating in the ROOTS intervention did not change associations among domain general skills and gains in mathematics. Findings indicate effective intervention may mitigate the effects of low domain general skills on math outcomes. Results illustrate the relationship between domain general skills and the concurrent development of linguistic and early numeracy skills for emergent bilinguals. This supports the consideration of cognitive competencies in design of instructional materials for mathematics.

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Keywords: Math intervention, emergent bilingual, domain general skills, early numeracy

50. Examining the factor structure of communal socialization in mathematics and associations with elementary students' math identities

Tamika L. McElveen* (1), Caroline Byrd Hornburg (2), Amanda S. Mayes (1), Dana Miller-Cotto (3), Ma Bernadette Andres-Salgarino (4), Sara A. Schmitt (1), Sarah R. Powell (5), David J. Purpura (1)

1: Purdue University, United States of America; 2: Virginia Tech, United States of America; 3: University of Delaware, United States of America; 4: Santa Clara County Office of Education, United States of America; 5: The University of Texas of Austin, United States of America

This study examined how teachers' communal socialization, a culturally sustaining pedagogy and practice that connects academic content to the value of and sense of responsibility to one's community, fosters students' sense of identity in elementary mathematics. The Communal Socialization Scale, previously administered to high schoolers, was adapted for an elementary context and administered to 155 children (50% fourth graders, 57% female, 38% Latine, 35% White, 11% African American) in ten math classrooms. In Research Question 1, we examined the factor structure and dimensionality of the scale. Confirmatory Factor Analyses did not support the three-dimensional structure of the original scale, rather a two factor model of Community Utility and Global Responsibility was found ($\alpha = .88$). To further examine the factor structure of the measure, our test of measurement invariance revealed item variances between several groups, including school district, grade level, gender, and race.

In Research Question 2, we examined the relation of communal socialization to other developed or adapted measures of students' sense of identity in mathematics including Sense of Belonging to Mathematics (Barbieri & Miller-Cotto, 2021; Good et al. 2012), Factors Influencing College Success in Mathematics (Cribbs et al., 2015), Math Empowerment, and Math Environment scales. We found moderate and significant correlations between the Communal Socialization Scale and each of these measures reflecting associations between unique measures of mathematical identity. This study supports the continued examination of communal socialization in elementary mathematics classrooms to better understand the students' differing experiences and the potential benefits to students' math identities.

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Barbieri, C. A., & Miller-Cotto, D. (2021). The importance of adolescents' sense of belonging to mathematics for algebra learning. Learning and Individual Differences, 87.

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Keywords: Math identity, elementary, culturally sustaining pedagogy, communal socialization

51. The relation between numerical magnitude knowledge and math performance: The mediating roles of understanding of arithmetic operations.

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The current study aimed at investigating the mechanism underlying the relation between numerical magnitude knowledge and children's math performance. Understanding of arithmetic operations was the proposed mechanism. A sample of 256 third graders completed a series of tasks measuring their numerical magnitude knowledge, understanding of arithmetic operations, math performance, as well as other potential confounding factors such as intelligence and working memory. Bootstrapping were used for data analysis and testing the indirect and direct effect. The finding showed that 1) numerical magnitude knowledge and understanding of operations were the significant predictors of math performance after controlling children's nonverbal intelligence and working memory ability. 2) The effect of numerical magnitude knowledge on math performance was partially mediated by the understanding of arithmetic operations. To conclude, this study tested the mediating role of the understanding of arithmetic operations on the relation between numerical magnitude knowledge and children's math performance.

Keywords: numerical magnitude knowledge, understanding of arithmetic operation, math performance

52. Testing the benefits of an embedded math fluency and executive function intervention in children

Yi Feng* (1), Martin Buschkuehl (2), Gillian Grose (3), Susanne M. Jaeggi (1), Geetha Ramani (3), Eunice Ghil (1), Mary DePascale (3)

1: School of Education, University of California, Irvine, Irvine, CA, USA; 2: MIND Research Institute, Irvine, CA, USA; 3: Department of Human Development & Quantitative Methodology, University of Maryland, College Park, MD, USA

Math fluency, the ability to solve arithmetic problems quickly and accurately, is highly predictive for future math achievement. A lack in math fluency skills results in individuals devoting more cognitive resources to executive functions to solve math problems. In addition to this compensatory relationship, executive function skills contribute to math learning, thus, there is a bidirectional relationship between math and executive function skills. We created a novel intervention to maximize math learning by embedding executive function training within math fluency training. Consisting of three games that can be played on mobile devices, our intervention requires the retrieval of arithmetic facts while also completing increasingly difficult working memory and inhibitory control tasks. Three fourth grade and two fifth grade classrooms were assigned to either a training group that was asked to play the games at least four times per week over the course of three weeks, or a waitlist control group. Before and after the intervention, all participants were assessed on math fluency and executive functions, and in addition, they rated their perceptions of their own strengths in these skills. In this presentation, we will report the outcomes of the intervention by comparing pre- and post-outcomes for the two groups and by illustrating whether and how self-reported strengths relate to pre-existing skills and training effects.

Keywords: Math fluency, Executive functions, Game-based math intervention, Mobile learning

53. An evaluation of 4-year-old understanding of zero

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Several studies have investigated how children learn positive integers, but little is known about the acquisition of zero. This work had 2 aims: (1) analyze to what extent 4-year-old children understand zero from a cardinal (link zero to nothing), and ordinal (represent zero on a continuum with the other numbers) perspective; (2) investigate whether zero and other numbers share common prerequisites. For these purposes, we conducted this pilot study with 20 preschoolers (mean age = 51.5 ± 3.43 months). Participants completed the following tasks with and without zero: 1) Give-N task and 2) non-symbolic comparison of quantity. In addition, we assessed participants' skills regarding 3) naming numbers; 4) language abilities, as measured with a standardized vocabulary test (TNL), and 5) representation of numbers on fingers. The results showed that all children understand what "nothing" means, but only 55 % of them are able to link "zero" to "nothing" (Cardinal-Zero-knowers). This suggests a difficulty in understanding the lexical rather than the semantic meaning of zero. In addition, Cardinal-Zero-knowers show better skills in representing numbers on fingers and naming numbers, as well as more developed vocabulary than Cardinal-Zero-not-knowers. However, these differences are not found between children who know the cardinality principle and those who do not. Therefore, the cardinality for zero and other numbers may be acquired in different ways. Finally, we did not find any differences between Cardinal-Zero-knowers and Cardinal-Zero-not-knowers regarding the performance in the non-symbolic tasks with empty sets, so the cardinal and ordinal meaning of zero might be learnt independently.

Keywords: zero, empty sets, numerical cognition, childhood, numerical skills precursors

54. Examining the effects of pattern experience on algebraic problem-solving strategies in young adults

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Mathematics has often been described as the “science of patterns''. However, students frequently fail to notice patterns and relational structure within and across mathematics exercises. Prior research has demonstrated that opportunities to notice and reason about mathematical structure positively affect subsequent math performance1. However, few studies have examined how such experiences influence the strategies people use to solve problems. Here we examined patterns of strategy change in young adults who received either experience with extending mathematical patterns (i.e., stacked equations representing arithmetic sequences) or explicit instruction about the pattern structure. Consistent with prior work, we found that exposure to these relations via direct pattern experience improved performance on related math tasks (increased accuracy, decreased time to completion). Interestingly, however, we found that participants who started with non-pattern-related strategies were more likely to switch to pattern-related strategies if they received explicit instruction than if they received direct pattern experience. The data suggest that the explicit instruction provided to participants scaffolded their strategy explanations by providing clear and concise language about the relational structure of the pattern. It is also possible that participants in the pattern experience condition developed insight about problem-solving that was not articulated in their strategy explanations, but was reflected in their superior performance. These results highlight the importance of considering how different instructional experiences influence not only speed and accuracy, but also problem-solving strategies.

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Keywords: problem-solving strategies, patterning, algebra, relational reasoning

55. Cognitive and Emotional Mechanisms of Early Numeracy

Sylvia Gattas*, Alex Fraser, Mihaela Duta, Gaia Scerif

University of Oxford, United Kingdom

Regulatory mechanisms are essential for the development of foundational number abilities at pivotal stages in early childhood which set the stage for later mathematical success and prospective career choices. Maths anxiety (MA), one's negative feelings of worry about maths, often limits one's mathematical development by causing increased negative arousal, rumination and reduced inhibition. Literature proposed that possible reasons children between the ages of 4 to 7 years develop MA include fear of failure, social competition, punishment, and attitudes and motivations towards oneself and learning maths. Unfortunately, the development of and resilience against MA are severely understudied in this age-group. Here, we addressed both current limitations of studying developmental resilience mechanisms and proposed new state-of-the-art methodological approaches to address multiple components of MA. We leveraged a newly designed gaze-scoring software to examine attentional response within a pressure free environment and again within a pressure induced numeracy task. Gaze speed-accuracy and persistence throughout the task are measured in relation to their numeracy performance. Finally, we triangulate performance measures to child and parental reports of attitudes, motivation and behaviour. Our new methodology aimed to bridge our understanding of how young children might develop foundational coping mechanisms at the earliest stages of education, which might help to better equip their future maths brains.

Keywords: numeracy, maths attitudes, attention, gaze

56. Less is More?: Instructions Modulate the way we Interact with Continuous Features in Non-symbolic Dot-array Comparison Tasks

Aviv Avitan*, Avishai Henik, Hanit Galili

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Individuals’ ability to perceive, process and manipulate numbers and quantities has been studied extensively in the field of numerical cognition. A few accounts to numerical processing highlight one’s ability to perceive and evaluate sizes and amounts. This aspect is viewed as imperative to numerical processing due to the well-established relationship between quantities and several related visual properties. Apart from developmental and perceptual aspects that are believed to influence numerical processing, these theories postulate that top-down processes such as instructions may also influence numerical processing. The current study aimed to study whether instructions (i.e., report which has more vs. report which has less) indeed influence magnitude processing. In a series of five experiments, we showed that instructions modulated performance when both numerical and physical aspects of stimuli were evaluated. We suggest that these modulations indicate on a link between instructions and certain continuous features.

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Keywords: Numerical processing, Magnitude processing, Task instructions

Symposia: 2:30pm - 4:00pm

Emotion and Arithmetic

Chair: Patrick Lemaire

Aix-Marseille University, France

Recent data on the role of emotions in arithmetic will be presented. These data advance our understanding of when (under what conditions) and how (via which mechanisms) emotions influence arithmetic performance and processes. Research presented adopted either experimental approaches (i.e., manipulating participants' emotional states) or correlational approaches (i.e., testing participants with different characteristics, such as anxiety or phobia). The contributive value of the new findings presented in this symposium lies new insights regarding what are the important issues and how to address them when examining the role of emotions on arithmetic in particular, and on cognitive performance in general.

Keywords: Emotion, Arithmetic, Math Anxiety, Strategy, MEG

Presentation 1: Does math anxiety vary depending on situation?

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Artemenko, Christina (Department of Psychology, University of Tuebingen, Germany); Cipora, Krzysztof (Centre for Mathematical Cognition, Loughborough University, UK); Nuerk, Hans-Christoph (Department of Psychology, University of Tuebingen, Germany)*

Some individuals experience more math anxiety, i.e., a potential fear or unease towards numbers and arithmetic, than others. Anxiety research in general, however, differentiates between a trait component (how anxious one generally feels, thus differing between individuals) and a state component (how anxious one feels at the moment, thus differing between situations). This raises the question of whether math anxiety has a state component as well and how it relates to trait math anxiety and math performance. Our preregistered study aims to characterize the relation between state and trait math anxiety to math performance in adults, while controlling for general anxiety, test anxiety and math self-concept. Our preliminary results show that state math anxiety depended on the math situation and was larger when solving difficult as compared to simple arithmetic problems. However, state math anxiety was influenced by trait math anxiety and test anxiety: Individuals with higher levels of trait math anxiety experienced more state math anxiety. Additionally, the situation-dependent increase in state math anxiety was affected by test anxiety. At the same time, the difficulty-related decrease in math performance was not predicted by the increase in state math anxiety. These findings will be integrated into a theoretical framework on state and trait math anxiety and its relation to math performance.

Presentation 2: Relationships between mathematics performance and attitude to mathematics: influences of gender, test anxiety and working memory

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Dowker, Ann (Department of Experimental Psychology, Oxford University); Sheridan, Hannah (Lady Margaret Hall, Oxford University)*

Many studies have indicated that mathematics anxiety, and other negative attitudes and emotions toward mathematics, are pervasive and are associated with lower mathematical performance. Some previous research has suggested that working memory is related to both mathematics anxiety and mathematics (e.g. Ashcraft & Kirk, 2001). In the present study, 40 university undergraduates completed a battery of assessments investigating working memory, attitude to mathematics, test anxiety, and mental and written arithmetic. Attitudes to mathematics were significantly associated with the other variables: working memory, test anxiety and both measures of mathematical performance. The other variables were not strongly associated with one another. There were no gender differences in mathematical performance, but females exhibited more negative attitudes to mathematics and higher test anxiety than males. After controlling for test anxiety, there ceased to be significant gender differences in attitudes to mathematics. Science students had more positive attitudes to mathematics than humanities students, but the groups did not differ in test anxiety, Science students were better at written but not mental arithmetic. They were also better at working memory, but this was not a significant covariate when the groups were compared on mathematical performance and attitudes to mathematics The results are discussed, with particular focus on implications for future research on influences on mathematics anxiety.

Presentation 3: Negative Emotions and Arithmetic: A Neuroimaging Study

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Lallement, Camille (Aix-Marseille University & CNRS, Marseille, France); Lemaire, Patrick (Aix-Marseille University & CNRS, Marseille, France)*

How negative emotions influence cognition has been studied in several cognitive domains, including mathematical cognition. Previous research found decreased arithmetic performance under negative emotions. Unknowns are the neural correlates of such deleterious effects and the time course of brain activations. In the present study, we used magnetoencephalography (MEG) to further our understanding of how negative emotions lead participants to obtain poorer arithmetic performance. Participants accomplished a computational estimation task (provide an approximate product to multiplication problems) under neutral and negative emotion conditions. More specifically, they were asked to estimate the result of two-digit multiplication problems (e.g., 43x68) with either a rounding-down strategy (i.e., rounding both operands down to their closest decades, like doing 40x60=2400) or with a rounding-up strategy (i.e., rounding both operands up to their closest decades, like doing 50x70=3500). Problems were displayed superimposed on emotionally negative or neutral pictures. Our behavioral results replicate previous findings of poorer arithmetic performance in the negative emotion condition compared to the neutral emotion condition, especially when participants were asked to execute the harder, rounding-up strategy. Brain-imaging data revealed not only correlates of such emotion-related differences, but also uncover the dynamic of brain activations (e.g., with ventral affective systems first being activated upon negative pictures, followed by a deactivation of dorsal systems involved in mathematical cognition). These findings help further our understanding of

mechanisms via which negative emotions influence arithmetic performance and specify the time course of both domain-general and domain-specific mechanisms involved in arithmetic.

Presentation 4: Emotion and Arithmetic in children

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Lemaire, Patrick (Aix-Marseille University & CNRS, Marseille, France)*

In a wide variety of cognitive domains, such as attention, memory, reasoning, or decision-making, emotions can enhance or hinder cognitive performance, and effects of emotions on cognition change during childhood. Although correlational studies suggest that negative emotions lead children to obtain poorer arithmetic performance, experimental evidence are mixed, with some studies reporting deleterious effects and others no influence. In this wok, we first bring new unambiguous evidence of how emotions influence children's arithmetic performance and, second, adopt a strategy perspective to further understand the responsible mechanisms via which emotions modulate arithmetic performance in adults, and how this modulation changes during cognitive development. In this strategy perspective, cognition and cognitive development are investigated in terms of which and how many strategies are used to accomplish a cognitive task, as well as how participants select and execute cognitive strategies on each item. After reporting a set of data documenting age-related differences in effects of emotion on children's (aged 8 to 15 y.o.) performance during arithmetic problem verification tasks, I will discuss data showing that emotions change how participants execute and choose among available strategies on each item. The data also document when these effects of emotions on strategic aspects of participants' performance change with children's age and when they do not change with age. These findings have important implications to investigate and understand the role of emotions on cognitive performance in arithmetic and on children's age-related differences therein.

Interventions for Improving Math Skills: Exploring the Evidence, Limitations, and Practical Considerations of Different Intervention Types

Chair: Katie Gilligan-Lee

University of Surrey, United Kingdom

Mathematical difficulties in childhood can have significant downstream effects on later education, everyday life, employment, and socio-economic status. Although improving mathematics achievement has become an economic priority in many countries globally, there is still no clear consensus on the best approaches for delivering these improvements. This symposium is a collaboration between four early career academics who will each discuss a distinct approach to improving mathematics performance in childhood including spatial training, home-based interventions, mathematics apps, and interventions with a home-school pairing. We will discuss how the evidence presented should be interpreted to provide meaningful guidance for parents and teachers.

Keywords: Mathematics Intervention, Spatial thinking, Maths apps, Home learning environment

Presentation 1: Hands-On: Investigating the role of physical manipulatives in spatial training and transfer to mathematics

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Gilligan-Lee, Katie (University of Surrey); Hawes, Zachary (University of Toronto); Williams, Ashley (University of Surrey); Farran, Emily (University of Surrey); Mix, Kelly (University of Maryland)*

Recent studies show that spatial training interventions lead to improvements in mathematics. However, outcomes vary based on whether embodied action, the interaction of the learner with some aspect of the physical environment (e.g., physical manipulatives), is used during training. This study investigates whether embodied training using physical manipulatives leads to larger, more durable training effects in the spatial domain, and greater transfer of gains to mathematics, compared to non-embodied and control training. The study has a randomised, pre-post, follow-up, training design (N = 157; mean age 8yrs). Participants were randomly assigned to one of three training groups and all participants completed four 30-minute intervention sessions. The spatial training groups completed spatial visualisation activities either with (hands-on spatial training) or without (hands-off training) concrete objects. The control group completed a vocabulary intervention. A battery of spatial and mathematics tasks were completed pre-training, post-training and at follow up (6 weeks post-training). All data have recently been collected and the results will be presented for the first time at MCLS. From a theoretical perspective, understanding the role of embodiment in cognitive training in the spatial domain will help to develop a mechanistic understanding of the spatial-mathematical relationship and why there is a causal effect of spatial thinking on mathematics. Practically speaking, this study will refine the optimal design of spatial training for use in mathematics learning and instruction, which has significant implications for spatialisation of the classroom.

Presentation 2: Meta-analyses and narrative review of home-based interventions to improve literacy and mathematics outcomes for children between the ages of 3 and 5 years

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Cahoon, Abbie (Ulster University); Jiménez Lira, Carolina (Universidad Autònoma de Chihuahua); Estévez Pérez, Nancy (Cuban Neurosciences Centre); Benavides Pand, Elia Veronica (Universidad Autònoma de Chihuahua); Campver García, Yanet (Cuban Neurosciences Centre); Paz García, Daniela Susana (Universidad Autònoma de Chihuahua); Simms, Victoria (Ulster University)*

The purpose of these meta-analyses were to examine the effectiveness of home-based interventions aimed at improving literacy and mathematics outcomes for preschool aged children (mean age = 4.29; range = 3.07 to 5.32 years) and to develop an understanding of what home-based interventions work in different contexts. A total of 32 studies met the inclusion criteria for these meta-analyses; 30 studies included sufficient data for inclusion in the meta-analyses and 2 studies did not contain sufficient quantitative data and instead were summarised in a narrative review. The average weighted effect size for interventions with literacy (d = 0.10; CI = -0.17, 0.38; n = 27) and mathematical outcomes (d = 0.18; CI = -1.62, 1.99; n = 8) were small. Hence, these meta-analyses showed that home-based interventions had minimal effect on literacy and mathematical outcomes for pre-schoolers. There were more home-based interventions with literacy (N = 28) than mathematical outcomes (N = 10). The heterogeneity showed no variability indicating that all intervention impacted on children's outcomes to similar effect. Overall, many interventions were relatively light touch (i.e., time spent engaging in parent training) and the engagement requirement of the parent in some studies was minimal (e.g., reading a short text message). More in-depth research into the components of interventions (e.g., focus, training approaches) and evaluation of interventions before they are implemented is essential for ensuring that early interventions will be effective and lead to the development of the intended skills.

Presentation 3: Can Maths Apps Add Value to Learning? A Systematic Review and Content Analysis

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Outhwaite, Laura A (Centre for Education Policy and Equalising Opportunities, UCL Institute of Education, UK); Early, Erin (Centre for Education Policy and Equalising Opportunities, UCL Institute of Education, UK); Herodotou, Christothea (Institute of Educational Technology, Open University); Van Herwegen, Jo (Department of Psychology and Human Development, UCL Institute of Education, UK)*

Educational maths applications (apps) are an emerging trend in young children's learning environments aiming to raise attainment. To examine whether and how apps can support mathematical learning and development, the current study conducted a systematic review of the existing research in this area and a content analysis of the identified maths apps. In the systematic review, 50 studies examining 77 maths apps used at home or at school with children in the first three years of compulsory school to support mathematical attainment were thematically synthesised. Studies predominately reported greater learning outcomes for children using the evaluated maths apps compared to a range of control conditions. However, it remained unclear what the active ingredients (i.e., mechanisms), or combination of ingredients, of successful maths apps were and how they linked to current theories of mathematical development and learning science. In response, a content analysis of the apps' mathematical content and design features was conducted using a combined top-down (deductive) and bottom-up (inductive) approach. For studies that sufficiently reported data to calculate effect sizes on children's leaning outcomes with the maths apps, a qualitative comparative analysis (QCA) was also conducted. Results showed learning outcomes with maths apps were maximised when apps provided a scaffolded and personalised learning journey (programmatic levelling) and explained why answers were right or wrong (explanatory feedback), as well as giving praise, such as "Great job!" (motivational feedback). Implications for future research based on the quality of existing studies, and gaps in the current literature will be discussed.

Presentation 4: A Meta-Analysis of Mathematics Interventions Conducted in Informal Learning Environments with Caregivers and Children

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Nelson, Gena (Boise State University); Carter, Hannah (Boise State University); Boedeker, Peter (Boise State University)*

Recently, there has been an upward trend in empirical research that investigates the effectiveness of math interventions in informal learning environments (e.g., homes, museums). Given the long-term benefits of early success with math, a growing need exists to understand the characteristics of effective math interventions in informal learning environments and their potential benefits for young learners. The purpose of this meta-analysis was to examine the effectiveness of math interventions implemented in informal learning environments by children's caregivers. This study included 23 preschool to third-grade math interventions (for children ages 3 to 9), and the meta-analysis of 81 effect sizes yielded a statistically significant summary effect ($g = 0.28$, 95% CI [0.08, 0.48]) on math achievement outcomes. Significant moderators of the treatment effect included intensity of caregiver training and type of outcome measure. Training with follow-up support yielded larger effects than no training or training without follow-up support. Larger effects were reported on broad measures of early numeracy, compared to narrow measures. The results also indicate that home-based interventions paired with school-based interventions produce additional gains in math achievement (though not to a statistically significant level). The results of this meta-analysis offer several recommendations for researchers and practitioners, particularly given the growing evidence base of math interventions conducted in informal learning environments.

Current Perspectives in Developmental Dyscalculia

Chair: Daniel Ansari

University of Western Ontario, Canada

The current symposium gathers together four groups of researchers, each approaching the issue of math learning difficulties, including Developmental Dyscalculia (DD), from different perspectives and methodologies. Research objectives of each presentation range from issues in diagnosis, phenotypic characterization, and characterization of the neural bases of DD to understanding the precursors and response profiles of individuals with DD. The methods applied across the presentations include longitudinal behavioral analyses, synchronization-based EEG, and both Frequentist and Bayesian fMRI. As discussant, Daniel Ansari will tie together themes of these current perspectives in DD and guide questions about where the field stands now.

Keywords: developmental dyscalculia, diagnosis, intervention, characterization

Presentation 1: Disentangling Developmental Dyscalculia phenotypes and prevalence

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Santos, Flávia (University College Dublin, Ireland); Primi, Caterina (University of Florence, Italy); Dowker, Ann (University of Oxford, UK); von Aster, Michael (University of Potsdam, Potsdam, Germany)*

Diagnosis of Developmental Dyscalculia (DD) is a challenging issue. For instance, discrepancy criteria (IQ and mathematics performance) are recommended. But even when applied, numerical cognition cut-offs are controversial. In this study, we assessed the performance of 304 children aged 7-12 years, balanced per gender, in a numerical cognition battery. We tested for the dimensionality of the battery and compared z-scores and percentiles to estimate the prevalence of DD. We observed age-related but not gender-related differences. Using a stricter criterion, i.e., 5th percentile we found 14 children with DD, while z-score-criterion of -1.5 SD from the mean added eight cases. Both rates, respectively 4.6 % and 7.4%, are within the average prevalence range and equivalent between genders. In addition to clearly establishing the severity marker, we consistently found deficits in at least three tasks for children under percentile 5: problem solving, counting backwards, and mental calculation. Even so, a close inspection of the 22 cases of DD detected by the battery strongly underlines the individual differences as these children exhibited unique phenotypes within the 12 tasks of the battery. We discussed the dimensionality of the numerical cognition battery which revealed the four-factors model (cardinal, verbal, symbolic and ordinal), with significant correlations (from .89 to .97) at the .001 level. Theoretically it means that the battery tasks are tackling interdependent components, validating Shalev and von Aster (2007). The findings have implications for using both cut-off measures in terms of the best practice for clinical and research purposes.

Presentation 2: Precursors of mathematical learning difficulties before the start of school

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De Smedt, Bert (University of Leuven, Belgium); Wijns, Nore (University of Leuven, Belgium); Torbeyns, Joke (University of Leuven, Belgium); Verschaffel, Lieven (University of Leuven, Belgium)*

Is it possible to already identify predictors of mathematical learning difficulties in preschool? We sought to answer this question by retrospectively analyzing the data from a 5-year longitudinal study that followed more than 400 children from preschool (age 4-5 years) until grade 3 (age 8-9 years). Mathematical learning difficulties (MLD) were defined as performing persistently below the 25th percentile on standardized curriculum-based mathematics achievement test in grades 1 and 3 of primary school. We selected a group of control children who consistently performed between the 25th and 50th percentile on the same tests in grades 1 and 3. We deliberately selected these children in order not to inflate potential group differences. The final sample consisted of 31 children with MLD and 32 average achievers. All children completed the same set of mathematical tasks during year 2 (age 4-5 years) and year 3 (age 5-6 years) of preschool (nonsymbolic comparison, symbolic comparison, counting, number order, numeral identification, arithmetic, repeating patterning, growing patterning). They also completed a set of cognitive measures (vocabulary, spatial ability, verbal working memory and visuo-spatial working memory) in preschool year 3. Group differences were observed for most of the administered tasks in both preschool years. Follow-up logistic regression analyses revealed that counting in preschool year 2 and repeating patterning in preschool year 3 as well as vocabulary and spatial ability were the most critical predictors of group membership. These data suggest that counting and repeating patterning are key factors to identify children at risk for MLD in preschool.

Presentation 3: Arithmetic training improves neural functionality in children with dyscalculia

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Soltanlou, Mojtaba (University of Surrey, UK); Borjkhani, Hadi (University of Tehran, Iran); Nuerk, Hans-Christoph (University of Tuebingen, Germany)*

Arithmetic training in typically developing (TD) children suggests an enhancement in fast procedural as well as retrieval strategies. These improvements can be observed in EEG theta and alpha frequency bands. For instance, using the event-related synchronisation and desynchronisation (ERS/D) method revealed decreased alpha ERD for both one-digit and two-digit multiplication problems after two weeks of training in TD children (Soltanlou et al., 2018). Alpha ERD represents a reduction of localized amplitudes, associated with the increased excitability of cortical regions and increased reliance on retrieval strategies. This cortical excitability reflects a rise in information processing. Therefore, decrease in alpha ERD after arithmetic training represents decrease in cortical activities. However, neurocognitive changes from TD children cannot be simply generalized to children with mathematical disabilities (MD). These children are our target group, who need evidenced-based educational interventions.

Therefore, we examined neurocognitive changes in children with MD who underwent two weeks of multiplication training. Brain activation was measured in 23 children (age range = 10-15 years old using EEG before and after training to assess training-related changes. We analysed ERS/D in theta and alpha frequency bands together with behavioural performance including both response time and accuracy. The results of these analyses are compared to the findings of a similar study in TD children. These findings will provide important insights about learning-related neurocognitive changes in children with MD that would help further development of evidence-based interventions.

Presentation 4: Developmental Dyscalculia is not associated with atypical brain activation during basic number processing, mental arithmetic, or visuo-spatial workin

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Wilkey, Eric D. (The University of Western Ontario & Louisiana State University); Kwok, Fu Yu (National Institute of Education, Singapore &Macquarie University, Australia); Peters, Lien (The University of Western Ontario, Canada); Khiu, Ellyn (National Institute of Education, Singapore); Bull, Rebecca (Macquarie University, Australia); Lee, Kerry (The Education University of Hong Kong, Hong Kong); Ansari, Daniel (The University of Western Ontario, Canada & National Institute of Education, Singapore)*

Compared to reading difficulties, comparatively little is known about the neurobiological correlates of Developmental Dyscalculia (DD). Furthermore, neuroimaging studies of DD are characterized by small sample sizes and variable inclusion criteria, which make it problematic to compare across studies. In addition, studies to date have focused on single deficits among children with DD (e.g., mental arithmetic), rather than probing differences across multiple domains. Here, we used functional Magnetic Resonance Imaging (fMRI) to probe brain differences associated with DD in a sample of n = 68, 8–10-year-old children (30 DD) in three tasks commonly reported to show behavioural deficits in children with DD: basic number processing, mental arithmetic, and visuo-spatial working memory. Behaviourally, children with DD were less accurate than their typically achieving (TA) peers for the basic number processing and arithmetic tasks, but there were no differences in visuo-spatial working memory. A pre-registered, whole-brain, univariate analysis of the fMRI data (DD and TA) revealed areas commonly associated with each task. However, the examination of differences in brain activation between children with and without DD revealed no consistent group differences in brain activation. In view of these null results, we ran an exploratory, Bayesian analysis of the data to quantify to the amount of evidence for no group differences. This analysis provides supporting evidence for no group differences across all three tasks. These findings contradict previous literature and reveal the need to investigate the neural basis of DD using multivariate and network-based approaches to brain imaging.

Children' Math Learning: Exploring Informal Contexts and Family Influences

Chair: Susana Beltran-Grimm

Purdue University, United States of America

Research suggests that home math environments is related to children's math development and that parent-child math engagement in informal contexts may be particularly important. This symposium will further our understanding of parent-child math engagement in informal contexts and family influence and their relation to the development of math learning. Drawing from qualitative and quantitative approaches, the four studies examine how parent-child engagement in informal numeracy activities and number talk in informal contexts relate to their beliefs and children's math learning. The studies highlight multiple aspects of the home environment and cross-domain relations that may exist with children's skill development.

Keywords: Number talk, early math development, home math environment

Presentation 1: Parents' numeracy support during informal versus formal contexts: Fathers report more informal engagement than mothers

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Douglas, Ashli-Ann (Vanderbilt University); Msall, Camille (Vanderbilt University); Rittle-Johnson, Bethany (Vanderbilt University)*

Parent-child engagement in informal numeracy activities (those during which numeracy concepts are learned incidentally) versus formal numeracy activities relate to children's numeracy skills in different ways (1). However, little is known about factors that relate to their engagement. We examined the characteristics of a measure of parent-child numeracy engagement and whether this engagement varies with parent-child demographic characteristics.

Participants were 161 parents (51% mothers) of 3- to 5-year-olds (55% males) who completed an online survey. Most were White (74.5%) and had at least their bachelor's degree (59% of mothers, 58% of fathers).

A model with separate factors for informal and formal numeracy engagement had better fit than a single-factor model, $\chi2$ (1, N = 161) = 52.52, $p <.001$, per confirmatory factor analyses. Additionally, both subscales had acceptable reliability, $\alpha = .76$ and .71.

Parents reported formal engagement more often than informal, $t(160) = 11.49$, $p < .001$. Fathers reported more informal engagement than mothers, $t(159) = 2.84$, $p = .003$, and their education levels were positively related to their informal engagement, $t(159) = 2.34$, $p = .003$. Notably, this was driven by father-child engagement in card and board games. Contrary to prior research (2), mothers' education levels were unrelated to their engagement, but child age was positively related to informal engagement, $F(2, 158) = 3.50$, $p = .03$. Finally, neither type of engagement varied significantly by child gender or parent race which have not been examined in previous research. Implications for future research including with fathers will be discussed.

Presentation 2: What are parents and children doing when they talk about number? A qualitative study of number talk during home cooking

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Nelson, Ariadne (University of Chicago)*

Parents' number talk predicts preschoolers' concurrent and prospective math skills (e.g., Levine et al., 2010). However, little is known about the interactional context, sequence, or function of family number talk during everyday activities. This limits our understanding of the role of number talk in family interaction and child learning. Using Conversational Analysis, a qualitative, microanalytic approach, I examined when, how, and for what purpose parents and preschoolers engaged in number talk while cooking together.

Thirty parents—predominantly middle-class, college-educated parents of color—audio-recorded themselves cooking with their 3- to 5-year-old child for a home-based math intervention. Detailed transcripts of the families' first two cooking activities were prepared. Sequences in which families used numeric language, asked numeracy questions, or performed numeracy tasks were identified. These sequences were analyzed turn by turn, attending to sequence organization, turn design, and position within larger action trajectories.

Four patterns in how families engaged in number talk emerged:

1. Parents or children used numeric language in passing as they performed a social action.
2. Parents voiced numbers in the recipe while facilitating children's performance of physical actions of the recipe.
3. Parents engaged children in pedagogical conversations that invited children to use their numeracy knowledge to plan and implement recipe tasks.
4. Parents prompted children to display numeracy knowledge that was irrelevant for completing the recipe.

Parent number talk within each pattern had different implications for children's participation in numeracy and cooking, suggesting more nuanced analysis of and recommendations for family learning interactions is needed.

Presentation 3: Examining the role of parent-child math games for children's statistical understanding and math abilities

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DePascale, Mary (University of Maryland, College Park); Ramani, Geetha (University of Maryland, College Park)*

The home math environment can play a critical role in early math development [1]. For example, playing math-related games at home can relate to young children's mathematical knowledge [2], as math games can provide opportunities to learn and practice math-related concepts and engage in math talk with parents during play [3]. Thus, understanding how children can learn from play-based math experiences at home is important. The current study examined the effectiveness of a home-based, experimental graphing game intervention for children's statistical understanding and math abilities.

Children (n=148, M age=71 months, 50% female) and their parents were randomly assigned to one of three conditions: graphing board game, graphing card game, or literacy board game, and completed a pretest, 4-week intervention, and posttest. At each test session, children completed statistical understanding and math ability measures. During the intervention, families played games together in their homes. Families recorded one session of gameplay, and parent and child use of talk during play was examined.

Multigroup growth models indicated that children who played graphing games improved more than children who played literacy games on measures of statistical understanding and arithmetic ($p<.001$). Families who played graphing games used more numbers and math talk than families who played literacy games ($F(2,101)=20.98$, $p<.001$). Talk during play did not relate to gains abilities. These findings provide evidence on the effectiveness of gameplay in the home environment for promoting children's early statistical understanding and math skills, with implications for family math engagement and child math achievement.

Presentation 4: Latine parents conceptualization of children's math learning environments

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Beltran-Grimm, Susana (Purdue University); Purpura, David (Purdue University); Cosso, Jimena (Purdue University)*

Recent research on home math environments has established a need to consider home math environments within cross-cultural contexts (Hornburg et al., 2021). It is clear that parents and children engage with mathematics in their everyday lives within different contexts. This is notably prominent in Latine families (Goldman & Booker, 2009). Culture is not an external factor that affects learning; rather, learning is inherently cultural, and culture is at the core of children's proximal (e.g., home environments) (Civil et al., 2005). Using a mix-method approach (survey and focus groups), this paper will examine parents' perceptions of everyday math activities within the context of family relationships. This paper will analyze Latine parents' home math environments. A survey of 350 parents has been completed, and data will analyze to measure HME in a variety of ways, such as direct number activity math activities (puzzles games, measuring, cooking) to understand the HME of Latine parents. The Focus group will be analyzed using a descriptive and interpretive thematic analysis approach to explore Latine parents' perspectives on the type of HME environments they create at home. The Focus group will include about 20-24 Spanish-speaking Latine parents to explore access to math books/e-books, identify parent preferences for different features within book/e-books, investigate factors that may be associated with parent preferences for supports within e-books such as reading anxiety, math anxiety, and beliefs around the importance of reading and math.

Symposia: 4:30pm - 6:00pm

Dyscalculia in the Brain

Chair: Karin Kucian (1), Michael Skeide (2)

1: University Children's Hospital Zurich, Switzerland; 2: Research Group Learning in Early Childhood, Max Planck Institute for Human Cognitive and Brain Sciences Leipzig, Germany

Developmental dyscalculia is a specific learning disorder that profoundly impairs the acquisition of basic numerical and mathematical skills. This symposium provides insights into the neuronal correlates of this learning impairment, beginning with new insights that show for the first time that dyscalculia originates from atypical fronto-parietal network development. Moreover, the potential of predicting future numerical competences by means of brain imaging is discussed. Finally, further characteristics in terms of brain morphometry and brain network integrity in children with developmental dyscalculia will be presented.

Keywords: Dyscalculia, Brain, Imaging, Prediction, Development

Presentation 1: Early childhood predictors of dyscalculia: Altered structure and function within a fronto-parietal brain network

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Kuhl, Ulrike (Machine Learning Group, Center for Cognitive Interaction Technology, Bielefeld University, Germany); Sobotta, Sarah (Research Group Learning in Early Childhood, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany); Consortium, Legascreen (Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany); Skeide, Michael (Research Group Learning in Early Childhood, Max Planck Institute for Human Cognitive and Brain Sciences Leibzig, Germany)*

Developmental dyscalculia affects the acquisition of basic numerical-arithmetical skills. However, our understanding of the neural precursors of this deficit is limited. In an endeavor to identify neurobiological predictors of developmental dyscalculia, we investigated functional and structural brain profiles of 3- to 6-year-old children without formal mathematical learning experience via MRI. Behavioral follow-up assessments at the age of 7 to 9 years enabled us to identify and match cases to a typically developing control group.

From MRI data acquired early in life, we were able to predict whether an individual would develop dyscalculia or not with up to 87% accuracy, thus surpassing classical behavioral screening benchmarks. Predictive power was highest for functional measures of right posterior parietal and right dorsolateral prefrontal cortex, as well as their structural and functional connectivity.

These results support a domain-specific role of these regions and their interplay for visuospatial numerosity and calculation problem-solving, respectively. Additionally, the young age at which we found predictive features emphasizes the importance of timely intervention measures in children at risk of developing dyscalculia, helping them compensate for their difficulties early on. Finally, as predictive power is highest in domain-specific regions, affected children might benefit more from instruction that is symptom-specific, rather than targeting domain-general skills like working memory.

Presentation 2: Can we predict the development of numerical competences based on brain imaging?

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McCaskey, Ursina (Center for MR-Research, University Children's Hospital Zurich, Switzerland); Ressel, Volker (Center for MR-Research, University Children's Hospital Zurich, Switzerland); Meienberg, Fiona (Medical Faculty, University of Zurich, Switzerland); Tuura, Ruth (University Children's Hospital Zurich, Switzerland); Kucian, Karin (Center for MR-Research, University Children's Hospital Zurich, Switzerland)*

Successful mathematical performance relies on the development and establishment of well-organised networks in the brain. A disturbance of the connections between brain regions for number processing leads to impaired numerical performance, as reported in children with dyscalculia. The goal of the present study was to investigate the predictive merit of neuronal and behavioural measures for future math performance.

In the present longitudinal study, we collected neuropsychological measures and diffusion tensor images (DTI) with an interval of 4 years from totally 21 children with and without dyscalculia (mean age 9.4years). Integrity of white matter tracts as described by fractional anisotropy (FA) was calculated for the whole brain and correlated with performance of different numerical tasks.

Results reveal, that a high FA value in the left superior longitudinal fasciculus (SLF) at baseline is associated with a better outcome in basic numerical abilities 4 years later. In addition, better numerical skills at baseline predict higher FA value in the right SLF at the follow-up measurement. This is in line with the literature, showing that higher FA values in the SLF are positively associated with numerical performance. Moreover, our findings also show that the quality of the SLF predicts learning gains in arithmetic.

In conclusion, our findings reveal that the quality of fibre connections (SLF) predicts learning gains in arithmetic and basic numerical competences 4 years later. On the other hand, the behavioural measures also predict the future quality of the fibre connections, revealing a bidirectional relationship between structure and function.

Presentation 3: Morphology of the Intraparietal Sulcus and Developmental Dyscalculia

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Schwizer Ashkenazi, Simone (Neuropsychology, Dept. of Psychology, University of Zurich, Switzerland); Roell, Margot (Laboratory of Child Development and Education Psychology, University of Paris, France); McCaskey, Ursina (Center for MR-Research, University Children's Hospital Zurich, Switzerland); Tuura, Ruth (University Children's Hospital Zurich, Switzerland); Borst, Gregoire (Laboratory of Child Development and Education Psychology, University of Paris, France); Jäncke, Lutz (Dept. of Psychology, University of Zurich, Switzerland); Kucian, Karin (Center for MR-Research, University Children's Hospital Zurich, Switzerland)*

The intraparietal sulcus (IPS) is regarded as one of the key structures involved in number processing, and alterations in function and structure of the IPS have been identified in children with Developmental Dyscalculia (DD). However, most conducted studies focused on the activation of the IPS and less on the structure of the IPS, although changes in IPS volume, length or depth have also been reported. A novel approach is to evaluate qualitatively the sulcal pattern of the IPS. This procedure was followed based on the notion that the sulcal patterns are determined in utero and presumed to remain relatively stable after birth. Both, in a group of typical achieving children and in a group of healthy adults, part of the variability in math performance could be explained by the participants' IPS pattern. More concretely, a specific feature of the IPS such as the presence of perpendicular branches sectioning the IPS was associated with better math performance.1

In our study, we evaluated the structural features of the IPS by applying an expanded set of pattern criteria in typically achieving children and in children with DD at two time points. We will present whether a) we could replicate the previous finding, b) we were able to identify children with DD according to the pattern of the IPS, and c) the pattern remained stable between the two time points. Furthermore, we will discuss whether we see this method as a possible tool for early detection of DD.

Presentation 4: Increased structural covariance in brain regions for number processing and memory in children with developmental dyscalculia

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Michels, Lars (Department of Neuroradiology, University Hospital Zurich, Switzerland); Büchler, Roman (Department of Neuroradiology, University Hospital Zurich, Switzerland); Kucian, Karin (Center for MR-Research, University Children's Hospital Zurich, Switzerland)*

Successful numerical cognition relies on the development and establishment of a well-organised network in the brain. Fast and accurate connections between brain regions are crucial for efficient transfer and adjustment of numerical information. There is converging evidence that developmental dyscalculia is associated with alterations in this neurofunctional network. Yet, there are no studies, which examined the network integrity in dyscalculia by means of structural covariance network analyses, which allows the examination of brain networks arising from inter-regional correlations of anatomical measurements and partially reflects structural and functional network connectivity. We compared whole-brain maps of volume based structural covariance between 19 children with developmental dyscalculia and 18 typically developing children. We found elevated structural covariance in the dyscalculic group between the anterior intraparietal sulcus to the middle temporal and frontal gyrus. A hippocampus subfield analysis showed higher structural covariance in the dyscalculic group for area CA3 to the parahippocampal and calcarine sulcus, angular gyrus and anterior part of the intraparietal sulcus as well as to the lingual gyrus. Lower structural covariance in this group was seen for the subiculum to orbitofrontal gyrus, anterior insula and middle frontal gyrus. In contrast, the primary motor cortex (control region) revealed no difference in structural covariance between groups. Our results extend functional magnetic resonance studies by revealing abnormal grey matter integrity in children with developmental dyscalculia. These findings thus indicate that the pathophysiology of developmental dyscalculia is mediated by both structural and functional abnormalities in a network involved in number processing and memory function.

An Examination of the Relation between Math Anxiety and Math Achievement

Chair: Nathan T.T. Lau

Western University, Canada

Math anxiety – the feeling of apprehension towards math – is negatively associated with math achievement. This symposium presents different perspectives regarding the underlying mechanism behind this association. The first talk presents evidence to suggest that peer's math anxiety may be predictive of math achievement. The second talk presents evidence that sufferers of math anxiety may have worse metacognitive awareness of their math problem solving performance. The third talk examines how state and trait anxiety may differently relate with the difficulty of math problems. The fourth talk examines whether it is math anxiety that predicts later performance or the other way around.

Keywords: Math Anxiety, Math Achievement, Metacognition, Problem Solving, Contextual

Presentation 1: Disentangling the Individual and Contextual Effects of Math Anxiety: A Global Perspective

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Lau, Nathan T.T. (Western University, Canada); Hawes, Zachary (Applied Psychology and Human Development, Ontario Institute for Studies in Education, University of Toronto); Tremblay, Paul (Western University, Canada); Ansari, Daniel (Western University, Canada)*

Math anxiety is a common affective disorder in students that is characterized by intrusive thoughts that disrupts critical cognitive resources required for math problem solving. Consistent associations between math anxiety and math achievement have been observed across countries and age groups, placing math anxiety among other important correlates of math achievement, such as socio-economic status and magnitude representation ability. However, studies examining math anxiety's relation to achievement have largely focused on the effect of students' own math anxiety (individual effect), while little is known regarding the effect of math anxiety in students' educational context (contextual effect). Using three international studies of achievement (N=1,175,515), we estimated both the individual and contextual effects of math anxiety across the globe. Results suggest that while there are consistent individual effects in virtually all countries examined, the contextual effects are varied, with only approximately half of the countries exhibiting a contextual effect. Additionally, we reveal that teacher confidence in teaching math is associated with a reduction of the individual effect, and country's level of uncertainty avoidance is related to a lessening of the contextual effect. Finally, we uncovered multiple predictors of math anxiety, notably, student perception of teacher competence to be negative related with math anxiety, and parental homework involvement to be positively related with math anxiety. Taken together, these results suggest that there are significant between-country differences in how math anxiety may be related with math achievement and suggests that education and cultural contexts as important considerations in understanding math anxiety's effects on achievement.

Presentation 2: Mathematics anxiety and the metacognitive regulation of problem-solving behaviour

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Morsanyi, Kinga (Centre for Mathematical Cognition, Loughborough University, UK); Ackerman, Rakefet (Faculty of Industrial Engineering & Management, Technion—Israel Institute of Technology, Haifa, Israel)*

Metacognition involves processes by which people plan, monitor, evaluate and adapt their behaviour in response to their perceived success while performing some tasks. The present studies focused on the metacognitive regulation of problem solving in the case of maths anxious and non-anxious participants. In two studies, adults (n < 200 in each study) were presented with problem solving tasks, which either included numerical (Study 1) or non-numerical content (Study 2). Although the numerical and non-numerical tasks differed in their content, they had a very similar structure, and participants had to rely on very similar strategies to solve them. In the case of the numerical tasks, although, overall, maths anxious people were less confident in their maths performance than non-anxious people, they were relatively more overconfident (less well-calibrated), which indicates worse metacognitive awareness of their performance. Another sign that maths anxious people had issues with metacognitive regulation was that they were less able to identify unsolvable tasks than non-anxious participants. These patterns were still present when controlling for the effects of participants' numeracy and general anxiety levels. In the case of the non-numerical tasks, there was no difference in the accuracy of the metacognitive judgments of maths anxious and non-anxious participants. This suggests that mathematics anxiety is related to impairments in the metacognitive regulation of problem-solving behaviour, but this problem is specific to tasks with a numerical content.

Presentation 3: Unraveling the role of math anxiety in students' math performance

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Demedts, Febe (Centre for Instructional Psychology and Technology, KU Leuven, Belgium; imec research group itec, KU Leuven, Belgium); Reynvoet, Bert (Brain & Cognition, KU Leuven, Belgium); Sasanguie, Delphine (Research Centre for Learning in Diversity, HOGENT, Belgium); Depaepe, Fien (Centre for Instructional Psychology and Technology, KU Leuven, Belgium; imec research group itec, KU Leuven, Belgium)*

Math anxiety is one of the most studied affective factors related to learning mathematics and has consistently been found to be moderately negative associated with math achievement. However, some critical issues with regard to math anxiety are to date understudied and therefore indecisive. The first issue is related to the relationship between state and trait math anxiety and how these forms of math anxiety are related to math performance. Second, there is an ongoing debate about the domain specificity of anxiety and how trait math anxiety and general anxiety are related to math performance. The third issue is concerned with the predictive value of actual accuracy and the affective factor, state math anxiety, for individuals' math self-concept. This study addressed these issues by using a within-subject experimental design with easy and difficult math tasks. 181 secondary school students participated. First, we observed only a weak correlation between state and trait math anxiety. Moreover, results showed that state math anxiety was a better predictor for the performance in the easy math task, whereas trait math anxiety was a better predictor in case of the more difficult math task. Second, a moderate correlation was observed between trait math anxiety and general anxiety. However, only trait math anxiety was predictive for math performance in the difficult math task. Third, we observed that both actual accuracy and state math anxiety were predictive of individuals' math self-concept. These results provide insight into the role of math anxiety and its relation with math performance.

Presentation 4: The developmental emergence of math anxiety

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O'Connor, Patrick A. (Queen's University Belfast; University of Loughboroug); Morsanyi, Kinga (Queen's University Belfast; University of Loughboroug); McCormack, Teresa (Queen's University Belfast; University of Loughboroug)*

Math anxiety (MA) and math performance typically correlate negatively in studies of older children and adults, but not always amongst young children, with some theorists questioning the impact of MA on mathematics performance in this age group. An alternative theoretical possibility suggests that the directionality of the causal relation is reversed, i.e., that MA stems from poor early mathematics performance, leading to cumulative experiences of failure, which in turn trigger MA. To test this possibility, children were tested in their first (T1; aged 4-5); second (T2; aged 5-6); and fourth years of school (T3; aged 7-8). At T1 and T2, children completed measures of basic numerical skills, IQ and working memory, as well as completing curriculum-based math tests at the end of the school years. At T3, children completed two self-report math anxiety questionnaires. The results showed that MA could be reliably measured in a sample of 7-8-year-olds and demonstrated the typical negative correlation between MA and math performance. Importantly, although early formal mathematics skills were unrelated to later MA, there was evidence of a longitudinal relationship between basic early symbolic number skills and later MA, supporting the idea that poorer basic numerical skills affect the development of MA.

Math Language Development and Its Importance for Children's Math Skills

Chair: Alex M. Silver

University of Pittsburgh, United States of America

This symposium will focus on children's acquisition and use of math language (including number words, quantifiers, and spatial language). Contributions will compare the proposed mechanisms for the number word learning process (Silver and colleagues), discuss how number word knowledge is related to other math skills (Dramkin & Odic), examine distinct types of math language and their link with different aspects of math highlighting the special role of spatial language for children's math abilities (Turan & De Smedt), and describe an intervention for preschool teachers that encourages use of math language with the goal of promoting numeracy skills (Pelz and colleagues).

Keywords: math language, numeracy, spatial talk, number words

Presentation 1: Comparing mechanisms for number word acquisition

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Silver, Alex M. (University of Pittsburgh); Elliott, Leanne (University of Pittsburgh); Bachman, Heather J. (University of Pittsburgh); Votruba-Drzal, Elizabeth (University of Pittsburgh); Libertus, Melissa E. (University of Pittsburgh)*

How do children learn to map number words to their referred quantities? Some accounts propose that the Approximate Number System (ANS) provides the foundation for this process, such that symbolic number words are mapped onto these imprecise numerical representations, whereas others propose that the Object Tracking System (OTS) plays a critical role as children learn to map number words to small quantities within the subitizing range (see Sella et al., 2021). Here, we asked how young children who have not yet acquired cardinal principle knowledge (N=47, Mage=3.7 yrs) map number words to the referred quantities in a two-alternative forced choice Point-to-X task (e.g., "Which has three?"). Trials were designed with varying ratios and sizes of the response options to test whether performance was ratio-dependent, regardless of the size of the presented options, as suggested by the ANS account, or size-dependent, regardless of the ratio, as suggested by the OTS account. Performance was better for trials where the ratio between response options was large (e.g., 3 vs. 9) than when the ratio was small (e.g., 2 vs. 3), $p < .001$, regardless of the size of the numbers. However, performance was also better for trials where both numbers were small (e.g., 2 vs. 3) than where both numbers were large (e.g., 6 vs. 9), $p < .001$, regardless of the ratio between the response options. The results provide support for both competing accounts of number word acquisition.

Presentation 2: Linking number words to perceptual magnitudes

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Dramkin, Denitza (University of British Columbia); Odic, Darko (University of British Columbia)*

How do children link number words to perceptual magnitudes? We examine whether this link is a one-off event, such that once children can verbally estimate in one dimension (e.g., number) they can also estimate in others (e.g., length, area), or whether children must learn to map number words to each dimension independently (e.g., knowing how to verbally estimate in number, but not length and area).

Ninety 5- to 11-year-olds completed a verbal estimation task, where they judged “how many” items they saw in terms number, length, and area, with novel units provided for each dimension. To evaluate their performance, we calculated the slope and coefficient-of-variation (CV; Cordes et al., 2001) of their estimates.

We find that once children acquired a link between number words and number, they could extend this mapping to length and area, despite not having yet learned units for these dimensions in school. Children could even map number words to novel number units (e.g., “one” unit represented by 3 dots), which is even more impressive considering that if children did have item-specific links (e.g., “one” and 1 item) these would have had to be inhibited and that our youngest participants had not yet learned to formally multiply/divide. In ongoing work, we probe the extent to which children can flexibly utilize different number units in number estimation.

Our findings suggest that children understand the logic of number words: once they can link number words to one perceptual dimension, they can easily do so across dimensions and novel units.

Presentation 3: Understanding mathematical development in preschool children: the association between mathematical language and mathematical abilities

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Turan, Eylül (KU Leuven); De Smedt, Bert (KU Leuven)*

Mathematical language is critical for mathematical abilities in early childhood. To date, no study has disentangled the roles of different types of mathematical language, namely quantitative (e.g., more) or spatial language (e.g., above). Further, existing studies assessed only children’s numerical competencies, but did not consider broader domains of mathematics, such as measurement and geometry. We assessed 75 preschool children’s (Mage = 4 years 10 months) understanding of quantitative and spatial language. We investigated how both aspects of mathematical language correlate with children’s performance in different domains of mathematics (i.e., numerical competencies, measurement and geometry). We also measured children’s general abilities, such as their general language and spatial skill and investigated to which extent associations between mathematical language and mathematical abilities remained when these general skills were controlled for. Results indicated that both quantitative and spatial language were correlated with children’s numerical competencies, measurement and geometry scores. We further observed that spatial language, but not quantitative language, was a unique predictor of children’s mathematical abilities, particularly of their numerical competencies and their geometry performance, suggesting that spatial language is more critical than quantitative language. This relation between spatial language and mathematical ability disappeared when general abilities, i.e., general language and spatial skill, were taken into account. Follow-up analyses further indicated that spatial language partially mediated the association between these general abilities and mathematical abilities. These findings present evidence on the link between distinct types of mathematical language and different mathematical abilities, and they emphasize the role of spatial language in children’s mathematical abilities.

Presentation 4: Play-based materials to encourage math talk in preschool classrooms

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Pelz, Madeline (Wesleyan University); Trapani, Emma (Wesleyan University); Ferrara, Claudia (Wesleyan University); Williamson, Sophie (Wesleyan University); Shusterman, Anna (Wesleyan University)*

Numeracy skills are the strongest predictor of later academic achievement (Duncan et al., 2007), but socioeconomic factors and variation in exposure to these concepts lead to significant individual variation in math skills by the time children start formal schooling (Lee & Burkham, 2002). The frequency and quality of math talk that children are exposed to predicts their later math abilities, but many preschool teachers report little training and resources for early numeracy, leading to a limited amount of exposure to math concepts in preschools (Ramani et al., 2015).

To address this need, we developed the Wesleyan Preschool Math Games, a set of 12 games designed for use in preschool classrooms that target the development of numeracy skills through fun, hands-on, open-ended play by encouraging math talk. In addition to measuring the extent to which these materials support the development of early numeracy concepts, we also compare two methods of implementation. Each participating teacher took part in a numeracy training in which they were taught to introduce the games to their students using either a high-guidance or low-guidance approach. Teachers in the high-guidance condition were encouraged to use math talk to guide children's play directly towards each game's learning goals, while teachers in the low-guidance condition were instructed to allow children to explore the games more freely and to follow the child's lead. We will discuss the theory motivating the development of these games and implementation strategies, as well as how effectively they support the development of early numeracy in each of these contexts.

The Role of Spontaneous Mathematical Focusing Tendencies in Early Numerical Development

Chair: Jake McMullen, Jo Van Hoof, Minna Hannula-Sormunen

University of Turku, Finland

Next to mathematical skills, separate attentional processes exist that trigger the use of specific mathematical recognition skills. For example, ample research showed individual differences in children's tendencies to spontaneously focus on numerosity in situations that are not explicitly numerical. These individual differences are shown to be highly predictive for later mathematical development.

The objective of this symposium is to extend the research field on spontaneous mathematical focusing tendencies by (1) including new mathematical focusing aspects and (2) examining which contextual and cognitive factors may influence spontaneous mathematical focusing, answering an important open question in the research field.

Keywords: spontaneous mathematical focusing tendency, contextual factors, cognitive factors, early numeracy

Presentation 1: Cognitive Demands on Assessment of Spontaneous Focusing on Number

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Ribner, Andrew D. (Learning Research and Development Center, University of Pittsburgh); Funk, Laura (Learning Research and Development Center, University of Pittsburgh); Huerga, Lucia (Learning Research and Development Center, University of Pittsburgh); Libertus, Melissa E. (Department of Psychology, University of Pittsburgh)*

Young children's environments are filled with numerical information: Objects are clustered in sets (e.g., "four candies"), turn-taking requires ordinal reasoning (e.g., "you go first"), and printed numbers appear everywhere (e.g., "the 54 bus"). However, those same inputs also carry information that competes for salience with number, e.g., shape, size, color, and location. Various paradigms have been used to measure children's spontaneous focusing on number (SFON), including unprompted scene description tasks which assess whether children spontaneously talk about numerical information, imitation tasks in which children copy the number of actions of an assessor, and forced-choice tasks in which children pick one of several options which match a target on one characteristic with number being one of them. These paradigms differ in their demands on verbal skills, working memory (WM), and inhibitory control. We use data from a picture description and forced-choice task to better understand task demands on children's SFON and associations between SFON and mathematical skills. Data are drawn from an ongoing classroom intervention with 4- to 6-year-old children from low-income homes. Preliminary results (N=100) suggest attending to number in a scene description task relates to better symbolic number comparison and higher WM as measured by a spatial WM span task (ps<.05), whereas there are no associations between performance on a forced-choice SFON task and children's math, WM, inhibitory control, and verbal skills. Implications for the use of different tasks in further SFON research will be discussed.

Presentation 2: Children's (spontaneous focus on) numerical order during preschool

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Van Hoof, Jo (University of Turku); Harju, Heidi (University of Turku); Nanu, Cristina (University of Turku); McMullen, Jake (University of Turku); Hannula-Sormunen, Minna (University of Turku)*

Cardinality and ordinality understanding are essential for children's numeracy development (e.g., Lyons et al.; 2016). However, only children's cardinality skills have received lots of research attention. While there is large agreement that cardinality recognition skills develop around three to four years of age (e.g., Fuson, 1988), it is less clear when, and how exactly numerical order skills develop. Some researchers conclude that cardinality skills precede ordinality skills (Spaepen et al., 2018), while others claim the opposite (Lavie & Sfard, 2019).

Moreover, many studies focused on children's tendency to spontaneously (i.e., self-initiated) focus on numerosity (SFON) in everyday situations. Ample research highlighted its crucial role in children's mathematics development (e.g., Hannula, 2005). Here we present novel data and assessments of children's spontaneously focus on numerical order (SFONO).

Results of a case study with three 3-6 -year-olds will be discussed in which we examined if and how SFONO and numerical ordering skills manifests itself in children's verbal and non-verbal actions. Tester-child interaction took place in the context of a large battery of activities allowing observation of children's different ways of using numerical order, in guided and spontaneous situations. Results show that the children show different utterances of numerical ordering and SFONO, both verbally as action-based. Educational implications and directions for future research will be discussed.

Presentation 3: Individual Differences in Contextual Influences on Children's Attention to Numerosity

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Mazzocco, Michèle (University of Minnesota); Bye, Jeffrey K. (University of Minnesota)*

The Attention to Number task (AtN; Chan & Mazzocco, 2017) is an experimental matching task. It involves choosing which of four options best matches a target stimulus, and which remaining options also match the target. By putting different combinations of features against each other across trials, we previously showed that the relative frequency with which individuals select numerosity-based matches is (a) higher among adults than preschoolers; and among children and adults it is (b) lower overall relative to matches based on more salient features (i.e., color or shape) and (c) lower when numerosity is pitted against more (vs. less) salient) competing features (Mazzocco et al., 2020). Here we pursued three goals: We replicated our original AtN findings with a more ethnically- and socioeconomically-diverse sample of children than reported previously, with a main effect of Salience on frequency of numerosity-based matches. We examined if developmental differences begin to emerge in primary school, by testing for effects of Age and Salience on frequency of numerosity-based matches among 5- to 8-year-olds, among whom main effects of Salience emerged without a main effect or interactions with Age. Finally, we modified the AtN task to maximize children's opportunity to nominate numerosity-based matches, and found that prior results continue to replicate. Thus our attempts to diminish effects of context failed: the AtN continues to reveal how visual context influences children's tendency to attend to numerosity, and the developmental differences in attention to numerosity on the AtN are not evident in the early school years.

Discussant

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Lyons, Ian M. (Georgetown University)*

The discussant of this symposium will be professor Ian Lyons from Georgetown University in Washington, DC. His research interests include investigating how children and adults come to understand numerical and mathematical concepts. Given his experience in the area of early numerical development, he will be the excellent discussant to provide additional context for the three talks in this symposium. He will also discuss potential future directions and challenges in the field working on spontaneous mathematical focusing tendencies.

THURSDAY 2 JUNE 2022

List of abstracts

(chronologically in order of the program)

Symposia: 9:00am- 10:30am

Spatial-Numerical Associations: Evolutionary, Developmental, and (neuro)Psychological Aspects

Chair: Konstantinos Priftis

University of Padua, Italy

Spatial numerical associations (SNAs) play a fundamental role in everyday life activities. This symposium has the aim to elaborate more on how SNAs appeared during phylogenesis (evolutionary aspects from animal cognition) and during ontogenesis (developmental aspects in newborn humans). Finally, the structure (cognitive psychology) and destruction (neuropsychology) of SNAs in adults will be explored.

Keywords: Spatial-numerical associations, mental number line, numerical cognition

Presentation 1: Spatial numerical associations: evidence from cognitive psychology and neuropsychology

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Priftis, Konstantinos (University of Padua, Department of General Psychology, Italy)*

The most frequently reported spatial-numerical association (SNA) is that between small numbers and the left side of space, and between large numbers and the right side of space (i.e., a horizontal left-to-right SNA). Nonetheless, numbers in everyday life are associated not only with the horizontal dimension, but also with the vertical (down vs. up) and the sagittal (near vs. far) dimension. I shall present data from some recent studies to support the idea that numbers are mentally represented in a three dimensional Cartesian space. More precisely, small numbers are associated with the left, down, near side of space. By contrast, large numbers are associated with the left, up, and far side of space. Furthermore, the three Cartesian axes can interact during spatial-numerical tasks. Finally, I shall briefly illustrate how spatial-numerical associations can be impaired in case of left neglect, a neuropsychological disorder affecting contralesional spatial awareness.

Presentation 2: At the roots of spatial numerical association: Insights from newborn domestic chicks

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Rugani, Rosa (University of Padua, Department of General Psychology. Italy)*

The spatial displacement of numbers along a left-right oriented continuum is a peculiar characteristic of number representation. Traditionally, such a spatial-numerical association, SNA, has been considered a by-product of culture, mainly linked to reading and writing direction. However, a very similar SNA has been described in infants, newborns and animals. This fresher evidence i) challenges the primary role of culture in determining the left-to-right direction of spatial-numerical association; ii) strongly supports that SNA originates from pre-linguistic precursors, heading the investigation into SNA's origin toward its neural representation. Nevertheless, the neural basis of SNA in animals, are mostly unknown. Here, I discuss studies that show that a disposition to associate number magnitudes onto a left-to-right-oriented space exists independently of socio-cultural factors. Young subjects with very little numerical experience, such as three-day-old chicks, associate numerical magnitudes with space. Furthermore, I'll present our newest studies which meets the challenge to unveil SNA's neural substrates. These indicated that i) both hemispheres can deal with spatial-numerical tasks, ii) SNA is mainly affected by right hemisphere processing, iii) SNA could be affected by brain-lateralization levels. Overall, these findings show that a disposition to associate numbers onto a left-to-right-oriented space exists very early in development and in absence-or with very limited- experience, paving the way to a deeper investigation of SNA's neural correlates.

Presentation 3: Relating number to space in infants' quantifying and ordering abilities

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De Hevia, Maria Dolores {Lola} (CNRS and Université de Paris, France)*

The use of spatial information to represent non-spatial domains is a fundamental cognitive ability. One prominent example is the case of numbers, so that numerical magnitudes are represented along a spatial continuum (known as the 'mental number line'). There are (at least) two ways in which number and space relate to one another: 1. different numerosities map onto corresponding spatial extents, and 2. different numerosities map onto different spatial positions. I will argue that these two mappings are functional at birth, and therefore independent of extensive experience with the environment. In particular, on the one hand, newborns expect that an increase (decrease) in numerosity/duration should be accompanied by an increase (decrease) in spatial length. On the other hand, newborns associate numerosities with spatial positions, so that an increase in magnitude is expected to occur in the right side and a decrease in the left side of space. Overall, these studies provide evidence that number-space links are functional at birth, supporting the view that the 'mental number line' is not a product of human invention. Outstanding research questions regarding the cognitive benefits of these mappings will be discussed.

Discussion

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Fias, Wim (University of Gent, Department of Experimental Psychology, Belgium)*

Prof. Wim Fias will be the discussant.

“One”, ●●, 3, Four: The Emergence of Early Numerical Knowledge

Chair: Francesco Sella (1), Attila Krajcsi (2)

1: Loughborough University, United Kingdom; 2: Eötvös Loránd University, Hungary

Early numerical knowledge strongly predicts later mathematical achievement. Yet, we have an unclear picture of how children progressively acquire such knowledge. This symposium brings together four studies that have implemented specific numerical and non-numerical tasks to unveil how different numerical competencies develop and interact. We provide evidence of the limited number knowledge in 5- and 6-knowers (Talk 1), the role of inhibition in moderating the relation between non-symbolic and symbolic number skills (Talk 2), the influence of non-symbolic and symbolic mapping on maths achievement (Talk 3), and the role of number ordering in early numerical development (Talk 4).

Keywords: Early numeracy, Counting, Preschool children, Number development, Symbolic number processing

Presentation 1: Subset-knowers can compare only the numbers they know

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Krajcsi, Attila (Eötvös Loránd University, Hungary); Reynvoet, Bert (KU Leuven Kulak, Belgium)*

Initial acquisition of the first symbolic numbers is measured with the Give a Number (GaN) task. According to the classic method, 1-, 2-, 3-, and 4-knowers are categorized as subset-knowers and it is assumed that these children have only a limited conceptual understanding of numbers. On the other hand, 5-, 6-, etc. knowers are categorized as cardinality-principle-knowers and it is assumed that they understand the fundamental properties of numbers. To validate this categorization method, here, performance in a symbolic comparison task was measured in those groups separately. It was found that similar to 1-4-knowers, 5-, 6-, etc. knowers can compare only the numbers that they know in the GaN task. We conclude that 5-, 6-, etc. knowers are subset-knowers because their conceptual understanding of numbers is fundamentally limited.

Presentation 2: The role of inhibition in the acquisition of symbolic numbers knowledge in two- to four years old children

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Fedele, Marta (KU Leuven, Belgium); Krajcsi, Attila (Eötvös Loránd University, Hungary); Reynvoet, Bert (KU Leuven Kulak, Belgium)*

Human’s ability to discriminate non-symbolic numerical quantities (●, ●●, ●●●…) improves during childhood. Concurrently, during their first years of life, children acquire the meaning of the first number words (one, two, three…) and learn to associate these abstract symbols with the cardinality of a set (i.e., cardinality principle). The relationship between non-symbolic and symbolic number skills during development is still unclear. On one hand, it has been suggested that the acquisition of exact symbolic numbers relies on the progressive sharpening of non-symbolic numbers representations. An alternative hypothesis is that the development of third cognitive skills, such as inhibitory control, supports the parallel improvement of non-symbolic skills and symbolic numbers skills. The current study investigates the role of inhibitory control on the development of numerical abilities in preschoolers. One hundred thirteen children with age ranging from 2- to 4-years-old were presented with a battery of tests, including a number words comparison task, a give-a-number task, an inhibition task, a numerosity comparison task, especially devised to maximize the validity of the task for young children. Our aim is to i) assess the validity of our version of the numerosity comparison task and its relation to the other measured numerical skills; ii) examine the correlation between inhibitory control skills and the accuracy in non-symbolic and symbolic numbers tasks; iii) test the hypothesis that inhibitory control moderates the relationship between non-symbolic and symbolic numbers skills in pre-schoolers.

Presentation 3: Symbolic and non-symbolic mapping in early years education

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Short, Dawn (Abertay University, UK); McLean, Janet (McLean)*

The present study examined how children's ability to map between symbolic (Arabic numerals) and non-symbolic (dot arrays) related to their maths performance. Participants were 398 children in the first year of formal schooling in Scottish schools (Mean age = 60 months), and 75% were from low SES backgrounds. The children completed symbolic to non-symbolic (SNS) and non-symbolic to symbolic (NSS) mapping tasks at two difficulty ratios (1:2; 2:3) plus standardised maths tasks which measured knowledge of number and simple calculations. The results showed that all the children performed better for SNS mapping tasks than NSS tasks. They were also more accurate on the 1:2 ratio. However, SES comparison revealed that the high SES children outperformed low SES children on all tasks. Overall, mapping task performance was significantly related to maths task achievement with low SES children showing significantly lower performance for mapping and achievement. The results suggest that mapping tasks could be a useful way to identify maths difficulties in young children beginning school and this early knowledge of difficulties could assist in improving children's maths achievement.

Presentation 4: The role of different types of ordering in mathematics in the first year of kindergarten

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van Hoogmoed, Anne (Radboud University, The Netherlands)*

The role of ordering in mathematics has gained much attention in the last decade. Whereas there is evidence for the role of symbolic order judgement in mathematics in older children and adults, the role of ordering in mathematics in young children in kindergarten is still debated. The contrasting results in previous research may be due to the different ways in which ordering is measured. In this study, both symbolic and non-symbolic order production and order judgement are examined in children in the first year of kindergarten (4-5 years of age). These different kinds of ordering will be related to precursors of mathematics, next to counting, symbolic and non-symbolic comparison, and working memory. The results reveal the role of ordering in early mathematics in addition to counting and comparison skills, and as such add to a new model early numerical development. Moreover, the results may inform math teaching in kindergarten.

Investigating Parents' Math Input to Young Children: Longitudinal and Experimental Data

Chair: Xiao Zhang, Caroline Cohrssen

The University of Hong Kong, Hong Kong S.A.R. (China)

Acquisition of early math skills is essential, because these skills are predictive of later math achievement and even adulthood socioeconomic status. Within a child's proximal environment, parents may facilitate early math learning by providing math-related materials, encouraging children to be involved in counting and other math activities, and engaging in various types of math talk. The aim of this symposium is to bring together researchers from Eastern and Western countries to share their longitudinal and experimental data about parents' math input to young children. The chairpersons, Dr. Xiao Zhang and Dr. Caroline Cohrssen, have common interest in home numeracy environments.

Keywords: home numeracy environments, math learning, children, experimental research, correlational research

Presentation 1: Caregivers' Number Application Talk and Young Children's Spontaneous Focusing on Numerosity and Number Interest: An Experimental Study

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Zou, Xinzhuo (The University of Hong Kong); Zhang, Xiao (The University of Hong Kong)*

A growing body of research has found the relation between caregivers' number talk and children's number learning outcomes. However, most prior research was correlational. To address this gap, the present study investigated whether one-time, experimentally invoked number application talk exhibited by caregivers enhanced their children's spontaneous focusing on numerosity and number interest. Eighty-one children (M = 61.17 months, SD = 4.46 months) and their caregivers were recruited from China. Caregivers were randomly assigned to one of the following three groups: (1) the number application talk group, (2) the number non-application talk group, and (3) the control group. Caregivers were asked to do grocery shopping and before grocery shopping, Groups (1) and (2) received brief interventions to increase the amount of caregivers' number application talk and number non-application talk, respectively. Children's SFON and number interest were evaluated twice, first before shopping (pretest) and then after shopping (posttest). The results showed that relative to the control group, children whose caregivers were in the number application talk group exhibited higher levels of SFON tendency and caregiver-reported number interest. There was a trend that the SFON tendency and caregiver-reported number interest of the number application talk group were higher than that of the number non-application group, although the trend was not statistically significant. The findings highlight the positive effect of caregivers' number application talk on children's SFON and number interest.

Presentation 2: Different Facets of the Home Numeracy Environment and Kindergarten Children’s Numerical Competencies

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Niklas, Frank (Ludwig Maximilian University of Munich); Mues, Anna (Ludwig Maximilian University of Munich); Wirth, Astrid (Ludwig Maximilian University of Munich); Birtwistle, Efsun (Ludwig Maximilian University of Munich)*

Early numerical competencies are essential for children’s later academic success at school. A critical context to advance these skills is the early Home Numeracy Environment (HNE). In the setting of the formal and informal HNE (see Skwarchuk et al., 2014), parents may support their children’s mathematical competencies development before the start of formal education. However, not all families are able to support their children adequately and some family circumstances can lead to low-quality HNEs. Despite research in recent years, a clear definition and operationalization of the HNE is still missing (Hornburg et al., 2021). This EU-funded longitudinal study (Niklas et al., 2020) addresses children’s numerical competencies development within the context of the HNE. Here, different facets of the HNE, namely, a parental survey on formal and informal aspects of the HNE, a checklist for mathematical games, and an observation of a numerical parent-child interaction were assessed. In addition, numerical competencies of N=500 children (Mage = 61 months, SD = 4.6); 51% girls; 190/310 children in cohort 1/2) were measured with standardized (sub)tests that focus on number symbol knowledge, counting, and easy calculations. The study children and their families were assessed twice within half a year. All facets of the HNE were significantly associated with children’s numerical competencies. In regression analyses, controlling for important child and family characteristics, different facets of the HNE were significant predictors of numerical competencies cross-sectionally and longitudinally. The findings will be discussed in the context of potential family interventions to support children’s numerical competencies development.

Presentation 3: The Longitudinal Interplay between Mother-child and Father-child Numeracy Activities and Young Children's Number Skills

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Zhang, Xiao (The University of Hong Kong)*

Over the past decade, a body of research has grown on the relation between parent–child numeracy activities and children’s number skills, generally focusing on the unidirectional effect of parent–child numeracy activities on children’s number skills. However, whether involvement of parents in numeracy activities is dependent on children’s differing levels of number skills remains unclear. Moreover, most prior studies have focused on parents as a unit or solely on mothers, overlooking the role of fathers and any possible reciprocal influences between mothers and fathers. Based on a longitudinal sample of 201 Chinese preschool children, this study examined how mother–child and father–child numeracy activities affected and were affected by children’s number skills and how mother–child numeracy activities influenced and were influenced by father–child numeracy activities. The results showed that mother-child and father-child number application activities positively predicted children’s number skills, and children’s number skills negatively predicted their parents’ engagement in number skill activities. Finally, mothers’ engagement in number book and number skill activities predicted fathers’ engagement. The findings shed light on the key numeracy activities that intervention programs should prioritize with young children in the years prior to school entry. They also highlight the importance of equipping both parents to support their child's early number skills.

Presentation 4: Assessing the impact of an innovative approach to supporting the home numeracy environment

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Cohrssen, Caroline (The University of Hong Kong); Wang, Rhoda (The University of Hong Kong); Richards, Benjamin (The University of Hong Kong)*

During the Covid-19 pandemic, Hong Kong kindergartens closed for extended periods. Hong Kong parents attach great value to their young children's academic learning. Consequently, there was a pivot to virtual teaching and learning. In addition, there is growing interest in play-based learning in China (Lin & Li, 2019). This proof-of-concept study replicates elements of a light-touch intervention that has been previously reported (Cohrssen & Niklas, 2016; Niklas et al., 2015, 2016). Children's learning is influenced by interactions with people, objects and symbols in the proximal environment (Bronfenbrenner & Morris, 2006). During preschool closures, we sent three-year-old children from low-income households wooden building blocks, a counter-based dice game and a storybook. Information regarding the study and signed consent was obtained from participating kindergarten principals and parents. Participants were randomly allocated at the classroom level to intervention or control groups. Parent surveys were completed before and after receiving an introductory video followed by three, weekly demonstration videos of playful and engaging interactions to support learning. We aimed to assess the videos' impact on the home learning environment. Frequency raw scores increased over time for both intervention and control groups, but differences in changes over time between the intervention and control groups were not statistically significant, even when controlling for maternal education. Scales for 'counting' and 'measurement' demonstrated significant increases in mean scores for the intervention group. Whilst smartphone videos may encourage kindergarten-parent collaboration, videos targeted at parents to support a child's home learning environment through play cannot be assumed to be effective.

From Counting to Arithmetic Fluency: Computational and Neural Bases of Arithmetic Procedures

Chair: Jérôme Prado

CNRS & University of Lyon, France

The ability to fluently solve simple arithmetic problems is an important building block for mathematical learning. It is often assumed that achieving arithmetic fluency involves lesser reliance on counting procedures and greater reliance on memory retrieval. However, recent studies suggest that procedural knowledge may still play an important role in building arithmetic fluency. This symposium will explore this idea by bringing together studies that investigate the mechanisms underlying arithmetic processing in children and adults, using a combination of computational and neural (fMRI, neuropsychology, iEEG) approaches. Together, the contributions will shed light on the role of procedural knowledge in mental arithmetic.

Keywords: arithmetic, procedures, computational, neuroimaging, neuropsychology

Presentation 1: Solving basic additions: behavioral and computational approaches

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Chouteau, Stephanie (Université Grenoble Alpes & CNRS); Mazens, Karine (Université Grenoble Alpes & CNRS); Thevenot, Catherine (Université de Lausanne); Lemaire, Benoit (Université Grenoble Alpes & CNRS)*

Are mental additions of single-digit numbers solved through memory retrieval or through an automatized counting procedure along a mental line? A method to investigate this issue is to combine a behavioral and a computational approach to provide a better understanding of the underlying cognitive mechanisms. At first, we conducted an experiment to compare two learning situations involving basic additions, one based on counting and the other on arithmetic fact memorization. Two groups of participants learned to verify additions such as "G+2=Q?” built on an artificial sequence of letters akin to a mental line ("XGRQD..."). The first group learned the sequence beforehand and could therefore count to answer whereas the second group had to learn the equations by rote without knowing how they were built. The results showed a persistent counting strategy for the majority of participants, while a minority began to memorize the most complex problems. In parallel, a computational model was implemented to further investigate how these basic additions could be solved based on what is known about human cognition and working memory. Autocop is based on an iterative counting process and considers practice on the mental line. Simulations performed on the data obtained on the artificial line showed the same effects as those detected in the participants who showed a persistent counting strategy. Nevertheless, the model is being adapted to consider the memorization strategy adopted by participants which could correspond to a balance between the reliability of the memory trace and the cost of the calculation.

Presentation 2: The neural development of arithmetic fluency: reconstructive or reproductive mechanisms?

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Díaz-Barriga Yáñez, Andrea (Université de Lyon & CNRS); Thevenot, Catherine (Université de Lausanne); Prado, Jérôme (Université de Lyon & CNRS)*

Is arithmetic fluency achieved through procedural automatization (i.e., reconstruction) or memory retrieval (i.e., reproduction)? The reconstruction account hypothesizes that as counting procedures become practiced, they become increasingly fast and automatic and take the form of rapid unconscious counting in adults (i.e., a quantitative change in the same strategy over development). In contrast, the reproduction account hypothesizes that participants should progressively stop counting and increasingly retrieve answers from memory (i.e., a qualitative change in strategy over development). Here we will present the results of a cross-sectional study in which we tested between these hypotheses by identifying the neuro-cognitive mechanisms supporting the development of arithmetic fluency. Specifically, we used fMRI to measure the neural correlates of the problem-size effect associated with single-digit addition problems in four groups of participants: 8-year-olds, 11-year-olds, 14- to 15-year-olds, and adults. In adults, we will show that an increase in the size of very small addition problems (with operands < 5) is associated with an increase of activity in regions typically associated with counting and procedural knowledge, such as the left inferior frontal gyrus and bilateral intraparietal sulcus. However, this effect was not observed for operands larger than 5, in line with previous behavioral studies suggesting that automatized counting may be limited to the smallest operands. We will then present analyses comparing the different groups of children to adults and will discuss whether a quantitative or qualitative change in neural mechanisms supports the development of arithmetic fluency.

Presentation 3: Distinct Contributions of the Cerebellum and Basal Ganglia to Arithmetic Procedures

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Saban, Will (University of Berkeley)*

Humans exhibit complex mathematical skills, often attributed to the exceptionally large neocortex. Using a neuropsychological approach, we report that degeneration within two subcortical structures, the cerebellum and basal ganglia, impairs performance in symbolic arithmetic. Moreover, we identify distinct computational impairments in individuals with cerebellar degeneration (CD) or Parkinson's disease (PD). The CD group exhibited a disproportionate cost when the arithmetic sum increased, suggesting that the cerebellum is critical for iterative procedures required for calculations. The PD group exhibited a disproportionate cost for equations with an increasing number of addends, suggesting that the basal ganglia are critical for the coordination of multiple cognitive operations. In Experiment 2, the two patient groups exhibited intact practice gains for repeated equations at odds with an alternative hypothesis that these impairments were related to memory retrieval. Overall, the results provide a novel demonstration of the contribution of subcortical structures to the computations required for complex cognition.

Presentation 4: Successive ignition of cortical sites across the human brain during arithmetic processing

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Pinheiro-Chagas, Pedro (University of California, San Francisco)*

To date, little is known about the fast spatiotemporal dynamics of activity across remote regions of the human brain during a cognitive task. Here, we report intracranial electroencephalography (iEEG) data from 10,076 sites in 85 subjects during arithmetic (math) and control conditions. Our recordings revealed significant change of activity in 45% of the sampled sites across the entire brain during simple addition calculations. A set of nine anatomically consistent and individually localizable brain regions were identified by their relatively high and preferential responses in the math compared to control conditions. In these regions sites with preferential responses to the math condition were orderly juxtaposed, along a single coordinate axis, to sites with preferential responses to non-math condition. Importantly, across anatomically consistent and individually localizable brain regions, we documented successive activation with a precise temporal order, which was replicated across subjects and trials. The degree of functional connectivity between the sites decreased as a function of temporal distance between regions, suggesting that information is partially leaked or transformed along the processing chain. Next, we showed that the activity of not only sites with preferential responses but also those with non-preferential responses to arithmetic stimuli were modulated by different features of the arithmetic computations, suggesting that arithmetic is coded in a highly distributed manner. Our results provide detailed temporal and individual anatomical information about the ways in which different brain regions are engaged in the subsecond scale to perform a task that requires the integration of information across multiple cognitive functions.

Symposia: 11:00am - 12:30pm

Language Influences on Basic Number Processing

Chair: Christine Schiltz, Silke Göbel

University of Luxembourg, Luxembourg

Numerical and mathematical thinking is thought to be influenced by language (e.g. Dowker and Nuerk, 2016; Bahnmüller et al., 2020). This symposium will examine how lexical and syntactic language factors and their mastery shape the exact number processing and arithmetic. The talks in this symposium will focus on studies investigating performance in basic numerical abilities (i.e. counting, transcoding) and arithmetic problem solving in participants with diverse language profiles. To obtain a broad, developmental perspective, we will consider the impact of linguistic factors in children and adults using within- and cross-language comparison paradigms.

Keywords: numerical development, transcoding, cross-linguistic comparison

Presentation 1: Children's spatial language predicts their later verbal number skills

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Lindner, Nadja (University of Potsdam); Moeller, Korbinian (Loughborough University); Dresen, Verena (fUMIT Tirol – Private University for Health Sciences); Pixner, Silvia (fUMIT Tirol – Private University for Health Sciences); Lonnemann, Jan (University of Potsdam)*

It is assumed that the process of number symbolization is influenced by the acquisition of so-called verbal number skills (e.g., verbal recitation of the number chain and naming Arabic numerals). For the acquisition of these verbal number skills, verbal and visuospatial skills are discussed as contributing factors (e.g., Cornu et al., 2018). Regarding this, children's verbal number skills have been found to be related to their concurrent spatial language skills such as mastery of verbal descriptions of spatial position (e.g., in front, behind) (e.g., Georges et al., 2021). In a longitudinal study, we investigated the predictive role of German-speaking preschoolers' spatial language skills on the acquisition of verbal number skills, such as upward counting and naming Arabic numerals. Results indicated that children's knowledge of spatial terms of position predicted their verbal number skills measured six months later, even after considering their general language skills. This suggests that better spatial language skills at age 4 facilitate future acquisition of verbal number skills and indicates that fostering children's understanding of specific verbal descriptions of spatial positions may positively affect children's future numerical development in the long run.

Presentation 2: Transparent Vietnamese number-naming system facilitates first graders transcoding - a cross-linguistic study with French

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Lê, Mai-Liên (University of Social Sciences and Humanities Vietnam); Noël, Marie-Pascale (UCLouvain)*

The Vietnamese number-naming system more transparently expresses base-10 than the French one does. Our study aimed to examine the language (base-10) effect on the transcoding performance and error nature in 68 French-speaking (FS) children and 173 Vietnamese-speaking (VNS) children in the first grade. They were presented with two transcoding tasks: verbal- and analog-Arabic. The results showed that the VNS children performed better than the FS children on both of the transcoding tasks. The FS children committed more lexical errors than the VNS children did, while the syntactic error rates were not different. We conclude that the transparency of the base-10 expressions or the reduced number lexicon led to a better transcoding performance in the VNS children, and the nature of the transcoding error reflects differences in the number-naming system. The differences in transcoding performance and errors are discussed based on the integration of the transcoding theoretical frameworks.

Presentation 3: Longitudinal contribution of number writing to arithmetic in different languages

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Banfi, Chiara (University of Graz); Clayton, Francina J. (University of York); Steiner, Anna F. (University of Graz); Finke, Sabrina (University of Graz); Landerl, Karin (University of Graz); Göbel, Silke M. (University of York)*

Number writing involves transcoding from number words (e.g., "thirty-two") to written digit strings (32) and is an important unique predictor of arithmetic. The existing longitudinal evidence about the relation between transcoding and arithmetic is mostly language-specific. In languages with number word inversion (e.g., German), the order of tens and units is transposed in spoken number words compared to Arabic numbers. This makes transcoding more challenging than in languages without number word inversion (e.g., English). We investigated whether the contribution of number writing to the development of arithmetic is similar in languages with and without number word inversion.

German- and English-speaking children were followed over the first three years of primary school. Number writing in Grade 1 predicted arithmetic in Grade 1, 2 and 3, over and above other non-numerical non-verbal reasoning and working memory) and numerical (symbolic and non-symbolic magnitude comparison) predictors. Crucially, the interaction with language was not significant, indicating a comparable importance of this predictor for arithmetic development in German- and English-speaking children. Thus, transcoding plays a crucial role in the development of arithmetic skills in languages with and without number word inversion.

Presentation 4: Bilingual number semantic priming : weak lexico-semantic activation from number words in the second language of mathematical acquisition

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Lachelin, Rémy (University of Luxembourg); Marinova, Mila (University of Luxembourg); Reynvoet, Bert (University of Ghent); Schiltz, Christine (University of Luxembourg)*

In Luxembourg, language of instruction for mathematics switches from German (LM1) to French (LM2) in 7th grade. Adults having completed this multilingual school curriculum are thus highly proficient in both languages. Our online study aimed to compare lexical and semantic access of numbers from 1 to 9 in both languages of participants trained in this multilingual education context. Arabic digits had to be read aloud in LM1 or LM2. They were preceded by a short number (51 ms) prime presented as Arabic digits, German or French number words. Results show generalized slower responses in the LM2 (French) compared to LM1 (German). Priming number distance effect (PDE) was used as an index for numerical semantic activation (Reynvoet et al., 2002). We observed a comparable PDE when priming with Arabic digits and number words in German. However, using French number words as primes did not yield a clear mark of PDE.

In conclusion, the slower LM2 responses are interpreted as weaker LM2 lexical retrieval compared to the LM1, which could be explained by a later age of mathematical acquisition. The lack of semantic activation from French number words compared to German suggests a weak lexico-semantic association of LM2 number words. These results confirm the cognitive role of language in processing numbers. They contribute to our understanding of bilingual number processing and might have important implications for designing school curricula in multilingual settings.

Math Skills, Self-Beliefs, and Emotions

Chair: Minna Torppa, Tuire Koponen

University of Jyväskylä, Finland

Math difficulties are found to be associated with negative self-beliefs and emotions such as low self-efficacy beliefs, low self-esteem, depression, and anxiety. This symposium brings together studies on the associations between math skills, self-beliefs, anxiety, and emotional well-being among children, adolescent, and adults. We present findings regarding the developmental associations between skills, self-beliefs and emotions, explore the effect of the rater of child's emotions on the associations between skills and emotions, and the role of parental math emotions in child's mathematical performance.

Keywords: Math skills, Self-Beliefs, Emotions

Presentation 1: The association between parents' mathematical anxiety and children's mathematical performance.

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Bellon, Elien (KU Leuven); Vanbinst, Kiran (KU Leuven); Dowker, Ann (Oxford University)*

In this talk, we will discuss the extent to which mathematical abilities of children are associated with the mathematical anxiety of their parents. The results of two studies will be discussed, namely one in preschool children (n = 83) and one in primary school children (n = 172). In these studies, both biological parents responded to a mathematical anxiety questionnaire. Additionally, their educational level and performance on an arithmetic test was studied. Children performed age-appropriate tasks to investigate their mathematical abilities, and primary school children additionally responded to a mathematical anxiety questionnaire. Our results in preschoolers indicate that parents' mathematics anxiety seems to be strongly associated with their own arithmetical ability but not that of their young children. Our results in primary school children also indicate that parents' mathematical anxiety is not associated with that of their primary school child. Importantly, both studies show that studies of how parental characteristics (e.g. mathematical anxiety, educational level) may influence children's mathematical performance need to take into account that mothers and fathers show significant correlations with one another for several of these characteristics. Moreover, some intergenerational associations differed when investigating mother-child versus father-child correlations. The findings of these two studies, their relevance and their implications will be discussed.

Presentation 2: Third graders' emotions in mathematics – different raters, different perspectives

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Mononen, Riikka (University of Oulu and University of Oslo); Tapola, Anna (University of Helsinki)*

Studies examining young students' mathematics emotions from different raters' perspectives (i.e., students, parents, and teachers), are still quite rare, and therefore we know little how consistent the evaluations are across different raters. In this study, we investigated third graders' experienced mathematics emotions (i.e., enjoyment, boredom, and anxiety) from the viewpoints of students and their teachers and parents, and the correspondence between these evaluations, while controlling for mathematics performance, gender, and mother's educational level. Participants were 123 Norwegian third graders, their parents, and teachers. Students completed a mathematics emotions questionnaire (AEQ-ES) and three mathematics performance tests. Parents and teachers rated their child or student with a question for each emotion. Students reported enjoying their mathematics learning, experiencing some boredom, and relatively low levels of anxiety. Hierarchical regression analyses showed that only the parent-rated emotions were significantly associated with student-rated emotions. Further, girls enjoyed mathematics more than boys, while boys experienced more boredom. Higher mother's educational level and students' better addition skills were associated with lower level of student-rated anxiety. These findings implicate that parents' evaluations of their child's emotions in mathematics coincide to some degree. Further, they highlight that the differences between the raters' perspectives should be acknowledged. This calls for longitudinal studies to further explore the relations and discussion on measurement validity.

Presentation 3: Trajectories of change in math self-efficacy and math achievement among primary school students

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Peura, Pilvi Illusia (University of Jyväskylä); Koponen, Tuire (University of Jyväskylä); Aro, Tuija (University of Jyväskylä); Aro, Mikko (University of Jyväskylä)*

The beliefs children hold about their capabilities (i.e., self-efficacy) in math are known to relate to their math achievement supporting persistent work and commitment to learn. Still, we know little how these efficacy beliefs develop and change in primary school and how changes in math skills and self-efficacy develop together. Theoretically four sources of self-efficacy (mastery experiences, verbal and social persuasions, vicarious experiences, and physiological and emotional states; Bandura, 1997) are hypothesized to build self-efficacy and changes in it. However, this association has been mainly examined cross-sectionally, and we know little how these sources relate to changes in self-efficacy over time. Moreover, changes in self-efficacy likely differ between children and thus use of person-oriented approach could extend our understanding of the varying changes over time. In this study, we extend the prior work by examining different trajectories of change in math self-efficacy and their math achievement among primary school students (N = 1327) from Grade levels 2 to 5. Using growth mixture modeling we will identify different trajectories of change in math self-efficacy and math achievement. Children's varying changes in the hypothesized sources of self-efficacy predicting change trajectories in self-efficacy will be further analyzed. Increased knowledge of the individual pathways building self-efficacy and math achievement and the learning experiences that relate to these changes could help us better design and target support for those with low beliefs and low achievement in math.

Presentation 4: Self-Concept as a Mediator between Reading Skills, Mathematical Skills, and Emotional Well-Being – A Longitudinal Study from Age 15 to 20

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Torppa, Minna (University of Jyväskylä); Aro, Tuija (University of Jyväskylä); Eklund, Kenneth (University of Jyväskylä); Parrila, Rauno (MacQuarie University)*

This study examines longitudinal associations between academic skills, self-concept (global and skill-specific), and emotional well-being from age 15 to 20 in a Finnish sample. The participants' (n=586) reading fluency, reading, comprehension (PISA), and math skills were tested in classrooms at age 15, questionnaires were used to assess self-concept at age 15, and emotional well-being at age 15 and 20. The predictive path models, with age 20 emotional well-being measure as outcome, and age 15 skill, self-concept, emotional well-being measures, gender, and educational track as predictors suggested no direct associations between age 15 skills and age 20 emotional well-being. Skills were, however, associated with the respective self-concept of ability in reading and math as well as with general self-concept (self-esteem), and educational track. Furthermore, reading and math skills at age 15 correlated with the concurrent emotional well-being. Age 15 emotional well-being, self-concept of ability in reading comprehension, self-esteem, and educational track in turn predicted age 20 emotional well-being. These results suggest that reading and math skills are associated with adolescent well-being but suggest no unique longitudinal effects on well-being. Adolescent well-being indicators such as global self-concept or internalizing problems, on the other hand, are associated with academic skills and may index worry also in the long run.

The Home Mathematics Environment of Latine Families

Chair: Jimena Cosso

Purdue University, United States of America

A line of recent research has focused on the importance of the home numeracy environment (HNE) in fostering children's mathematics understanding. Gaps in mathematics performance are already present in kindergarten, and the HNE may help to explain these gaps in the early years. However, research on the HNE has mostly focused on monolingual English-speaking European American families and there is a need to properly understand the engagement behavior of Latine families. In this symposium, we aim to bring together studies that focus on how Latine families support their children's early mathematics skills.

Keywords: Latine families, Home Environment, Math, Children Skills

Presentation 1: Latino Kindergarteners' Math Growth, Approaches to Learning, and Home Numeracy Environment

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Leyva, Diana (University of Pittsburgh); Yeomans-Maldonado, Gloria (Children's Learning Institute at The University of Texas Health Science Center at Houston); Weiland, Christina (University of Michigan); Shapiro, Anna (University of Virginia)*

Latino children have a substantial representation in the U.S. educational system: they make up about 25% of students in schools and are projected to represent about 30% of student population by 2050. There is very limited research on the relation between Latino kindergarteners' math development and approaches to learning (ATL), the set of competencies that promote learning regardless of the content, including attention, concentration, engagement, motivation, and task persistence. There are also mixed results regarding the role of Latino home numeracy environment in children's math development. This study examined the associations among Latino kindergarteners' ATL, home numeracy environment, and growth in math skills. Participants were 151 low-income Latino parents and their children (M age = 67 months; 52% female). In early fall (beginning of kindergarten), parents completed a home numeracy environment survey and children's ATL were assessed. At three time points during the kindergarten year (early and late fall, and spring), children's math skills were assessed. Positive and significant linear growth in Latino kindergarteners' math skills was observed. Latino kindergarteners' ATL positively related to variation in math skills, but not growth. Home numeracy environment did not relate to math skills. Findings highlight the unique role that ATL might play in supporting Latino kindergarteners' math development.

Presentation 2: Longitudinal Associations of the Home Mathematics Environment and Students' Math Outcomes in Early Elementary School

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Susperreguy, María Inés (Pontificia Universidad Católica de Chile and Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT)); Di Lonardo Burr, Sabrina M. (University of British Columbia); Xu, Chang (Carleton University); Douglas, Heather (Carleton University); del Río, M. Francisca (Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT) and Universidad Diego Portales); Salinas, Viviana (Pontificia Universidad Católica de Chile); LeFevre, Jo-Anne (Carleton University)*

The available research on the home mathematics environment (HME) with Latino children has been mainly conducted with children prior to Grade 1. This study will explore whether the HME reported by parents of Kindergarten and early elementary Chilean children continues to be a predictor of children's math performance a year later. Participants were 283 Chilean children from Kindergarten to Grade 2, and their parents, from low- and high- SES families. Parents reported on the HME they provide to their children (i.e., formal and informal math activities at home, math attitudes, math anxiety, math expectations, and math homework help) and their educational attainment, and they completed a math assessment (i.e., math fluency task) at the beginning of the study (Time 1). Children's mathematical performance was assessed with standardized tests at Time 1 and a year later (Time 2, n= 253), when they were in Grades 1-3. Based on research with Chilean and other Latino families, we hypothesized that parents' math fluency and educational attainment would be related to children's mathematical performance a year later. We also expected the home math environment factors (e.g., advanced home math activities and parental math anxiety) to play a role in children's mathematical performance, although with differences associated with the socioeconomic circumstances of the children and children's grade. Longitudinal associations between parental home math environment and Chilean children's mathematical performance will be discussed.

Presentation 3: Exploring the Factor Structure of the Latine Families Home Numeracy Environment Construct

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Cosso, Jimena (Purdue University); Purpura, David (Purdue University)*

The home numeracy environment (HNE) is an essential factor that helps explain children's early mathematics skills, however, given that research on the HNE has mostly focused on monolingual English-speaking children, the commonly used methods to measure the HNE through parents' self-reported questionnaires do not take into consideration cultural differences that contextualize the home environment (Homburg et al., 2021; Sonnenschein & Galindo, 2015). A culturally sensitive measure of the HNE was developed to understand the home numeracy engagement of Latine families by building up from semi-structured interviews with 15 Latine parents. This study will explore the factor structure of the HNE construct using this culturally sensitive measure. Participants were 216 first-generation Latine parents living in the U.S.A (children mean age = 2.88). HNE was assessed as part of a parental survey administered to Latine parents through Qualtrics and Prolific. Forty-two items from the survey asked parents to report their frequency in mathematics-related activities and attitudes (i.e., formal and informal math activities, math beliefs, and math anxiety). Using exploratory factor analysis, preliminary results suggest that the HNE construct of parents' math anxiety could be represented by five factors (i.e., interactions, games, anxiety, beliefs, household). The difference between common measures of the HNE and this measure that include relevant items for Latine parents (e.g., the difference between formal and informal activities) will be discussed

Presentation 4: Mexican parents' academic expectations and beliefs in relation to home learning practices.

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Jiménez Lira, Carolina (Universidad Autónoma de Chihuahua, Mexico); Simms, Victoria (Ulster University); Paz García, Daniela Susana (Universidad Autónoma de Chihuahua, Mexico); Benavides Pando, Elia Verónica (Universidad Autónoma de Chihuahua, Mexico); Cahoon, Abbie (Universidad Autónoma de Chihuahua, Mexico)*

Prior research shows that parental academic expectations predict their frequency of engaging their children in home learning activities. These expectations are often measured using items that include benchmarks which children should achieve prior to entering Grade 1. Studies with Mexican samples using these questionnaires have often found no relation to parents' reports of the frequency of their home learning practices. Thus, the goal of this study was to analyze parental academic educational expectations, the accuracy of their expectations for their children's counting skill, and beliefs of child performance as compared to others, in relation to the frequency of engaging in five types of home learning activities (i.e., technology, TV-programmes, number print, academic language and literacy activities) with their children. Mexican parents reported on the highest educational attainment they expected their child to achieve, their expectation with regards to children's counting and their child's highest count, their beliefs about their children's academic performance (i.e., counting, math, science, reading, writing, jigsaw puzzles) as compared to 100 other children, and the frequency with which they engage their children in home learning activities. Results show that only parental beliefs about performance as compared to other children were related to the frequency with which they engaged in home technology, number print, and literacy activities. These results highlight the importance of exploring distinct aspects of parental expectations and beliefs about their children's performance in relation to a broader range of home learning activities.

SNARC Effect: Different Stories told by Different Tasks and Different Samples

Chair: Krzysztof Cipora (1), Jean-Philippe van Dijck (2)

1: Loughborough University, United Kingdom; 2: Thomas More Antwerp, Ghent University

The Spatial-Numerical Association of Response Codes (SNARC) effect, that is the phenomenon than in speeded binary response setups participants respond faster to small / large magnitude numbers on the left / right side respectively, is quite robust and well-established. However, the more detailed look one takes onto this phenomenon, especially when considering different tasks and subject samples, the more complicated the picture becomes. In this symposium we wish to shed some light onto these nuances and argue, that they need to be considered to come to a fuller understanding of how and why we associate numbers with space.

Keywords: SNARC, Spatial-Numerical Associations, taks dependency

Presentation 1: The influence of situated factors on the SNARC effect: the role of context and task demands

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Mingolo, Serena (University of Trieste); Prpic, Valter (University of Bologna, De Montfort University); Agostini, Tiziano (University of Trieste); Murgia, Mauro (University of Trieste)*

Research on numerical cognition investigates the factors that modulate the SNARC effect (Dehaene et al., 1993) to better understand the processes underlying spatial-numerical associations (SNAs). This work aims to clarify how ordinality elicited by the context in which stimuli are presented or by task demands interact. Numerical stimuli were presented in the context of an overlearned numerical configuration in which numbers are ordered differently compared to the mental number line, namely a mobile phone keypad. Three experiments employed three tasks with different levels of consistency with the order elicited by the context to determine whether the order elicited by task demands can interact with the one elicited by the context. In Experiment 1, the task elicited the same order as the context, because it required to judge numbers based on their spatial position on the keypad. A spatial association consistent with the keypad emerged, showing that SNAs are driven both by the context and by the task when they consistently elicit the same order. In Experiment 2a, a magnitude classification task determined the lack of SNAs, probably because of the inconsistency between the contextual and task demand's order. In Experiment 2b, a parity judgement task determined the SNARC effect, suggesting that the order elicited by the context did not modulate the spatial association. Overall, three different tasks gave rise to three different results. This shows that the context alone cannot account for spatial-numerical associations, but that consistency between the orders elicited by context and task demands is needed.

Presentation 2: Task and setup dependency of the SNARC effect: uni- and bimanual parity judgment and magnitude classification

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Cipora, Krzysztof (Loughborough University); Gashaj, Venera (Swiss Federal Institute of Technology (ETH), University of Tuebingen); Nuerk, Hans-Christoph (University of Tuebingen)*

The SNARC effect (Dehaene et al., 1993) is typically measured either with the parity judgment and the magnitude classification tasks. At least to a certain degree it is assumed that both these tasks, at least at the very general level measure the same phenomenon. This is despite differences both at the conceptual (i.e., task relevance of the number magnitude) and empirical level (i.e., linear vs. categorical pattern of the SNARC slopes). However, if the SNARC effects measured with these two tasks are to be considered to reflect the same underlying phenomenon, they should be correlated. So far, the evidence for such a correlation is quite limited. In this study we tested the same participants with both parity judgment and magnitude classification task. On group performed both tasks in a typical bimanual setup, and the other in the unimanual setup using their dominant hand. In all conditions we observed a robust SNARC effect. Proportions of participants revealing a reliable SNARC effect as quantified by the bootstrapping methods was similar across conditions too (around 40.0-46.4%). In the bimanual setup, despite high reliabilities the SNARC effect observed in both tasks was not significantly correlated ($r = .11$, $BF01 = 4.35$). However, in the unimanual setup, despite lower reliability, the SNARC effect observed in both tasks was correlated ($r = .39$, $BF10 = 12.31$). These results call for theoretical reconsideration of what the typically measured SNARC effect represents.

Presentation 3: The spatial number representations and spatial skills in adults with different mathematical backgrounds

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van Dijck, Jean-Philippe (Thomas More Antwerp, Ghent University); Moorkens, Jolien (Thomas More Antwerp,); Fias, Wim (Ghent University)*

It is commonly accepted that spatial skills and mathematics are strongly intertwined (Hawes & Ansari, 2021). At the same time, there exists strong evidence that the mental representation of numbers has spatial properties (e.g., Dehaene et al., 1993). Currently however, the link between the spatial representation of numbers and mathematics is less clear, as some studies found positive relations between them, and others not (for a discussion see Cipora et al., 2020). Here we try to further shed light on this discussion by investigating differences in spatial skills and spatial number representations in students with different mathematical backgrounds. More precisely, we recruited students with six or more hours of formal (abstract) mathematics education and students with a more applied background in mathematics (STEM-like) and compared both groups in terms of their performance on different spatial skills and on different types of spatial numerical associations. Data-collection is in its end phase, but we predict better performance on the spatial tasks in students who have a more applied background in mathematics. The results will indicate whether the link between spatial processing and mathematics is a fixed intrinsic one, or whether it will be influenced by the level of mathematical abstractness.

Discussant

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Priftis, Konstantinos (University of Padua)*

The symposium will be concluded by the discussant.

Poster session 2: 12:30pm - 2:30pm

1. Hysteresis in training task of Approximate Number System: transfer effect to symbolic math abilities

Nadir Díaz-Simón*, Ignacio Cervieri, Alejandro Maiche

Universidad de la República, Uruguay

From an early age, humans have access to the Approximate Number System (ANS), which allows a preverbal, intuitive, and approximate sense of quantities. Several pieces of evidence show the emergence of a functional relationship between individual differences in ANS accuracy and mathematical performance, but the correlational nature of the studies and contradictory results do not allow us to clarify the nature of this relationship. In the present study, we conducted a randomized controlled trial with a pre- and post-test design, which aims to evaluate the hysteresis effect in modulating performance in a non-symbolic and approximate quantity comparison task and the subsequent transfer effect on symbolic mathematical performance. One hundred and twenty-eight students from senior kindergarten and first grade of elementary school participated in this study. The results show a hysteresis effect in Reaction Time and efficiency index for First Grade, but no transfer effect to symbolic mathematical abilities was found. These results raise several lines of debate to clarify the nature of the relationship between the two processes that can contribute to developing this discussion.

Keywords: Approximate Number System, hysteresis, math abilities, transfer effect

2. Investigating the relationships between absolute and relative magnitude processing in space and time: An SEM study

Rebekka Lagacé-Cusiac*, Paul F. Tremblay, Daniel Ansari, Jessica Grahn

University of Western Ontario, Canada

Previous studies have shown that spatial ratios (e.g., ratios in lengths, areas and numerosities) may be processed by a common ratio processing system. The aim of the current study was to determine whether temporal ratios are processed by the same system as spatial ratios. Two hundred and seventy-five participants completed a battery of spatial and temporal ratio estimation and magnitude discrimination tasks online. In ratio estimation tasks, participants estimated on a bounded line the ratio between the two magnitudes (e.g., 1:2 is indicated with a mark in the middle of the line). In magnitude discrimination tasks, participants indicated which of two magnitudes (e.g., two lengths) was the largest. Using structural equation modeling (SEM), performance on spatial ratio estimation tasks were correlated with performance on temporal ratio estimation tasks while controlling for participant's performance on the magnitude discrimination tasks. Spatial and temporal ratio processing were significantly related ($r = .63$) after controlling for absolute magnitude processing, providing support for a general mechanism for processing ratios across the spatial and temporal domain. Additionally, participants' ability to discriminate absolute magnitudes explained a large part of their performance on ratio estimation tasks (60-66%). This suggests that, even though participants' performance on ratio estimation tasks can in part be explained by a shared ratio processing system, performance is also largely explained by absolute magnitude mechanisms associated with spatial or temporal processing.

Keywords: Proportional reasoning, non-symbolic, spatial, temporal, number line estimation

3. Show me how you estimate and I will tell you your math performance

Lucia Vanessa Puyol Ferrari*

Universidad de la República, Uruguay

Mathematics is a fundamental competence to perform in everyday, academic and professional situations. When starting elementary school, one of the biggest challenge children have to face is making exact calculations. This generates fatigue and even rejection to learning mathematics, resulting in poor performance in this area. Gilmore, McCarthy and Spelke (2007) delve into the skills of symbolic approximate calculation and suggest that the difficulty in carrying out arithmetic operations could be due to the demands of operating with exact numbers. The aim of this investigation is to explore the relationship between approximate calculation and mathematical performance and what happens the following year.

Owers objectives try to find out if children can make approximate calculations by manipulating bigger quantities than those taught in school and to evaluate if the abilities in approximate calculation before entering elementary school affect the learning of exact calculus one year later. We evaluated 50 children in kindergarten and 80 in first grade.

The results show that approximate calculation seems to be a skill that is present in five-year-old children, through which they manage to manipulate amounts greater than those proposed in the curriculum. However, it is not a skill that is usually taught in the classroom.

The approximate calculation ability at level 5 would appear to be a good predictor of mathematical performance in first grade.This skill can be a good tool to identify and train children with possible difficulties in mathematics, as long as identified before starting elementary education.

Keywords: approximate calculation, math, kindergarten

4. Probing arithmetic knowledge through an enumeration task of grouped stimuli

Lorenzo Ciccione* (1,2), Stanislas Dehaene (1,2)

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Determining the exact cardinality of a set of objects requires a slow counting process; however, if the set is divided into recognizable subgroups, enumeration speed is enhanced. This ability to capitalize on grouping cues has been named "groupitizing"1, it appears in children after one year of formal education and it correlates with arithmetic skills. In our recent study2,we extended these findings to adults and we showed that participants with a higher mathematical knowledge benefit more from grouping cues (both in terms of enumeration accuracy and response times). We also formulated the hypothesis that the advantage for grouped stimuli is driven by implicitly computing arithmetic shortcuts: in fact, if sets are divided into subgroups that share the same numerosity, a multiplicative computation is possible (for example, allowing 3 groups of 3 items to be fast computed as 3x3). In support of this hypothesis, we found that: a) groupitizing disappears for items that are not divided into subgroups with the same number of items (for example, 9 items divided into one group of 4, one of 3 and one of 2); b) only grouped sets – and not ungrouped ones – lead to "table errors" (i.e., saying 6 instead of 9), suggesting that subjects select the wrong multiplication operands (3x2 instead of 3x3) or simply retrieve the wrong result from long term memory. Based on our results, enumeration tasks of grouped stimuli could therefore serve as an ideal implicit assessment tool of arithmetic knowledge.

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2) Ciccione, L., & Dehaene, S. (2020). Grouping Mechanisms in Numerosity Perception. Open Mind, 4, 102–118. https://doi.org/10.1162/opmi_a_00037

Keywords: numerical cognition, arithmetic, learning, groupitizing, mathematical knowledge.

5. Running an algorithm in your mind: the role of information-shifting in working memory

Dror Dotan*

Tel Aviv University, Israel

Solving multi-digit arithmetic problems mentally is hard, and many people never become proficient at it. However, the mechanisms underlying this ability are not fully understood. Here, I examined the ability to execute mentally a slightly different kind of algorithms – computer programs, presented as Python code.

Participants with basic programming level saw simple Python programs, one line of code at a time, and indicated the result of each line. Responses were faster when a line of code processed the same variable as the previous line, and slower when the variables differed – a cost of shifting the "focus of attention" in working memory. The switch-cost decreased during the experiment session, without a parallel decrease in the baseline performance, indicating a highly-specific training of this focus-shifting mechanism.

I also examined programs with functions. The function argument names were either identical with the main program's variable names or different. Identical names resulted in faster responses when entering the function, but slower responses when returning from the function to the main program. I propose that the function's and main's variables are stored in working memory as two separate datasets; identical names in the two datasets facilitate a "context switching" operation that occurs when entering the function, but disrupt a "restore" operation that occurs when returning to main.

Overall, this study shows the specific role of working-memory processes in mental simulation of computer programs. I propose that additionally, the mental-simulation paradigm can serve to examine the cognitive underpinnings of algorithmic thinking in general, including in mathematics.

Keywords: mental algorithms, executive functions, working memory, programming

6. Digital and hybrid games to enhance mathematical learning

Dinorah de Leon*, Alejandro Maiche

Universidad de la República, Uruguay

Mathematics learning can be reinforced through specific activities such as games that include numerical content. Numerical games have been developed for this purpose, showing that both digital games (Moyer-Packenham, et al., 2019) and physical material such as board games (Gasteiger & Moeller, 2021) are useful. However, recent games that combine digital and physical characteristics such as hybrid games seem to be promising, since this type of game combines the benefits of both modalities (Mora, Fagerbekk, Monnier, Schroeder & Divitini, 2016). In the present study we designed and tested an intervention program to compare the impact of both types of games on mathematical learning. The program was applied to 268 children between 5 and 6 years of age in the city of Montevideo. Children were assigned to one of the three conditions: digital, hybrid and a business as usual condition (BAU). The results show a significant improvement in the experimental groups (digital and hybrid) compared to the BAU in their mathematical abilities. However, when comparing the experimental groups, the results show greater advances in the hybrid game condition. This could suggest that the social interaction generated in hybrid games could be an important factor in the learning of mathematical concepts at these ages.

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Keywords: Mathematical games, mathematical learning, social interaction

7. The sums are larger than their natural number addends: Relation to operands understanding predicts growth in arithmetic/algebraic problem-solving

Terry Tin-Yau Wong*

University of Hong Kong, Hong Kong S.A.R.

In any addition/multiplication problems with natural numbers, the sums/products are always greater than the addends/multiplicands. The reverse is true for subtraction and division problems. This arithmetic principle is known as the relation to operands (RO) principle. Mastery of the RO principle was expected to predict arithmetic/algebraic problem solving as it may help problem solvers to correct their errors, but this prediction had not been examined empirically. The current study was conducted to test this hypothesis. A large sample (n = 202) fifth-graders were assessed on their RO understanding. They were also assessed on their arithmetic/algebraic problem-solving four times over two years. Potential confounding factors, such as fluid intelligence, working memory, processing speed, and numerical magnitude knowledge, were also included as controlled variables. Results from growth modeling suggested that while RO understanding did not predict initial performance in arithmetic/algebraic problem-solving, it did predict the growth in arithmetic/algebraic problem solving even after controlling for the potential confounding factors. The findings highlight the role of RO understanding in children's mathematical development. Interventions should be developed to enhance children's understanding of the RO principle.

Keywords: Relation to operands, arithmetic, growth

8. Brain representations of symbolic and non-symbolic magnitudes become estranged over development

Tomoya Nakai*, Cléa Girard, Léa Longo, Hanna Chesnokova, Jérôme Prado

Lyon Neuroscience Research Center, France

Accumulating evidence suggests that the human brain is endowed with an approximate number system (ANS) that allows for the processing of non-symbolic magnitudes (Feigenson et al., 2013). However, whether the ANS scaffolds the emergence of symbolic mathematics in children remains heavily disputed (Wilkey & Ansari, 2020). Here we measured fMRI adaptation to the repetition of dot arrays and Arabic numerals in 5 year old (n=43) and 8 year old (n=46) children. This allowed us to assess the relations between the neural representations of non-symbolic and symbolic magnitudes over development. To investigate representational differences in brain activation patterns, a searchlight decoding technique was applied with both intra-format (i.e., training and test stimuli were in the same format) and cross-format analyses (i.e., training and test stimuli were in different formats). For both age groups, robust intra-format decoding was found in a widespread brain system including the frontal, parietal, and occipital cortices. However, although we found significant cross-format decoding in the right dorsolateral prefrontal cortex (DLPFC) of 5-year-olds, such cross-format decoding was absent in 8-year-olds. Cross-format decoding in the right DLPFC was also significantly stronger in 5- than 8-year-olds. These results indicate that the brain representations of symbolic and non-symbolic magnitudes may overlap in young children but become estranged with development. This is consistent with the so-called symbolic estrangement hypothesis, suggesting that repeated exposure to symbolic numbers may allow children to manipulate symbols without referring to the quantity (Lyons et al., 2012).

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Keywords: fMRI, children, decoding, ANS, symbolic estrangement

9. Educators' Knowledge and Awareness of Developmental Dyscalculia: A survey study

Alison Roulstone*, Kinga Morsanyi, Julia Bahnmueller

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Specific learning difficulties in mathematics, also known as Developmental Dyscalculia (DD), affect 1 in 20 children in the UK. This means that there is at least one child with dyscalculia in most classrooms. Currently, there is limited research that explores educators' awareness and understanding of DD. Therefore, the purpose of this study was to explore educators' awareness of DD and examine educators' misconceptions and knowledge gaps related to DD. In addition, this study also aimed to investigate to what extent educators had access to training about dyscalculia, and how this compared to the accessibility of training about dyslexia. A final aim was to assess whether access to training was associated with fewer misconceptions about DD.

Online survey data were collected from 245 UK educators employed in early years settings, primary, and secondary schools. Educators responded to 24 statements about DD, and also indicated whether they had received any pre-service or in-service training in specific learning difficulties.

Overall, educators showed good levels of awareness of DD and did not display any significant misconceptions. Nevertheless, they still displayed some important knowledge gaps. This included uncertainty about the prevalence of DD, co-morbidity with other developmental disorders, gender differences, and how responsive dyscalculic learners were to intervention. Regarding training, findings indicated that a higher proportion of educators received in-service training in dyslexia (53%) than dyscalculia (21%). Educators receiving training in DD displayed significantly fewer misconceptions about DD. Recommendations concerning improvements to pre-service and in-service teacher training about DD are discussed.

Keywords: educators, training, knowledge of dyscalculia, misconceptions, developmental disorders

10. Complexity of parent spatial talk during spatial play predicts children's spatial skills

Danielle Fox*, Leanne Elliott, Heather Bachman, Elizabeth Votruba-Drzal, Melissa Libertus

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Engaging in spatial activities (e.g., puzzles) positively relates to spatial cognition, and increased exposure to spatial language is positively correlated with children's spatial word comprehension and performance on mental rotation and mapping tasks. Here, we investigated how quantity and quality (i.e., complexity) of parents' spatial language during parent-child interactions and reported frequency of spatial activities uniquely predict growth in children's spatial skills from 4 to 5 years of age.

Children (N=113) and their parents participated in a one-year longitudinal study starting when children were four years old. Measures of children's mental transformation and sensitivity to spatial features were administered at each time point. At time 1, dyads engaged in three semi-structured play activities, including a spatially-relevant puzzle task, which were transcribed and coded for parental spatial language input, and parents reported how frequently they engaged in specific spatial activities at home with their child via phone interview.

Parents who used more complex spatial language (i.e., longer spatial utterances) during the spatial puzzle activity but not the two non-spatial activities and reported more frequent engagement in spatial activities at home, on average, had children with more advanced spatial skills at age five, controlling for average utterance length, prior spatial skills, etc. These findings suggest that the complexity of parents' spatial language within a spatial activity, as well as the frequency of spatial activities, are particularly important for the growth of preschool-aged children's spatial cognition.

Keywords: spatial utterance complexity, spatial activities, preschool

11. "Took" vs. "Commandeered": Word Familiarity Affects Word Problem Performance in College Students

Joshua Jaffe*, Troy Gharibani, Shari Nudelman, Donald Bolger

University of Maryland, College Park, United States of America

Successful word problem performance requires identifying and transforming words into the appropriate operation. While a plethora of words can represent an operation, little is known about how word familiarity can affect performance. For instance, while "took" and "commandeered" represent a similar action, "took" is more commonly present in word problems. To fill this gap, this study recruited 84 undergraduate students to complete a series of one-step word problems. All word problems consisted of similar numerical components, and primarily differentiated by the verb. Twelve verbs were used in the study. Half of the verbs were categorized as familiar (i.e., took, received, gave), while the other half were categorized as unfamiliar (i.e., relinquished, confiscated, surrendered). After completion, participants self-reported if they understood what each verb meant. Only problems that contained verbs the participants understood were included in analysis. A paired sample t-test identified that participants performed significantly better on familiar problems ($M = 0.920$) compared to unfamiliar problems ($M = 0.899$), $t(83) = 2.836$, $p < 0.01$. No differences were seen on response times. An examination of the incorrect responses identified that participants made a similar number of miscalculation errors (i.e.,10+5=16) on both familiar and unfamiliar problems. However, participants were 70% more likely to make incongruence errors (i.e., used wrong operation; 10+6=4) on unfamiliar problems compared to familiar problems. This data suggests that participants exhibited more difficulty translating unfamiliar verbs into the correct operation and had trouble understanding unfamiliar verbs in a mathematical context.

Keywords: Word Problems, Word Familiarity, Operations, Incongruence Errors

12. The interactive effect of working memory and spatial anxiety on spatial skills changes with children's age

Xinhe Zhang*, Elizabeth A. Gunderson

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Spatial skills are essential for math learning and can be influenced by both cognitive and emotional factors. In prior work, higher mental transformation skill was related to lower spatial anxiety among girls with higher verbal working memory (VWM), but this was not the case for boys (Ramirez et al., 2012). Researchers theorized that high-VWM girls' VWM-intensive strategies were disrupted by anxiety-induced verbal ruminations. However, a recent meta-analysis showed that anxiety impairs VWM and visuospatial working memory (VSWM) to a similar degree, suggesting anxiety has a domain-general effect on attentional control (Moran, 2016). The current study examined whether VSWM interacts with spatial anxiety to predict spatial skills. Moreover, as VSWM and spatial skills are still developing during elementary school, we investigated how this interaction changes with age. Children (n=402) in first to fourth grade were tested. We found a significant three-way interaction of grade, VSWM, and spatial anxiety on mental transformation skills, but found no gender differences in this relation. Specifically, among 4th-graders (but not younger students), higher spatial anxiety was related to lower spatial skills for high-VSWM students. Our finding suggested that the interaction effects between working memory and spatial anxiety on spatial skills extend beyond VWM to VSWM, and become more pronounced as children's age increases.

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Keywords: Spatial skills, Spatial anxiety, Working memory

13. The influence of place value and physical size on multi-digit number processing

Ami Feder*, Sivan Cohen, Mariya Lozin, Michal Pinhas

Ariel University, Israel

Multi-digit number understanding is essential for managing life in a modern information society. Previous research has shown automatic processing for place value (i.e., the ordinal position of the digit in a digit string comprising the multi-digit number) or the physical size of the digits. The present study examined whether a digit's place value or its physical size has a greater impact on the automatic processing of two-digit numbers. In three experiments, participants performed a physical size comparison task where they were presented with pairs of two-digit numbers, where one digit (unit/decade) was physically larger than the other. The pairs appeared in frames, and participants were instructed to choose the larger frame, while ignoring the stimuli within. In Experiment 1, only unit-decade compatible pairs were used. In Experiment 2, both unit-decade compatible and incompatible pairs were included in sperate blocks, while in Experiment 3, both pair types were included in the same block. The results revealed that when only unit-decade compatible pairs were included, there was a size congruity effect only when the decade digits were physically larger. However, when unit-decade incompatible pairs were included, the size congruity effect emerged for unit-decade compatible, but not for incompatible pairs, regardless of the physical size of the digits, and their presentation mode (blocked vs. mixed). Overall, these results indicate a greater impact of the place values of the numbers' components, compared to their physical sizes. This reflects the internalization of the syntax of the decimal system.

Keywords: Multi-digit numbers, automatic processing, place value

14. Distinct Numerical Order and Magnitude Processing in Children: Connectome-Based Predictive Modeling

Mikael Skagenholt*, Kenny Skagerlund, Ulf Träff

Linköping University, Sweden

Research in numerical cognition has focused on cardinal discrimination abilities and their impact on arithmetic. Deficits, such as developmental dyscalculia, have traditionally been construed as grounded in cardinal processing [1]. This view is challenged by the dual systems model [2], arguing for two domain-specific core systems of number processing independently targeting numerical cardinality and ordinality (i.e., sequential positional value judgment). The nature of these systems remains unclear. Examining the separability of these processing systems, two corresponding symbol-based (i.e., Arabic digits) tasks were administered using fMRI. Neural activity analyses were performed, mapping neural correlates both uniquely and jointly recruited by the tasks. A second set of analyses leveraged Connectome-Based Predictive Modeling (CPM), investigating if task-based functional connectomes could predict outcomes of separately administered cognitive-behavioral measures. We hypothesized that the two systems would be separable, producing dissimilar connectomes with differing behavioral predictability. The ordinal number processing connectome was hypothesized to better predict arithmetic ability than its cardinal counterpart [3].

37 children (Mean age = 11.41, SD = 0.55, 12 girls) participated. Behavioral measures included: arithmetic calculation, fact retrieval, and equation scores; RT for number discrimination and ordinal number processing tasks; verbal and visuospatial working memory scores; reading ability; and age.

Cardinal discrimination relied on bilateral temporoparietal correlates, whereas ordinal processing recruited the bilateral IPS, cerebellum, and left PMC. CPM was not cross-predictive for the two tasks, indicating dissociable mechanisms jointly supported by visuospatial working memory. Neural correlates of learning and memory were predictive of age and arithmetic ability for the ordinal connectome.

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Keywords: fMRI, CPM, children, ordinal, cardinal

15. The Role of Visual Transparency of Multilevel Units on First- and Second-Graders' Unit Coordination

Anne Lafay* (1), Helena Patricia Osana (2), Mélanie Barilaro (2), Isabelle Atkins (3)

1: Université Savoie Mont Blanc, France; 2: Concordia University, Canada; 3: Université du Québec à Montréal, Canada

Children's understanding of the base-ten numeration system relies on the coordination of multiple levels of units (e.g., a group of 10 ones can be considered as one unit of 10; a group of 10 tens can be considered as one unit of 100). We investigated the effect of making units (i.e., denominations) visible in pictorial representations of quantity on children's multilevel unit coordination. We presented pictorial representations (collections of squares and rectangles) of multidigit quantities to first- and second-grade children (N = 142), who were randomly assigned to four conditions. The visibility of the lower-level units in the representations differed by condition: (1) control, no lower-level units visible; (2) ones-visibility, where only the ones in the tens and hundreds were visible; (3) tens-visibility, where only the tens in the hundreds were visible; and (4) ones-and-tens-visibility, where ones were visible in the tens and both ones and tens were visible in the hundreds. Children judged as true or false a statement about the number of ones or tens in two-digit numbers and the number of tens or hundreds in three-digit numbers. Results revealed that second graders outperformed the first graders regardless of condition. Further, second graders were better able than first graders to coordinate units in two-digit numbers when no lower-level units were visible; no grade effects were observed when the lower-level units were visually salient. We conclude that older children are less reliant than younger children on visibility in pictorial representations when coordinating multilevel units in base-ten quantities.

Keywords: Mathematical representation, base-ten numeration, unit coordination

16. Associating Verbs with Different Operations in Word Problems; Does This Impact Performance?

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Successful word problem (WP) performance requires understanding the linguistic relations between agents and objects largely dictated by verbs. Previous research demonstrated that an individual's mental representation of words affects their conceptual understanding and performance. For instance, individuals perceive “more” as representing addition, although the word's relation to the characters and objects (as in "has more than") determines its operation. Prior work has focused on words like “more” and “less,” while little research has examined verbs that are not directly associated with mathematical constructs. Mathematical problem-solving outside of the academic context is full of non-math specific words. In this study, 86 undergraduates were asked to solve a series of one-step WPs with twelve different verbs. Afterwards, participants self-reported if they associated these words with being an addition problem or subtraction problem. Overall, the words “got,” “received,” “acquired,” “relinquished,” received clear consensus on their perceived operation, while others did not. For questions that each participant solved incorrectly due to incongruence (i.e., adding instead of subtracting), we looked at how many of the errors were consistent with their self-reported association of the word. Overall, it was 1.56 times more likely for the participants to solve the WP incorrectly using an operation that was consistent with their association than vice versa. An examination of only the clear consensus words showed it was 2 times more likely to fit the participants' self-reported associations. These results suggest that individuals associate verbs with specific operations and that associations can affect overall WP performance.

Keywords: Word Problems, Verbs, Incongruence

17. The role of spontaneous focus on numerical magnitude in the relation between non-symbolic and symbolic numerical abilities

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Previous research in the field of numerical cognition has cast a doubt on the existence of a direct relation between approximate, non-symbolic abilities and more formal, symbolic abilities. Recently, authors have put a strong emphasis on the ability to process numerical information in the face of conflicting visual features such as non-numerical dimensions of magnitude, as a predictor of numerical and mathematical skills. However, how this ability relates to the association between non-symbolic numerical abilities and math achievement remains unclear. To investigate this question, we tested 101 adults (mean age = 21.06 years; SD = 5.13) on a spontaneous sorting task (adapted from Ferrigno et al., 2017) which allowed us to assess the tendency to spontaneously focus on numerical magnitude in the face of competing alternative non-numerical dimensions (Size and Spacing, DeWind et al., 2015). The interaction between non-symbolic numerical abilities and the tendency to spontaneously focus on numerical magnitude significantly predicted math achievement ($b = 1.04$, $p = .003$). The relation between non-symbolic numerical abilities and math achievement was only present in individuals showing a greater tendency to spontaneously focus on numerical magnitude ($t(88) = 3.74$, $p < .001$). These results suggest that the role of the ability to spontaneously focus on numerical magnitude in the face of conflicting non-numerical magnitudes should be considered when investigating the relation between non-symbolic and symbolic numerical abilities.

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Keywords: spontaneous focusing, magnitudes, math achievement

18. The Role of Mathematical Skills and Executive Functions in Physics Problem Solving.

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Considerable in-depth studies have been carried out in the disciplines of psychology, neuroscience and education concerning the contribution of executive functions to the students' learning process across all school ages. Physics problem solving is one of the key skills that students should develop through physics education and is closely related with executive functions. Previous research has primarily focused on investigating the role of executive functions in students' conceptual change when learning physics yet developing students' physics problem solving skills is one of the primary goals in physics curriculums. Through several studies there have been descriptions concerning the links between executive functions and mathematical skills as well as the role of mathematical skills in physics problem solving. Nevertheless, there is limited research that has examined the contribution of both executive functions and mathematical skills on physics problem solving. To address this gap, this small-scale experiment administered executive functions, physics problem solving and mathematical skills tasks to 20 Greek students (Mage = 16.81 years, SD = 1.87). All the physics and mathematical skills assessments demonstrated a strong positive correlation among them. The figure matching executive function task presented a positive correlation with the physics problem solving and the mathematical skills assessments, when testing for response time and efficiency subsequently. These results offer the opportunity to create a new theoretical approach for physics problem solving that could be the springboard for further investigation, which could result in designing pioneer interventions concerning physics' teaching practices and better prepare students for challenging academic events.

Keywords: executive functions, mathematical skills, physics problem solving, response time, efficiency

19. Form over Content: Shared Symbolic Format Shows Greater Similarity than Shared Numerical Content

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The neural basis of symbolic numerical processing (digits) and its relation to nonsymbolic numerical processing (dots) has been a subject of intense debate. Though digits and dots share numerical content, they also differ in format (symbolic vs nonsymbolic). A key question is whether these format differences supersede shared numerical content. One way to test this idea is to examine whether digits are processed more similarly to letters (shared symbolic format, different content) than dots. In parallel, one can ask whether dots are processed more similarly to line-lengths (shared nonsymbolic format, different content) than digits. We tested this idea across individuals using behavioral correlations, and within individuals using representational similarity analysis (RSA) of neural data. At the behavioral level, we found significant unique correlations between digits and letters, between dots and lines, but not between digits and dots. At the neural level, we found greater similarity for shared numerical content (digits with dots) than not (letters with lines), suggesting neural measures are sensitive to shared semantic processing. However, we also found that neural similarity was significantly greater between digits and letters (shared symbolic format) than between digits and dots (shared numerical content) across a network of fronto-parietal regions, including bilateral IPS; no regions showed the opposite. These findings indicate that numerical stimuli have more in common with non-numerical stimuli of similar formats than with each other, and suggest that symbolic vs nonsymbolic format exert a stronger influence on both behavior and brain than semantic content.

Keywords: symbolic, nonsymbolic, format, content, fMRI

20. Perceptions matter: Perceived math involvement moderates associations between math anxiety and interest in activities and careers

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Math-anxious individuals consistently avoid activities and careers that involve math. In past work, whether a given activity or career "involves math" has been determined by the researcher, often by designating activities or careers as "STEM" or "non-STEM". However, this work ignores the perceptions of the participants themselves. This could be consequential – if a math-anxious participant does not themselves believe that a given career involves a great deal of math, their math anxiety seems unlikely to affect their interest in that career even if that career has received the "STEM" designation by the researcher. In this work, we tested this idea by asking participants to rate not only their level of interest in 48 activities and 48 careers, but also how much they perceived that each activity or career "involves math" on a scale from 0 to 4. Results demonstrated substantial variability in perceived math involvement on the vast majority of activities and careers. Moreover, as predicted, we observed a significant interaction between math anxiety and perceived math involvement in predicting interest in both activities and careers. In other words, the more a math-anxious person perceives an activity or career as involving math, the lower their interest in that activity or career is. Broadly, this work suggests that individuals' own perceptions of how much math is involved in an activity or career play an important role in shaping their desire to engage with that activity or career. Implications for theory and practice will be discussed.

Keywords: Math Anxiety, Math Avoidance, Career Interests

21. Human use of clustering to solve traveling salesperson problems

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The traveling salesperson problem (TSP) is a graph-theoretical problem that computers find difficult to solve. It involves finding the shortest path connecting a set of points to each other, visiting each point exactly once, and returning to the starting point. Humans are surprisingly good at solving TSPs, with solutions within 10% of optimal for problems up to 100 points, constructed in time linear with the number of points. We propose that humans solve TSPs by initially clustering the points and connecting them first within and then between clusters. In a series of three studies involving 47, 46, and 67 participants, we found evidence for clustering strategies to solve TSPs. In the first study, participants clustered stimuli with 10 to 40 points twice, at different time points. Participants were generally reliable at clustering across time, with more reliable clusters being drawn for more statistically clustered stimuli. The second study followed a similar paradigm, but participants solved the TSP instead of clustering. We found that human TSP solutions followed the same pattern, with generally reliable TSP solutions and more reliability for TSP solutions of statistically clustered stimuli. In the final study, participants clustered and solved the TSP for the same stimuli at different time points. Participants' TSP solutions followed their clusterings *perfectly* for 52% of all trials. Their TSP solutions deviated from their clusterings more for statistically less-clustered stimuli than statistically clustered stimuli. These studies suggest that clustering is a common strategy humans use to solve many different graph-theoretical problems.

Keywords: graph theory, problem solving, strategies

22. Cognitive Correlates of First Graders' Fraction Knowledge

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Many students struggle to understand fractions. However, from an early age, children can reason about fractional quantities in informal contexts. In order to assess such knowledge, and characterize specific aspects of such understanding, we constructed and administered a 43-item measure for first-graders ($n = 106$, 46% female, $M_{age} = 6.88$ years). Scores on the fractions measure ranged from 26% to 91%, with a mean score of 58%, and $\alpha > .9$. We examined associations between the fractions assessment and performance on math- and spatial-related measures (whole number line estimation, whole number knowledge, spatial scaling, proportional reasoning), vocabulary, working memory and inhibitory processing. All correlations were significant, with moderate to large effect sizes from $r = .19$ to $r = .63$, with the exception of inhibitory processing. However, linear regression analysis revealed that only whole number knowledge was significantly related to early fraction skill ($\beta = .42$, $p < .001$), when all variables were considered together. Whole number knowledge and early informal fraction knowledge may constitute an integrated early understanding of the full mathematical system, even though, at later ages, knowledge about integers interferes with using formal fractions, perhaps due to notational confusion.

Keywords: fractions, mathematics, executive function

23. Optimal dosage for domain-specific mathematical abilities for children aged 3-7-years-olds: Evidence from log data from an educational maths app

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Touchscreen-based apps are widely used to deliver mathematical content to children, and the log data that is collected while children play them provide a useful data source to investigate mathematical development. At the moment, the recommended amount of time children should play a game to show improvements in mathematical learning (i.e., dosage), is often defined by practical constraints, as opposed to theoretical justifications. To better understand the required dosage, as well as to compare dosage between different mathematical abilities, log data collected passively from children's gameplay of an educational maths app, named Funexpected, was analysed. Funexpected is an evidence-based educational maths app for 3-7-years-old children. Games target domain-specific mathematical abilities such as magnitude comparison, basic counting abilities and arithmetic. The present study used generalized additive models to understand longitudinal gameplay progression over a period of 11-months for a sample of 2,167 children. Moderator variables included the child's age and the difficulty level of the game. This study will demonstrate the methodological utility of log data from maths apps as a data source providing insight into the development of mathematical abilities. Likewise, this study will provide theoretical justification for future dosage implementation in maths app research and practice, as well as provide insight into variations of dosages across domain-specific mathematical abilities. This will allow for dosage selection in future studies to be grounded in an evidence-based approach, and therefore increasing the potential benefits children acquire from educational maths apps.

Keywords: mathematics, apps, development, early years

24. Improving Algebra Readiness for Middle School Students through Project STAIR

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Students with learning disabilities demonstrate lower mathematics performance in 8th grade than peers without disabilities (NCES, 2019). With intervention, however, the mathematics trajectories of students with disabilities can improve (Krawec et al., 2012). Project STAIR (Supporting Teaching of Algebraic Individual Readiness) is a federally funded model demonstration project aimed at improving the algebra readiness of middle school students (MS) at-risk or with learning disabilities in mathematics. The project has contributed empirical evidence to the research and practitioner literature on the effectiveness of a system of instructional practices for supporting MS student's readiness for algebra. Implementation has been focused on the process of systematic data-based individualization (DBI), assessment, and evidenced based instructional practices through professional development (PD) and ongoing coaching.

The goal of this presentation is to provide cumulative findings across the four years of implementation. Data will be shared from Cohort 1 (2018 -2019), which consisted of four school districts, 22 teachers, and 56 students; cohort 2 (2019-2020), which consisted of four school districts, 17 teachers, and 50 students; and cohort 3 (2021 – 2022) school year which consists of 6 teachers and 16 students. Outcomes from Core PD sessions, student assessments, and coaching cycles (includes pre-observation assessment, classroom observation, and a post-observation session) will be included. Findings from this exploratory research point to the promise of Project STAIR for improving teacher perceptions related to support of students experiencing mathematics learning difficulty as well as increasing specific DBI practices, including teachers' ratings of importance, understanding, and confidence with assessment practices.

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Keywords: Mathematics, data-based individualization, middle school, math difficulties

25. "Which Graph Shows What They Saw?": Measuring Children's Early Statistical Understanding

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Basic statistical literacy is essential for understanding and making inferences from information received from external sources and for developing critical thinking skills necessary for engagement in real-world contexts [1]. Although graphing is a central topic area in early math development, it is often not a focus of instruction in early grades [2], and few previous studies have considered young children's graphing skills. Further, despite the lifelong importance of graphing skills and statistical literacy, research shows that middle school, high school, and college students struggle with interpreting and constructing graphs [3]. Therefore, understanding children's early graphing abilities is important for their later development and achievement. In the current study, a new measure of young children's statistical understanding was developed. Items included questions about interpreting and constructing picture graphs and bar graphs. Children's performance was examined in relation to their math abilities and math anxiety. Children (n=178, Mage = 71 months, 50% male) completed measures of statistical understanding, arithmetic (addition, subtraction, and word problems), magnitude comparison (single- and double-digit pairs and sets), and math anxiety. Preliminary analyses indicate that children's statistical understanding positively relates to their arithmetic and magnitude comparison abilities (all $r(176)$ between .474 and .770, $p<.001$) and negatively relates to math anxiety ($r(176)=-.154$, $p=.04$). Additional analyses will further examine predictors of statistical understanding, and results will be discussed in terms of understanding children's early math development.

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Keywords: statistical understanding, graphing, early math development

26. Development of symbolic magnitude and order processing and their relation with arithmetic

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Being able to efficiently process both the absolute magnitude and the relative order of number symbols (e.g., digits) is key for arithmetic development. However, longitudinal studies have not yet investigated how symbolic magnitude and ordinal processing interact in the prediction of arithmetic performance in primary school. This longitudinal study tested 1) whether there is a developmental shift in the predictive contribution of symbolic magnitude and order processing to arithmetic performance between Grades 1 and 2, and 2) whether the development of symbolic numerical abilities is characterized by reciprocal predictive relations between symbolic magnitude and order processing. In two independent samples from the UK (N = 195) and Austria (N = 161), symbolic magnitude processing uniquely predicted arithmetic in Grade 1, but did not predict arithmetic development later on. Symbolic order processing was not yet predictive of arithmetic development in Grade 1, and only emerged as a unique predictor of future arithmetic performance in Grade 2. We also observed cross-lagged predictive relations between symbolic magnitude and order processing across the entire study period in both samples. In conclusion, our findings confirm that the predictive contributions of symbolic magnitude and order processing to arithmetic development are highly interactive and change substantially across the first years of primary school. The dynamic change in the predictors of arithmetic during this period may be driven by a shift in arithmetic development and instruction from procedural strategies to retrieval of arithmetic facts.

Keywords: symbolic magnitued processing, symbolic order processing, arithmetic development, primary school

27. Exploring the role of executive functions in first graders comprehension of conventional counting rules

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Previous research indicates that executive functions (EF) are linked to math performance in primary school children. Most studies have investigated this relationship focusing on general mathematical ability. Nevertheless, more insight is needed to know how each component of EF (i.e, updating, inhibitory control and shifting) contributes to specific math skills. In the current study, we examined the role of EF in counting comprehension, since counting is a prerequisite for the basic arithmetic development and its full understanding is a long process. Specifically, we explored the relationship between children's knowledge of the optional nature of conventional counting rules (when detecting correct but unconventional correct counts) and the three components of EF.

67 primary school children in grade 1 performed the following tasks over different sessions: (i) a standardized math test (TEMA-3), to assess participants' general mathematical competence; (ii) K-BIT, as general intelligence test; (iii) three EF measures; and (iv) a computer-presented detection task which included three different pseudoerrors (unconventional correct counts) and three control trials. In the detection task, participants had to judge the correctness of every counting and justify their answers. Bayesian analysis showed a relationship between our participants' general mathematical ability and shifting, consistent with previous studies. Regarding children's performance on detecting pseudoerrors, their level of success was very low, also in line with prior research. Furthermore, it was not related to any EF measure. This suggests that first graders' difficulties when detecting counting pseudoerrors could be more related to conceptual misconceptions than to EF measures.

Keywords: Counting, pseudoerrors, mathematical ability, executive functions, Bayesian inference

28. Examining Executive Function as a Moderator of Math Language on Early Numeracy Achievement

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Executive functioning skills (EF) and math language are important predictors of later math achievement (Schmitt et al., 2017). Higher levels of EF have been associated with greater benefit from classroom instruction in kindergarten (Ribner et al., 2020) and more benefit from exposure to number talk in preschool (Silver et al., 2021). Given these findings on the role of EF as a moderator between input on children's math performance, we hypothesized that EF may also moderate the relation between children's math language and their numeracy skills. The hypothesized interaction was tested in a linear regression (N = 571, 48% female, Mage=57.5 months, Mincome=$18,671) with Spring numeracy skills as the dependent variable and Fall skills (EF, math language, and their interaction) were included as predictors. Fall numeracy skills, child age, and child gender were also included as covariates. Results replicated previous work showing EF and math language predict later numeracy performance, however, results did not support the hypothesized interaction (B=.125 p = .194). Posthoc, exploratory analyses revealed a significant interaction between EF and math language skills when associated with numeracy performance at the Fall timepoint (B=.291, p = .009) as well as a significant association with Spring numeracy performance when Fall numeracy was not included as a covariate (B=.216, p = .011). These results highlight the importance of continued effort aimed at understanding the relationship between overarching cognitive skills, such as EF, and their influence on skills and growth in more specific cognitive skills.

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Keywords: Math Language, Executive Function, Early Numeracy

29. Global and Local Mechanisms in Number Magnitude Processing

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Two-digit Arabic numbers are hierarchical stimuli by nature. The unit-decade compatibility effect (in a two-digit number comparison task, responses are faster when the comparison between tens and the units lead to the same decision, e.g., 53-68, both 5 < 6 and 3 < 8, relative to trials where the comparison leads to different decision, e.g., 59-74, 5 < 7 but 9 > 4) is taken as evidence of compositional processes. However, the link between the compositional processing in two-digit numbers and hierarchical visual processing (i.e., global and local mechanisms) remains to be determined. Only very recently (Pletzer et al., 2021) it has been shown that people with a greater tendency towards the global processing of visual information show less compatibility effect (i.e., less compositional or more holistic processing). However, the employed task was not specific enough to tell whether the preference to global and local visual information was facilitating or interfering. In the present study, we wanted to determine the nature of the relationship between global-holistic and local-compositional processing of two-digit numbers and hierarchical visual stimuli. To this end, 38 participants completed a number comparison task (Nuerk et al., 2001) and a global-local task where we were able to specify both global and local interference and facilitation (Soriano et al., 2018). The results showed that the local, but also the global interference predicted the unit-decade compatibility effect. We interpret these results in terms of inhibitory processes which seem to be shared between two-digit number and visual hierarchical processing.

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Keywords: number comparison, unit-decade compatibility effect, global-local processing

30. The SNARC Effect in Mayan Numerals

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This dissertation proposes to study the indigenous Mayan numerical system through the lens of three theoretical frameworks: ethnomathematics, neuroconstructivism, and educational neuroscience. Thirty undergraduates from Utah State University will participate in an 2.5 hour online course designed to teach written Mayan numerals and spoken Kaqchikel Mayan number words. The participants will be split into two instructional groups that reflect the two different number naming strategies from modern and historical Kaqchikel- the Pan-Mayan Count (PMC) and Modified Kaqchikel Count (MKC). The course, broken into five 30 minute sessions, covers the vigesimal (base-20) Mayan numerical system in-depth, covering topics from finger-counting to multiplication as well as relevant historical and cultural information.

I will assess participants online at several time points using a Mayan numeral size-congruency Stroop task and a Western Arabic numeral size-congruency Stroop task to investigate the development of automaticity of numeral processing in the numerical system that they are learning. I hypothesize that the participants who learn to count using the MKC will experience a significant increase in performance over time on the Mayan Numeral Size-Congruency Stroop in comparison to the PMC group.

Participants will also take a Mayan numeral parity judgement task. I hypothesize that exposure to the vertical structure of the written Mayan numerical system will create a vertical spatial numerical association response code (SNARC) effect, though this SNARC effect may be moderated by the transparency of order and reading direction of the number-naming system that the participant learns (PMC or MKC).

Keywords: Mayan numerals, math instruction, automaticity of processing, SNARC effect, regularity

31. Impact of language experience on intuitive numerical processes in early childhood

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Humans rely on an intuitive numerical representation to compare sets of objects based on their numerical amount.1 This system is not capable of exactly representing discrete numerical quantities. With development2 and the acquisition of exact number concepts3 this intuitive representation becomes more precise. Spoken languages have an abstract association between the number-word and their numerical meaning. However, in American Sign Language (ASL), numerical incorporation is a morphological process in which a number is incorporated into a handshape, a classifier, or a pronoun of a sign4 making the numerical information salient and visible. The question we ask in this pilot data is whether this morphological property can improve intuitive numerical abilities at an age when children start mastering number concepts. To test this question, we are recruiting 3-5-year-old deaf children who are early signers and hearing non-signing peers. Children will be compared on a dot comparison task, a Spontaneous Focusing on Numerosity task5, and a 1:1 correspondence task, as well as measures of their exact number understanding. If the morphological properties of ASL support earlier intuitive numerical development, we expect our Deaf signing group to show better performances on the intuitive tasks compared to their non-signing peers while showing comparable exact number understanding. This study would have translational implications supporting the use of explicit numerical representations, such as those used in ASL, for teaching numerical concepts in young children.

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Keywords: Numeracy, numerical cognition, American Sign Language (ASL), language experience

32. Early number skills as predictors of mathematic skills in the entrance to kindergarten

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Kindergarteners' mathematical skills, such as verbal counting or number comparison, have found to be strong predictors of later arithmetic and mathematical skills in school age. Research and empirical evidence related to the predictive value of early math skills on mathematical skills in kindergarten, however, is less extensive. Even less is known how early we can identify a risk for later undesirable outcomes in mathematics. Both dimensional and categorical approaches to measurement of number skills were used to study 1) the extent to which early number skills at age of 2.5-3.5 years predict math at age of 5.5-6.5 years in Finland after taking the child's age (birth month) into account, and 2) whether lack of number skills around the 3 years of age of can work as early risk indicators for low math performance in kindergarten and thus predicting possible difficulties in school-age. Number concept, number sequence knowledge, counting objects skills and number symbol knowledge were assessed individually on four timepoints between ages 2.5 and 6.5 from 149 Finnish children. Preliminary analysis suggested that both number concept and number sequence knowledge at age of 2.5-3.5 years are unique predictors of math skills in the entrance to kindergarten. The results emphasize the importance of attracting children's interest towards mathematical phenomena already around the age of 3. Observing early mathematical abilities can further help to identify children in need of closer monitoring of math skill development. Findings are discussed in light of early identification of risk for later math difficulties.

Keywords: Early mathematical skills, development, predictors, early identification

33. Growth Mindset Message Influences Parents' Choices of Games

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Parents play a critical role in children's early cognitive development by engaging them in informal learning activities, such as reading books and building with blocks (Jirout & Newcombe, 2015; Sénéchal et al., 1998). Moreover, parents who more firmly believe that ability can be improved (i.e., growth mindset) reported a higher frequency of informal learning activities (Muenks et al., 2015).

The present study tested whether a growth-mindset message would lead parents to choose more challenging verbal and spatial activities, which may be more stimulating for children's ability development. Parents of 3- to 5-year-olds ($N = 140$) from Amazon MTurk were randomly assigned to read an article describing that intelligence can be improved through a stimulating environment or a control article on déjà vu. Before reading the article, parents completed questionnaires on the home learning environment and parental beliefs in both verbal and spatial domains. After reading the article, parents indicated how they would play several verbal and spatial games with their children by choosing from three options for each game — the three options varied in difficulty level. For example, the options for building with blocks were three models varying in the number and type of blocks needed.

Parents reading the growth mindset article chose more challenging activities than those reading the control article (std. beta = 0.40, $p < .001$), controlled for the home learning environment, parental beliefs, and demographic characteristics. These findings illustrated the effectiveness of a brief growth-mindset message in encouraging parents to choose stimulating learning activities.

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Keywords: home learning environment, growth mindset, spatial activities, verbal activities, parents

34. Brain correlates explaining children's improvement in math attitudes

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Math attitudes are related to math achievement and math gains, yet we do not know how the brain supports changes in math attitudes. To answer this question, 51 children solved a single-digit multiplication task inside the scanner when they were approximately 11 (time 1; T1) and 13 (time 2; T2) years old. Children also completed standardized testing of math attitudes and multiplication skill at both T1 and T2. We examined whether brain activation at T1 was associated with math attitudes at T1 as well as with changes in attitudes over time, and whether changes in brain activation were associated with changes in attitudes over time. We identified regions of interest in middle and superior temporal gyri (MTG/STG) and in inferior frontal gyrus (IFG), associated with the storage of multiplication facts in long-term memory and the cognitive effort involved in accessing them, respectively, as well as in bilateral inferior and superior parietal cortices (IPL/SPL), associated with calculation-based back-up strategies. Results revealed clusters in left middle to superior temporal gyri at T1 associated with math attitudes at T1 and with their longitudinal improvement. However, changes in attitudes were not associated with brain changes over time. These findings suggest that relying on the storage of arithmetic facts, involved in memory retrieval, plays an important role in explaining the development of positive math attitudes.

Keywords: attitudes, fMRI, children, multiplication, longitudinal

35. Measuring the Spatial Home Learning Environment: Initial Test of the Spatial Toys and Activities Checklist (STAC)

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The early home learning environment (HLE) is important for spatial learning, given significant individual differences in spatial ability at school entry (e.g., Levine et al., 2012). Measurement of the spatial HLE is fairly new. Therefore, we looked to research on the literacy HLE, which has found that book checklists (where parents select books they recognize from real titles and plausible foils) mitigate response biases and correlate more strongly with children's literacy skills than self-reported frequency of literacy activities (Sénéchal et al., 1996). Here, we created a novel Spatial Toys and Activities Checklist (STAC) with 40 real spatial toys (e.g., "Blokus") and 20 plausible foils (e.g., "Snapweez") and explored its relation to parent-reported spatial and literacy HLEs and beliefs.

Parents of 3-5-year-olds (N=140) completed online questionnaires in the spatial and literacy domains, including checklists (spatial games & book titles), frequency of home learning activities, beliefs about their children's interest and ability, and beliefs about importance of these domains for their children. Checklists were scored using d' (hits minus false alarms).

The STAC was positively correlated with parent's beliefs about their child's spatial ability and interest (rs>.23, ps<.01), whereas the spatial HLE questionnaire was not (ps>.05). Surprisingly, the STAC was negatively correlated with parent reports of the spatial HLE (r=-.23, p<.01), and was not correlated with parents' beliefs about the importance of spatial activities. Our novel measure (STAC) relates to parents' spatial beliefs, differs from a spatial HLE questionnaire, and warrants further investigation of its relation to children's spatial skills.

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Keywords: Home Learning Environment, Parent-Report, Spatial Activities, Checklist

36. Negotiating Number Knowledge during a Math Game: A Pilot Exploration of African American Mothers and their Preschool Children

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The focus of this pilot investigation was to examine the strategies that African American mothers employed as they were engaged in a numeracy activity with their preschool children. To this end, we observed 8 mother child dyads "playing" Ho-Ho Cherry-O (Hasbro Toy Company) and examined the strategies that mothers used to introduce numeracy concepts (Gelman, 1978; Zippert, & Rittle-Johnson, 2020). Our results revealed that mothers primarily relied on counting and labeling, followed by elaborations of cardinal values of the numbers. We also observed stylistic differences in mothers' use of numeracy concepts. High numeracy mothers often began the activity by providing detailed instructions about the purpose of the activity and employed a scaffolding type of procedure, which involved using a stable order procedure (i.e., counting the cherries, and providing number names) querying the children's knowledge of stable order and number names) and clarifying the children's incorrect with responses with elaboration. Alternately, Low numeracy mothers directly launched into the activity, and instructed primary through questions, without specifically querying their children about numeracy concepts. During the discussion of our poster, we will offer suggestions on which strategies and maternal styles, correlated with children's engagement in the activity, and offer suggestions on assessing the evolution of numeracy skills in African American households.

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Keywords: Number Knowledge, African American Mothers, Stylistic Differences

37. Exploring the Equitability of Continuing Virtual Research Post-Pandemic Using In-Person vs. Virtual Math Assessment Data

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Introduction: The COVID-19 pandemic has impacted learning environments across the globe. Educators and researchers had little time to adapt to a virtual format to accommodate a world on lockdown. In this study we compared sample demographic and assessment data collected within a school setting pre-pandemic, and virtually mid-pandemic. This data will be important when deciding if continuing to collect data virtually is practical and equitable post-pandemic.

Method: Participants were preschool-aged children (N= 259) with an average age of 4.5 years (M= 53.84 months). The assessment used is a measure developed by researchers to test children's ability to attend to and flexibly switch focus between incongruent dimensions of magnitude, both numerical and spatial. This Flexible Attention to Magnitude (FAM) task, has been predicted to be related to children's executive functioning skills and overall math achievement.

Results: Results showed there were more white children and significantly fewer Black/African American children in the virtual sample compared to the in-person sample. This is noteworthy given that the samples were both drawn from the same sources (a local preschool initiative). An ANCOVA showed an interaction between method and trial level ($F(1.848, 404.78) = 3.48$, $p=.035$, $n^2_p=.016$). A follow-up test revealed significantly higher scores for the virtual sample on post-switch (round 2) trials ($t(269)=2.30$, $p=.022$) and mixed (round 3) trials ($t(262)=4.97$, $p<.001$). These results suggest that equity in in-person vs. virtual research methodology be considered moving forward.

Keywords: FAM, equity, virtual research, assessment

38. Calculation methods and arithmetical accuracy from grades 3 - 8: Algorithmic approaches are less accurate than number-based yet increasingly preferred

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Number-based strategies (NS), i.e. the strategies with the fewest and simplest calculation steps, are considered easier than the standard algorithm (SA) and could therefore be expected to yield higher accuracy in items designed to elicit such methods (Hickendorff, 2018). However, research on strategy efficiency in multi-digit arithmetic shows somewhat inconsistent results (Hickendorff et al, 2019).

In this study we investigated effect of arithmetic operation and grade on proportional use and accuracy of SA and NS in Danish students. Students from 3rd (749), 6th (731) and 8th (818) grade solved three or four items in multi-digit addition, subtraction and multiplication (3rd grade only addition and subtraction) in a free-choice setting. For each solved item the method was categorised as SA, NS or other (the latter excluded in this analysis), and the answer was scored as correct or wrong.

Across all grades, NS was more accurate than SA (NS vs. SA for 3rd grade [proportion+/-95%CI]: 0.68+/-0.05 vs. 0.85+/-0.07; 8th grade: 0.86+/-0.05 vs. 0.94+/-0.02). Accuracy differed between operations with addition and multiplication showing highest and subtraction lowest accuracy. For all operations, NS outperformed SA on accuracy. Despite lower accuracy of SA, proportional use of SA increased from 3rd (0.78) to 8th (0.87) grade. Hence, the reason for students valuing SA over NA increasingly with age must be rooted in other (yet unidentified) reasons than experience of computational accuracy per se.

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Keywords: Multi-digit arithmetic, strategies, standard algorithm, accuracy

39. Situation model theory in basic mathematics: Word problems and background knowledge

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In this study, we intend to investigate how participants' background knowledge in three domains (science, sports, and cooking) affect their performance on arithmetical-reasoning and proportional-reasoning word problems. Undergraduate participants will complete several survey items, including the Abbreviated Math Anxiety Scale (Hopko, et al., 2003), the cooking skills measure (Lavelle, et al., 2017), and items to gauge their familiarity with science and United States sports. Participants will then respond to 108 math questions. These questions include 36 addition problems, 36 subtraction problems, and 36 proportional reasoning problems. Problems will be embedded equally within four different contexts: science, sports, culinary, and no context or purely mathematical. We will use structural equation modeling, including confirmatory factor analysis, to evaluate the effect of hypothesized latent variables corresponding to experience in the three domains and mathematics. Ultimately, we intend to further consider the situational model theory (SMT) of problem solving as described by Bagnoud, et al. (2018). The SMT contrasts with schema theory in that SMT asserts that cognitive representations are constructed for each new problem depending on its "specific contextual elements" (p. 116), rather than representations being constructed based on schema associated with certain keywords and phrases. Thus, data constituting further evidence of SMT would involve context familiarity variables' strong prediction of performance on problems in the corresponding context, when controlling for the effect of mathematical ability and anxiety.

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Keywords: numerical cognition, word problems, arithmetic, background knowledge, text comprehension

40. How do reasoning skills of relations and conditional inferences predict mathematical problem solving?

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Relational reasoning and conditional reasoning are proposed to contribute to mathematical achievement, but they have not been investigated in the same study. In fact, reversible thinking may underlie both the reasoning about antithetical (oppositional) relations and the process of identifying invalid conditional inferences (affirmation of consequent (AC) and denial of antecedent (DA)), and these processes may contribute to mathematics learning. The current study therefore attempted to explore the contribution of antithetical reasoning to mathematical problem solving, with the mediating role of conditional reasoning of invalid inference forms. With its longitudinal design of six-month intervals, sixth graders (n = 228) received assessments of antithetical reasoning (T1), conditional reasoning (T2), and mathematical problem solving (T3). Mediation analyses were conducted with participants' prior nonverbal intelligence and verbal working memory as covariates. The results showed that the ability to identify invalid inferences partially mediated the prediction from antithetical reasoning to mathematical problem solving. The findings help clarify the interrelation among relational reasoning, conditional reasoning and mathematical achievement.

Keywords: Relational reasoning, conditional reasoning, mathematical problem solving, antithesis, invalid inferences

41. Spatial Skills and Number Skills in Preschool Children: The Moderating Role of Spatial Anxiety

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Spatial ability is a strong and stable predictor of mathematical performance. However, of the three key components of spatial ability, spatial perception and spatial visualization have received less attention than mental rotation in relation to specific mathematical competencies of young children. Even less is known about the role of spatial anxiety in this relationship. This study examined the longitudinal relations of spatial perception and spatial visualization to three number skills (i.e., number line estimation, subitizing, and word problem-solving) among 243 preschool children, and whether these relations varied as a function of spatial anxiety. The results showed that children's spatial perception and spatial visualization in the third preschool year (T1) were positively associated with their word problem-solving six months later (T2). Children's spatial perception (T1) was also positively associated with later subitizing and number line skills (T2). Spatial anxiety measured at T1 significantly moderated the relations between spatial visualization and word problem-solving. Specifically, the positive relation between T1 spatial visualization and T2 word problem-solving was stronger for children with moderate levels of spatial anxiety than it was for their peers with high or low levels. In addition, spatial anxiety moderated the relation between spatial perception and subitizing: the relation between the two was stronger for children with low levels of spatial anxiety than it was for those with moderate or high levels. The findings offer valuable insights into how spatial cognition and affect jointly relate to children's early number skills.

Keywords: spatial skills, word problem-solving, subitizing, number line estimation, spatial anxiety

42. Development of arithmetic strategies for simple addition problems – when larger problems are retrieved whereas smaller problems are counted

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In the literature, whereas some researchers conclude that, in adulthood, all the answers to addition problems with a sum up to 10 are retrieved from memory, some other researchers conclude that very small problems with operands from 1 to 4 (i.e., small problems) are solved by automated counting procedures. Interestingly, these last researchers suggested that the answers to additions with sums between 8 and 10 (i.e., medium problems) could be retrieved from memory. This conclusion was reached because solution times are constant for problems with sums 8, 9 and 10. This view is iconoclast because larger problems would be retrieved whereas smaller ones would be counted. To explore this question, we adopted a developmental approach and tested three groups of children aged between 8 to 13 years in a simple addition task and through a sign priming task. The results show that as soon as the age of 8, solution times for medium problems were shorter than solution times for small problems. Moreover, still from 8 years, there was no increase in solution times for medium problems. Additionally, at the age of 13, sign priming effects, interpreted as reflecting the use of counting procedures, were significant for small but not for medium problems. All in all, our results suggest that medium problems are retrieved before smaller problems during development. These results question most of the current theoretical models and favour a revised version of horse-race type model where procedures can win over retrieval.

Keywords: Mental arithmetic, Mathematics, Strategies, Memory retrieval, Automatization

43. Spreading of activation across items or positions in working memory sequences

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When comparing numbers to a standard number (e.g. 5), we respond faster and make less errors to more distant (e.g. 1 or 9) as compared to neighbouring numbers (e.g. 4 or 6) [1]. Other work showed that such a distance effect is also observed for items maintained in working memory [2]. Imagine a task where participants memorise a random sequence of letters (e.g. DPRT) that has to be maintained in the correct serial order. Participants again respond faster when comparing more distant (e.g. DR) than neighbouring items (e.g. DP). It is currently not clear whether the observed distance effect in WM results from a spreading of activation across memorized items (e.g. from P to R), or across ordinal positions (e.g. from 2nd to 3rd position). To study this, we investigated whether a distance effect can be found across positions or items of different memory sequences. Participants were asked to memorize two sequences consisting of 4 items. Then we asked participants to categorize items from the memory sequences. Across three experiments we systematically varied the need to access the item or the position information for successful task performance. Regardless of these manipulations, an item or position distance effect across the different memorized sequences was never observed. Instead, our data confirmed the presence of a distance effect within the same sequence. We conclude that items at the same position from different memory sequences do not share a common representation while items in the same memory sequence are directly related to each other.

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Keywords: Working Memory, Order, Distance effect

44. Getting to the point: Decimal naming in different languages

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How do speakers of different languages name decimal numbers? Based on prior work demonstrating that native Greek speakers name decimals differently than English speakers (Jones, Gilmore, & Xenidou-Dervou), the goal of this study is to explore systematic variations in decimal naming based on linguistic background and experience by administering a decimal naming questionnaire online via Prolific to a sample of adults who speak different languages. Participants were asked to name several different decimals (e.g., 3.45, 7.4921) in the language in which they typically do mental calculations, and to translate literally into English (e.g., “three point four five” or “three point forty-five”). We also collected demographic information from participants including linguistic experience using the LEAP-Q (Kaushanskaya, Blumenfeld, & Marian, 2020), age, and level of education. We then coded participants’ responses into categories to better understand the breadth of decimal naming conventions across different languages, focusing on different types of chunking that are evident in decimal naming (e.g., for 3.45 which speakers opt for "three point forty-five" vs. "three point four five"). Similar to prior work showing that the length of digit names in different languages relates to performance on tasks involving numbers (Ellis, 1992), this work has implications for better understanding how decimal naming may impact mental arithmetic.

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Keywords: decimals, linguistic experience, mental arithmetic

45. Investigating Mature Number Sense: Middle School Students' Brief Assessment Scores Correlate with Their Use of Number Sense Strategies

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Improving children's "number sense" has been a core component of recent mathematics curricular and instructional reforms in the US. Students with mature number sense make sense of numbers and operations, use reasoning to notice patterns, and flexibly select the most effective and efficient problem-solving strategies (McIntosh et al., 1997). Due to its dispositional nature, some have argued that mature number sense is an aspect of mathematical cognition that can only be measured through resource- and time-intensive probes of student thinking, such as in-depth one-on-one interviews (e.g., Howden, 1989) or lengthy tests of strategy usage (Yang, 2019). However, without a practical, rigorously validated measure for classroom use, researchers have yet to gather systematic evidence on the state of students' mature number sense. We aimed to address this by rigorously developing a brief assessment of mature number sense with valid and reliable scores. In this study, we gathered additional convergent evidence of validity for our measure with students in grades 6-8. We compared middle school students' ($N = 40$) scores on our brief assessment with an established, though time-intensive, measure (Yang, 2019) and in-depth interview of student strategy usage. We found scores on all three measures of mature number sense to be strongly related ($r > 0.7$), and this held true for our brief assessment even when controlling for students' addition fluency scores ($pr > 0.6$). Researchers and educators can use the brief assessment to efficiently investigate middle school students' rich mathematical thinking, furthering knowledge of a key component of mathematical cognition.

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Keywords: Mature Number Sense, Measurement, Middle School

46. The Role of Parents' Ability Mindsets on Parent-Child Interactions During Math Activities

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Parents play a critical role in developing children's foundational math skills before formal schooling. However, parents vary in their quality of engagement in math learning activities with their children, which can impact children's motivation and academic performance. Past work indicates parents' general beliefs about fixedness of ability can affect their levels of unconstructive engagement, such as controlling and performance-oriented teaching behaviors. However, no studies have examined how parents' specific beliefs about fixedness of ability in math may affect behavior on math tasks.

We examined this open question by inducing parents (N=76) to hold either an entity mindset (ability is fixed) or an incremental mindset (ability is malleable) about math by having them read "fake" articles. Parents then completed a math activity with their preschoolers. During this activity, we coded parents' unconstructive involvement. Afterward, parents completed surveys on their beliefs about general theory of intelligence (TOI) and fixedness for math (PBAF).

Parents in the math entity mindset condition showed higher math fixedness beliefs than parents in the math incremental mindset condition. There was no difference in general TOI beliefs between the conditions. Parents with more entity-based TOI scores showed more unconstructive involvement. However, condition and parents' beliefs about math ability fixedness did not explain additional variance in parents' unconstructive involvement.

While parents' unconstructive involvement was related to parents' general TOI, it was not related to their math-specific beliefs. This suggests short-term alterations in parents' specific ability beliefs about math are not powerful enough to alter unconstructive involvement during parent-child interactions.

Keywords: Parent-Child Interactions, Mindset, Beliefs

47. Do tape diagrams in explanations of worked examples foster conceptual understanding? Evidence from early algebra

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A challenge in designing mathematics instruction is fostering conceptual knowledge. One technique that has been shown to be effective is explaining worked examples. In this study, we examined whether including visual representations in worked examples can promote gains in conceptual knowledge and whether the benefits of visual representations depended on whether the worked examples were correct or incorrect. We tested this by randomly assigning 41 middle-school participants (Mage = 12.8 years) to solve linear equations and to think aloud while explaining correct and incorrect worked examples that were presented either with tape diagrams ($n = 20$) or no diagrams ($n = 21$). Participants made more mentions of conceptual principles when explaining incorrect worked examples than when explaining correct ones ($p < .05$), and they were more likely to mention underlying algebraic concepts such as “doing the same thing to both sides” ($p < .05$) and “inverse operations” ($p < .05$). The interaction between worked example type and tape diagram presence did not reach significance ($p = .05$); however, participants most frequently mentioned conceptual knowledge principles on incorrect worked examples with tape diagrams. Finally, participants who mentioned more conceptual principles during self-explanations of incorrect worked examples had higher conceptual knowledge posttest scores ($p < .05$). These results contribute to our theoretical understanding of how external representations support conceptual explanations and how these explanations enhance conceptual understanding in early algebra. Practically, practitioners may use these results to investigate ways to encourage students to express conceptual ideas about equation solving in the classroom.

Keywords: conceptual knowledge, tape diagrams, worked examples, self-explanation

48. Spatial biases in arithmetic problem solving: interference and/or facilitation?

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Studies in mental arithmetic have revealed spatial-numerical associations, wherein subtraction appears related to the left and addition to the right side of space, demonstrating that spatial and arithmetical processes are somehow related. Some studies investigated the effect of processing space on solving arithmetical problems while others investigated the reverse effect; some studies showed a facilitating effect of one process over the other, while others showed an interfering effect[1,2,3]. However, how and when this reciprocal influence takes place and produces facilitation and/or interference is still unclear. Here, we used a dual-task paradigm in which participants had to solve subtraction/addition problems and report the location of lateralised (left vs. right) targets, while the synchrony of the two tasks varied (targets presented before the problem, along with the operator, along with the second operand, vs. during calculation). Results show an interference of the arithmetical task on the spatial task: when erroneous, the reported position fits the spatial association of the operation (i.e., saying “left/right” after a subtraction/addition when targets had appeared on the right/left); this interference is absent when targets appear before the problem is presented. Results also show a possible mixture of slight facilitating and interfering effects of the spatial task on the response latencies of the arithmetical task: for addition, participants tend to respond faster when targets had appeared on the right than on the left, except when they were presented during the calculation step, in which case latencies increase. Findings are discussed in light of recent proposals on arithmetical solving.

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Keywords: mental arithmetic, spatial-numerical associations, dual task

49. Magnitude Processing Shows Few Relationships with Math Performance in Children with Low Math Ability: An fMRI Study

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Numerical magnitude processing plays an important role in successful math achievement and is impaired in those with poor math abilities. Magnitude processing activates regions in bilateral parietal cortex (PC) and inferior frontal cortex (IFC); these regions overlap with those activated during arithmetic, particularly during calculation-based arithmetic (involving procedural computation), relative to retrieval-based arithmetic (involving memory/verbal processing) (1). While previous studies show that brain activity during magnitude processing correlates with math performance, to clarify the role of magnitude processing in math learning, it is important to know if this relationship is stronger for calculation- versus retrieval-based arithmetic. Here we tested for such brain-behavior relationships in 54 children (aged 8-12) with low math ability, performing <92 on either Calculation or Math Fluency tests (2). Whole-brain analysis, contrasting symbolic-nonsymbolic magnitude matching with shape matching (thresholded at voxelwise p<.001 uncorrected; clusterwise p<.05 FDR-corrected), revealed bilateral PC and IFC activation, similar to prior use of this task (1). Four regions of interest were created around the group map maxima in left and right PC and IFC, and mean activation values were extracted for correlations with the Calculation and Math Fluency tests. Only one of the eight correlations was significant (surviving Holm-Bonferroni correction), and indicated greater activity in the right PC (including intraparietal sulcus) in those with worse calculation-based arithmetic (r=-.39, p=.004). Surprisingly, behavioral performance of magnitude judgment (3) did not correlate with Calculation or Math Fluency. Together, our findings in children with low math skills present a departure from those previously described in typically-developing participants.

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Keywords: fMRI, magnitude processing, brain-behavior relationships, calculation, arithmetic fluency

50. Endlessness without the Successor Principle

Isabelle Boni*, Steven Piantadosi

University of California Berkeley, United States of America

The meanings of early number words may be learned by linking sets of numbers and their corresponding labels in the ordered count list. However, it is less clear how we learn that the numbers are endless. One theory is that children must first learn the successor principle: the notion that every number has a successor, produced by adding 1. Other research shows that endlessness and the successor principle are predicted by distinct mathematical abilities, suggesting they may be learned separately. We find evidence in Tsimane' adults with minimal formal schooling that it is possible to understand endlessness without understanding the successor principle. We explore some potential alternative mechanisms for understanding endlessness. This research can help us understand how abstract mathematical principles are learned.

Keywords: infinity, endlessness, successor principle, abstract

51. Children with difficulties in learning mathematics - How do their working memory skills differ from typically developing first graders?

Kirsten Winkel* (1), Isabell Zipperle (2)

1: University of applied Sciences Saarbrücken, Germany; 2: University of Mainz, Germany

Children with difficulties in learning mathematics differ from their peers not only in terms of their mathematics-specific competencies, but also in terms of other cross-curricular competency areas. In many of these areas, they make more mistakes and need more time. They also make more mistakes in working memory tasks. But no studies could be determined for the time needed. The present study addresses this need for research, which is explicitly stated in a meta-analysis. Methodologically, it is based on the studies that fulfill the inclusion criteria of this meta-analysis. Our results from over 400 first graders show that children with special difficulties in learning mathematics not only make more mistakes in working memory tasks, but also need significantly more time for these basic cognitive skills. As expected, the differences are smaller than the differences in mathematics-specific skills, but the effect sizes found in this study underscore how important it is to consider working memory skills and the time dimension in addition to mathematics-specific skills when diagnosing and supporting children in order to effectively implement individual learning plans and to meet the heterogeneous learning conditions of these children.

Keywords: impairment in mathematics, dyscalculia, S3 guideline, working memory, response times arithmetic

52. You don’t multiply roses and tulips like books and cheese: world semantics and solving strategy selection

Jean-Pierre Thibaut*

LEAD, CNRS University of Bourgogne, France

Introduction: The choice of an algorithm in arithmetic problem solving should not depend on the nature of the objects featured in the problem, either apples or sets of seconds. In contrast, we hypothesize that adults’ and children’s use of algorithms depends on the nature of the manipulated objects. We illustrate this claim with word distributive problems that can be solved either by factorization or by development. Hypothesis: strategy choice will be influenced by the semantic distance between the objects that are featured in the problem and/or the presence of a structuring item (e.g., bouquet in a distributive problem involving tulips and roses) (see Coquin-Viennot & Moreau, 2003).

Participants: 84 fifth grade children and 84 university students

Design: Objects featured in the problems were from the same basic level category (apples and apples) or from distant superordinate categories (e.g. apples and computers). The other factor was the presence or absence of a structuring element (e.g. fruit baskets, or presents)

Materials: There were 5 experimental problems in each condition and 5 filling problems, to avoid or minimize focus on a single solving procedure.

Procedure: children seen in their classroom and adults answered via Qualtrics

Results. There were more factorizations in adults than in children.

In adults, more factorization for items (more factorization for apples and apples than for apples and computers). Interestingly, the effects were more important in adults, suggesting that semantic influences increase rather than decrease with development.

References:

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Keywords: arithmetic word problem, world semantics, devlopment, factorization

53. Do children's concepts of zero relate to their mental representation of integer magnitudes?

Nicholas A Vest, Martha W Alibali*

University of Wisconsin-Madison

At around age 5, children begin to understand that zero is a number and to correctly identify it as the smallest natural number (Wellman & Miller, 1986). A few years later, when they begin to learn about integers, their concept of zero shifts, and they begin to view zero as the reflection point between positives and negatives. In this research, we test whether children's concepts of zero and their mental representations of integer magnitudes change in tandem. To do so, we used a symbolic magnitude comparison task, and we focused specifically on participants' responses to mixed-sign comparisons (e.g., -2, 6). Past research has shown that adults demonstrate an inverse distance effect for mixed-sign pairs, due to the psychophysical scaling of magnitude representations of the mental number line for natural numbers and its reflection for negatives (Varma et al., 2019). We hypothesized that children who held a conception of zero as the reflection point between positives and negatives would also show this inverse distance effect, but children who held a conception of zero as the smallest number would not. In a study of 55 children (grades 5-7), we found that children's concepts of zero changed with grade level. Contrary to our hypothesis, children who viewed zero as the reflection point did not demonstrate the inverse distance effect for mixed-sign comparisons. We conclude that children's concepts of zero shift with experience in formal education; however, there was no evidence for a relation between zero concepts and mental representations of integer magnitudes.

References:

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2. Varma, S., & Schwartz, D. L. (2011). The mental representation of integers: An abstract-to-concrete shift in the understanding of mathematical concepts. Cognition, 121, 363-385.

Keywords: numerical cognition, mathematics, distance effect

54. Factors of powerful Math Education visualized in Flemish elementary school

Sabine Vandevelde*, Hilde Rabaut, Delphine Sasanguie

HOGENT Research Centre for Learning in Diversity, Belgium

Math and so math education is important. Teachers sometimes struggle with this: they don't which practices are evidence-based or don't know how to put this in practice or do things without being aware of it. In this practice-oriented scientific study we looked at which evidence-based influenceable factors contributing to powerful math education are present in Flemish elementary schools. Good practices existing in school already nowadays were illustrated to inspire other teachers.

Hereto, starting from the meta-review of Hickendorff et al. (2017), we completed an extra meta-review for 2017-2020. After detecting all evidence-based 'influenceable' factors (i.e. in which the teacher can intervene) contributing to effective math, we made a questionnaire asking teachers if and how often they applied these in daily math practice. This online, intensive questionnaire was sent out to all Flemish schools. There were 114 respondents. Afterwards, respondents were contacted online, to gain more insights into their answers and to make an appointment to visit the school and observe and film their math lessons.

Next, the most powerful and influenceable factors were selected. Math lessons were filmed in 14 schools. The movie clips were coded based on the factors from the literature study independently by two researchers.

The aim is creating a website showing the factors with extra information and movie clips of examples how to realize this in the classroom.

At this stage, we are still visiting schools in order to film the math lessons. By the time of the poster presentation, the website will be under construction.

References:

Hickendorff, M., e.a. (2017). Review van de samenhang tussen beïnvloedbare factoren in het onderwijsleerproces en de rekenwiskundeprestaties van basisschoolleerlingen. Universiteit Leiden. Geraadpleegd via https://www.nro.nl/wpcontent/uploads/2017/12/Rekenen-op-de-basisschool-review-405-17-920.pdf

Keywords: math education, elementary school, powerful math education

Symposia: 2:30pm - 4:00pm

Mathematical achievement in context

Chair: Denes Szucs

University of Cambridge, United Kingdom

This symposium takes an integrative look at factors affecting mathematical performance throughout the lifespan. We start with the question of whether mathematical ability is fix or malleable and how it may be affected by healthy ageing. The question of malleability of mathematical ability is strongly related to (false) beliefs about mathematical skills that affect learning. This will be addressed in the second talk. The third talk will take a focused look at math anxiety, a potential emotional block of mathematical learning and development. Finally, we discuss a large scale model overviewing several factors setting the context of mathematical development.

Keywords: Mathematical performance, healthy ageing, malleability of mathematical ability, learning, math anxiety

Presentation 1: The malleability of numerical abilities

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Cappelletti, Marinella (Goldsmiths University, UK)*

Popular views hold that numerical abilities are innate, universal and cross cultural. However, not much is known regarding the malleability of these abilities, namely to what extent they can be modulated by factors such as education, age, brain injury, and training. I will present evidence from the literature and from our own studies based on experimental, neuropsychological and neuroimaging techniques to suggest that numerical abilities are at the same time resilient to healthy ageing and robust to neurological insult, and yet successfully malleable by education and training. I will also discuss a recent study that aimed to further test the flexibility of numerical abilities capitalising on reward processes.

Presentation 2: Math Myths Make Hard Learning Math

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Girelli, Luisa (Universita degli Studi di Milano-Biocca, Italy)*

Mathematics is universally considered a key component of the educational curriculum, and math learning outcomes are constantly under the spotlight of attention, not only as indicator of educational policies and practices, but also as predictor of individual and societal well-being. Similarly, engaging students in STEM higher education, and pursuing STEM careers is becoming a worldwide priority for promoting innovation and economy. Yet, despite the general attention towards math and math-related education no other academic discipline pays a similar cost in terms of misconceptions. Math Myths include the fact that math is cold, abstract, difficult and largely gendered (Ernest, 1995). No surprise if it also generates harmful and aversive reactions as reflected by the highly investigated phenomenon, math anxiety. Building upon a flourishing literature, it will be shown that the stereotyped public image of math is pervasive in the media and across social contexts including schooling, academy, and job market, leading math myths to reproduce themselves. Scholars' responsibility in amplifying these myths by pursuing some catching lines of research is also discussed.

Presentation 3: Academic anxiety and math performance: the working memory riddle

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Caviola, Sara (University of Padova, Italy)*

Maths success is an essential aspect of school life for children. Not only cognitive processes, such as working memory or general cognitive skills, but also emotional factors are involved in mathematical learning. A large body of research is offering an increasing number of examples of how negative feelings towards maths (i.e. math anxiety - MA) can deeply interfere with a successful mathematical achievement. Across multiple studies, we explored the reciprocal influence among cognitive and emotional factors in math achievement. Different forms of anxiety have been evaluated, with math anxiety (MA) and test anxiety (TA) consistently being associated with various aspects of mathematics. In this talk, we evaluated the impact of these forms of anxiety, distinguishing between different types of mathematical tasks. In investigating this relationship, we have also included potential moderators, such as age, gender, working memory, type of task, and type of material. Results showed that both MA and TA had a significant impact on mathematics. Socio-demographic factors had modest moderating effects. Working memory (WM) also mediated the relationship between MA and TA with mathematics, however, this indirect effect was weak.

Presentation 4: The wider context of mathematical achievement during development

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Szucs, Denes (University of Cambridge, UK)*

The cognitive, emotional and social foundations of mathematics learning and development are typically studied in isolation. However, it is increasingly clear that a thorough understanding of math development must consider these domains in a unitary framework. This talk will depict a wide ranging model to guide the interpretation of mathematical developmental data. The model highlights cognitive, emotional and social context (education and society) related factors and illustrates their importance.

Math and Teaching Anxiety Experienced by Preservice and Practicing Elementary School Teachers

Chair: Nandrea Burrell

Florida State University, United States of America

Existing studies have shown that math anxiety is commonly experienced by preservice and practicing elementary school teachers. This anxiety relates to teacher attitudes and beliefs and some work suggests it has impacts on student math achievement. This symposium connects research aimed at understanding math anxiety and math teaching anxiety among teachers internationally. Touching on different correlates of anxiety about math and about teaching math, such as teachers' general anxiety, their specialization, their teaching experience, and the grade level they teach, these presentations highlight some important contributions to work centered on teachers and their anxiety about math and teaching math.

Keywords: math anxiety, teaching anxiety, teachers

Presentation 1: Not all elementary school teachers are scared of math

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Artemenko, Christina (Department of Psychology, University of Tuebingen, Germany); Masson, Nicolas (Institut de Recherche en Sciences Psychologiques, Université catholique de Louvain, Belgium); Georges, Carrie (Institut de Recherche en Sciences Psychologiques, Université catholique de Louvain, Belgium); Nuerk, Hans-Christoph (Department of Psychology, University of Tuebingen, Germany); Cipora, Krzysztof (Centre for Mathematical Cognition, Mathematics Education Centre, Loughborough University, United Kingdom)*

Teachers are strong role models for their pupils, especially at the beginning of education. This also holds true for math: If teachers feel anxious about math, the consequences on the mathematical education of their pupils is detrimental. Previous studies have shown that (future) elementary school teachers have higher math anxiety than most people studying other subjects. Here, we set out to conceptually replicate these findings by comparing math anxiety levels of preservice and practicing German and Belgian elementary school teachers to a reference group of German university students from various fields of study. Moreover, we questioned this finding by asking which elementary school teachers experience math anxiety, considering gender, specialization, and experience, and investigated how math anxiety relates to teaching attitudes towards math.

We replicated the previous finding by showing that female elementary school teachers have a higher level of math anxiety as compared to other female students. Importantly, female preservice and practicing elementary school teachers without math specialization indeed had higher levels of math anxiety than female students from other fields and almost a quarter of them experience critical math anxiety. In contrast, female elementary school teachers with math specialization did not show an increased level of math anxiety as compared to the reference sample. Considering that not only these but all teachers, regardless of specialization, teach math in elementary school in the investigated educational systems, the math anxiety of elementary school teachers is a potential problem for their pupils' math attitudes and learning.

Presentation 2: Math Anxiety in Pre-service Teachers as a Function of School Type and STEM Specialization

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Schillinger, Frieder (Institute of Psychology, Ludwigsburg University of Education); Artemenko, Christina (Department of Psychology, University of Tuebingen)*

The level of math anxiety in those training to become elementary school teachers was recently shown to depend on their specialization: teachers without math specialization exhibited significantly higher levels of math anxiety than those with math specialization (Artemenko et al., 2021). The aim of the present study was to replicate and extend these findings by comparing math anxiety in preservice elementary (N = 150) and secondary (N = 102) school teachers in Germany depending on their specialization. Results revealed that math anxiety was lower in students specializing in science, technology, engineering, and mathematics (STEM), but no difference was found between preservice elementary and secondary school teachers. The present study replicates previous findings regarding which STEM teachers are less prone to math anxiety, and further demonstrates that elementary and secondary school teachers have similar levels of math anxiety. However, unlike in secondary school, teachers in elementary school often need to teach mathematics irrespective of their specialization. High levels of math anxiety in elementary school teachers therefore remain a matter of concern given detrimental consequences for their students’ attitudes towards and achievement in mathematics.

Presentation 3: Mathematics teaching anxiety in Romanian pre-service elementary teachers

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Hunt, Thomas (School of Psychology, University of Derby, UK); Popa, Ioan-Lucian (Faculty of Exact and Engineering Sciences, "1 Decembrie 1918" University of Alba Iulia, Romania); Bagdasar, Ovidiu (School of Computing and Engineering, University of Derby, UK)*

Whilst there has been exponential growth in maths anxiety research in recent years, this has tended to focus on the general student population. Perhaps counterintuitively, a high proportion of teachers and trainee teachers appear to experience maths anxiety. More recently, research has acknowledged an important distinction between general maths anxiety and a more context-specific maths teaching anxiety, with maths teaching anxiety shown to be related to factors such as length of teaching experience, qualification status, and the level of education being taught. There are several negative implications associated with maths anxiety and maths teaching anxiety among preservice and practicing teachers, including issues with teacher recruitment and retention, transfer of anxiety to students, poor teaching practices, and general negative work experiences. Despite this, there is a limited body of research evidence to draw upon, particularly involving more diverse teaching populations. In the present study, 238 Romanian preservice elementary teachers completed an online survey including measures of maths teaching anxiety, maths anxiety, and general anxiety. A further, open-ended question provided participants with an opportunity to describe their personal experiences with maths anxiety. Findings will inform current practices regarding teacher training and will contribute to the growing literature in this area.

Presentation 4: Understanding the Relationship Between Teaching Anxiety, Grade Level, Subject, and Teaching Experience Among Practicing Elementary School Teachers

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Burrell, Nandrea (Florida State University, USA); Ganley, Colleen M. (Florida State University, USA); Schoen, Robert (Florida State University)*

Existing research shows that elementary school teachers often experience math anxiety when doing math and when teaching math. However, it is currently unknown whether teachers experience more anxiety about teaching math compared to when they are teaching other subjects. Research shows that teachers of older grades tend to experience less anxiety about teaching math, but we do not know if this is true of anxiety about teaching other school subjects or whether additional years of teaching experience can act to alleviate anxiety about teaching math and other subjects. The current study aims to broaden the existing research by comparing anxiety about teaching different school subjects and examining how grade level and years of teaching experience relate to teachers' math anxiety, anxiety about teaching math, and anxiety about teaching other school subjects.

To examine these relations, we will conduct analyses using data from the REALM project, which includes 233 teachers of grades K–3 in Florida. General math anxiety and anxiety about teaching math were measured using the Math Anxiety Scale for Teachers. We also asked one item each about anxiety felt while teaching science, reading, social studies, writing/grammar, and math. Teachers reported their years of teaching experience. We will conduct two repeated measures ANCOVAs comparing (1) levels of general math anxiety and anxiety about teaching math and testing their relations with grade level, and teaching experience, and (2) anxiety about teaching different school subjects and testing their relations with grade level and teaching experience.

The Development of Attentional Biases in Numerical Cognition

Chair: André Knops

National Center of Scientific Research (CNRS) & University of Paris, France

Both mental arithmetic and numerical quantity perception modulate the locus of spatial attention. In this symposium, attentional modulations in newborns, toddlers, preschoolers and 1st-to-4th-graders have been investigated with behavioral and eye-tracking methods. The results allow to further determine the developmental trajectory, as well as the role of task setting (arithmetic vs. mere quantity perception), format (symbolic vs. non-symbolic quantity information), approximate number system acuity, and number knowledge in the emergence of attentional biases in numerical cognition. This will help defining boundary conditions for theoretical accounts of the role that attention plays in numerical cognition.

Keywords: spatial attention, space-number associations, operational momentum, development, eye tracking

Presentation 1: Asymmetric Spatial Attention in Early Numerical Cognition

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McCrink, Koleen (Barnard College, Columbia University)*

This talk will detail two recent experiments that have examined how lateralized aspects of spatial attention influence spatial-numerical cognition in early childhood. In Study 1, newborn infants were tested multimodally, with auditory quantities presented alongside visual object arrays in two test trials. These test scenes varied with respect to which side (either left or right) numerically matched the auditory number. The infants looked longer to the test trials in which the left side of the visual display exhibited a quantity that matched the presented auditory quantity. This study provides the first evidence for an untrained, innate bias for humans to preferentially process quantity information presented in the left field of vision. In Study 2, children aged 1 to 5 years were tested via an eye-tracking paradigm wherein they viewed a target hidden in one of five vertical locations. This set of locations underwent a surreptitious 90° spatial transposition. Infants and 4-year-olds, but not toddlers, fixated on the side of space in the horizontal array that corresponded to a left-to-right mapping of information learned in the vertical dimension. These data illustrate a decrease in left-to-right processing around the age of two, as children recede from infantile spatial biases and progress to exhibiting culture-specific spatial biases in early childhood. Taken together, these studies suggest that lateralized spatial attention is a central aspect of our numerical cognition from birth, but its presence fluctuates in early childhood as we become enculturated observers of our world.

Presentation 2: Developmental trajectory of attentional shifts during single-digit arithmetic: an eye-tracking study among 2nd and 4th Graders

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Masson, Nicolas (Institute of Cognitive Science and Assessment (COSA), Department of Behavioural and Cognitive Sciences (DBCS), Faculty of Humanities, Education and Social Sciences (FHSE), University of Luxembourg, Luxembourg; Psychological Sciences Research Institute an); Stephany, Martine (Institute of Cognitive Science and Assessment (COSA), Department of Behavioural and Cognitive Sciences (DBCS), Faculty of Humanities, Education and Social Sciences (FHSE), University of Luxembourg, Luxembourg); Dormal, Valérie (Psychological Sciences Research Institute and Institute of Neuroscience, Université catholique de Louvain, Belgium); Schiltz, Christine (Institute of Cognitive Science and Assessment (COSA), Department of Behavioural and Cognitive Sciences (DBCS), Faculty of Humanities, Education and Social Sciences (FHSE), University of Luxembourg, Luxembourg)*

Recent studies conducted in adults have demonstrated that mental arithmetic involves shifting attention along a spatial continuum. Although little is known on when these attentional shifts develop in childhood during the acquisition of arithmetic. Previous behavioural studies suggested that they would not be recruited until 4th or 5th Grade. Here, we used an eye-tracker with high spatio-temporal resolution to measure spontaneous eye movements used as a proxy for attentional shifts, while children of 2nd (N=50) and 4th (N=48) Grade solved simple additions (e.g., 4+3) and subtractions (e.g., 3-2). At odds with previous studies, our results show horizontal and vertical attentional shifts in both groups. Critically, horizontal eye movements were observed in 4th Graders as soon as the first operand and the operator were presented. These attentional shifts were only observed later in 2nd Graders, after the presentation of the second operand just before the response was made. This demonstrates that spatial attention is recruited in children to solve arithmetic problems, even in early stages of learning. The time course of these attentional shifts suggests that with practice in arithmetic children learn to use spatial attention to anticipatively guide the search for the answer and facilitate the implementation of solving procedures.

Presentation 3: Operational momentum in preschoolers in non-symbolic and symbolic modes - the interrelations between magnitude and spatial processing

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Haman, Maciej (University of Warsaw, Poland)*

Operational momentum (OM) is a phenomenon that seems to document the spatial-attentional underpinnings of mental arithmetic. So far, OM has been demonstrated both in children and adults, but the developmental course of OM is far unclear and, in particular, little is known about this phenomenon in the preschool period, when symbolic numerical abilities compliment previous non-symbolic ones. Moreover, three phenomena are investigated under the common label of “OM”: (1) overestimation/underestimation of the results of addition/subtraction, (2) overestimation/underestimation of successive elements of increasing/decreasing numerical sequences, and (3) the association of addition with the right and subtraction with the left side. We present a portion of the results of a large research project on the numerical development of preschoolers (3-7 years old), in which we used three arithmetic tasks and two number-line estimation tasks (NLE), both in non-symbolic and symbolic formats, together with a number of other measures of spatial/numerical abilities. Some form of OM was demonstrated in each of the arithmetic tasks, but the OM tendencies were not correlated between tasks. Positive relationship between the precision and linearity of mapping in non-symbolic NLE and OM tendency in symbolic arithmetic was the only significant relation between these two effects. Our results seem to suggest that OM is not the result of the permanent properties of the number representation (e.g. its logarithmic scaling), but an effect of on-line processes possibly involving spatial attention mechanisms. Moreover, at its earliest stage, symbolic arithmetic appears to be grounded in non-symbolic abilities, which has recently been questioned.

Presentation 4: The developmental trajectory of the operational momentum effect in 3-7-year-old children

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Omont, Sixtine (University of Paris); Coolen, Ilse (University of Paris); Salle, Jeanne (Télécom Paris); Knops, André (National Center of Scientific Research (CNRS) & University of Paris, France)*

The operational momentum effect (OM) describes the tendency to overestimate results of addition problems while underestimating the outcome of subtraction problems. Although the exact cognitive origins of this bias remain debated, it has been taken as an index of the involvement of spatial processes (e.g. spatial attention) in numerical contexts (i.e. spatial-numerical association). Examining the developmental trajectory of the OM effect may help identifying putative mechanisms driving this effect, for example by clarifying the role of acquired symbolic number knowledge.

Here we present the first cross-sectional results of a longitudinal study that investigates the developmental trajectory of the OM effect in children aged 3, 5, or 7 years. Children were presented with non-symbolic addition and subtraction problems. Exploiting a bootstrapping approach allowed us to estimate the preferred outcomes for additions and subtractions. Overall, children underestimated the outcome of addition and subtraction problems. We found no difference between addition and subtraction in 3-year-olds. In 5- and 7-year-olds we observed an inverse OM effect.

These results are in line with previous findings and suggest that the OM effect emerges only later in childhood, putatively driven by formal mathematical training.

Relations between Logical Reasoning and Mathematical Competence

Chair: David Braithwaite (1), Kinga Morsanyi (2), Terry Tin Yau Wong (3), Jérôme Prado (4)

1: Florida State University; 2: University of Loughborough; 3: University of Hong Kong, Hong Kong S.A.R. (China); 4: French National Center for Scientific Research & University of Lyon, France

The link between logic and mathematics has been recognized by people from different fields, but empirical investigations on this link remain scarce. The current symposium aimed to present studies that investigated the relations between different forms of logical reasoning (i.e., conditional reasoning and transitive reasoning) and different mathematical outcomes (e.g., geometric proof, number ordering, comparison, fraction magnitude, etc.). The discussion is expected to shed light on the cognitive processes being shared between logical reasoning and mathematical problem-solving.

Keywords: logical reasoning, mathematics, cognitive processes

Presentation 1: Associations between geometric proof and probabilistic reasoning among adults

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Braithwaite, David (Florida State University)*

Most students first encounter formal proof in the context of geometry. The inclusion of geometric proof in math curricula has often been justified on the grounds that studying geometric proof fosters deductive reasoning, yet this assumption has rarely been tested empirically. The present study employed an individual differences paradigm to investigate links between geometric proof and reasoning in other domains. Participants (N = 99) were university students, all of whom reported having previously taken a course in geometry. Individual differences in accuracy on a researcher-developed geometric proof task predicted differences in accuracy on a math reasoning task with non-geometric content, the Probabilistic Reasoning Scale (PRS; Primi et al., 2017). This relationship was partially mediated by differences in accuracy on a conditional inference task (Morsanyi et al., 2018) with non-mathematical content, suggesting that geometric proof and probabilistic reasoning both involve domain-general deductive reasoning. The fact that the mediation was partial, not full, implied that geometric proof also involves competencies that are distinct from deductive reasoning but involved in probabilistic reasoning. Exploratory analyses suggested that one such competency may be the effective use of given information during math problem solving.

Presentation 2: Maths and logic share the same basic cognitive processes

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Morsanyi, Kinga (University of Loughborough); van Bers, Bianca (University of Amsterdam); O'Connor, Patrick (Queen's University Belfast)*

Transitive inference has been found to be related to mathematical skills in children, adolescents and adults. The aim of this study was to better understand the factors that underlie this relationship. Transitive reasoning builds on the ability to form relations between concepts, but it goes beyond these in that inferences can be made about items that are not presented together. For example, if I know that Abel is taller than Bob, and Bob is taller than Cecil, I can infer that Abel is taller than Cecil. It has also been suggested that transitive inferences build on similar representations as the mental number line, in that they rely on spatial representations of a series of items lined up in a given order. The present study investigated the links between transitive reasoning and symbolic and non-symbolic comparison skills, number ordering ability, number line estimation, as well as performance on a curriculum-based mathematics test in 10-year-old children (n=100). The results showed that performance on a maths test, non-symbolic comparison and number ordering skills were all significantly related to transitive reasoning skills after controlling for the effect of children’s age and verbal and non-verbal intelligence. A path analysis also showed that both transitive inferences and number ordering skills mediated the link between non-symbolic magnitude comparison and maths ability. This suggests not only that maths and logic share the same basic cognitive processes, but it also shows that logical reasoning skills make a significant contribution to complex maths performance beyond sharing some basic processes.

Presentation 3: The link between transitive reasoning and mathematics achievement in preadolescence: The role of relational understanding

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Wong, Terry Tin-Yau (University of Hong Kong); Morsanyi, Kinga (University of Loughborough)*

The current study aimed at investigating the link between transitive reasoning and children’s mathematical competence as well as the potential mechanisms involved. A sample of 101 sixth graders were assessed on their transitive reasoning skills, their mathematical competence, various potential mediators as well as general cognitive factors (i.e., fluid intelligence, verbal and visuospatial working memory, as well as inhibition skill; all serving as control variables). The results showed that children’s transitive reasoning performance significantly predicted their mathematical competence beyond the effects of general cognitive factors, and the relation was mediated by fraction magnitude knowledge and Relation to Operands (i.e., the sums should always be greater than the addends in addition problems with natural numbers) understanding. The findings not only confirmed the relation between transitive reasoning and mathematical competence, but also shed light on the mechanisms underlying such a relation.

Panel discussion

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Prado, Jérôme (French National Center for Scientific Research & University of Lyon)*

Panel discussion on the relations between logical reasoning and mathematical competence.

The Role of the Approximate Number System in Number Processing and Related Methodological Challenges

Chair: Hans-Christoph Nürk (1), Attila Krajcsi (2)

1: University of Tübingen, Germany; 2: Eötvös Loránd University, Hungary

For decades, the approximate number system (ANS) is a concept that has gained significant attention in numerical cognition research. Despite the large amount of work, there are still methodological debates about how the ANS should be investigated. The present symposium discusses four approaches that go beyond the current practices. The talks highlight the importance of the reliability in correlational studies (Szűcs, Krajcsi), the need for paradigms measuring toddlers' ANS sensitivity (Simms, Lindskog), the various generators of comparison distance and size effects (Krajcsi, Kojouharova), and the role of the temporal non-numerical features in numerosity perception (Dolfi, Cutini, Testolin, Zorzi).

Keywords: approximate number system, priming distance effect, numerical development, comparison size effect, temporal non-numerical properties

Presentation 1: Symbolic number comparison and number priming do not rely on the same mechanism

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Szűcs, Tamás (Eötvös Loránd University, Hungary); Krajcsi, Attila (Eötvös Loránd University, Hungary)*

In elementary symbolic number processing, the comparison distance effect (in a comparison task, the task is more difficult with smaller numerical distance between the values) and the priming distance effect (in a number processing task, actual number is easier to process with a numerically close previous number) are two essential phenomena. While a dominant model, the approximate number system model, assumes that the two effects rely on the same mechanism, some other models, such as the discrete semantic system model, assume that the two effects are rooted in different generators. In a correlational study, here we investigate the relation of the two effects. Critically, the reliability of the effects are considered, therefore, a possible null result cannot be attributed to the attenuation of low reliability. The results showed no strong correlation between the two effects, even though appropriate reliabilities were provided. These results confirm the models of elementary number processing that assume distinct mechanisms behind number comparison and number priming.

Presentation 2: When the word "more" doesn't matter: Measuring toddlers non-symbolic number processing using a novel task

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Simms, Victoria (Ulster University, United Kingdom); Lindskog, Markus (Uppsala University, Sweden)*

Much research has investigated children's non-symbolic number processing and its relation to mathematical ability. However, surprisingly few studies have investigated performance in 18-36 month-olds, where symbolic number concepts begin to emerge, and the extent results indicate poor performance. We tested 74 2 - 3.5 year-olds recruited from two sites (Ulster and Uppsala). They completed a novel dot-comparison task where children were shown, but not verbally instructed, how pushing a more numerous array resulted in reward and a Give-N task. Overall, participants performed above chance on the dot comparison task, indicating that non-symbolic number processing skills can be measured in toddlers without verbal instructions. We found no relation between performance on the non-symbolic number processing task and knower-level. Our results warrant two conclusions. First, verbal instructions involving the concept of more are not necessary to measure non-symbolic number processing skills in young children. Second, the development of a symbolic number concept seems independent of the development of non-symbolic comparison skills but may become artificially related when researchers use quantifiers such as "more" to measure the former.

Presentation 3: Various sources of the symbolic and nonsymbolic numerical comparison size effects

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Krajcsi, Attila (Eötvös Loránd University, Hungary); Kojouharova, Petia (Institute of Cognitive Neuroscience and Psychology, Hungary)*

In a number comparison task, the trials are easier (faster and less error-prone) when the values are relatively small, termed the size effect. According to the classic approximate number system (ANS) model, the size effect is an artifact of the psychophysical ratio effect. However, alternative models assume that, in symbolic comparison tasks, the size effect is a frequency effect: Smaller numbers are easier to process because they are observed more frequently. Former rigorous tests have demonstrated that while the nonsymbolic comparison works according to the psychophysical models, the symbolic size effect is dominantly influenced by the frequencies of the digits. In our first study, it was investigated whether the symbolic comparison size effect can be changed by modifying the stimulus frequency and whether a partial effect of the ANS can be observed. We found that the size effect could be successfully modified by the stimulus frequency and no influence of the ANS could be observed. In the second study, the effect of the stimulus frequency on nonsymbolic comparison performance was investigated. We found that the size effect was partially influenced by the stimulus frequency, however, in terms of the diffusion models, the change was not transmitted by the drift rate (as seen in the psychophysical models or the symbolic numerical size effect), but it was conveyed by the threshold parameter. These findings identify three independent sources of size effects with a distinct pattern of symbolic and nonsymbolic comparison tasks. These results suggest different mechanisms behind symbolic and nonsymbolic number processing.

Presentation 4: The effect of temporal cues in sequential numerosity comparison

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Dolfi, Serena (University of Padova, Italy); Cutini, Simone (University of Padova, Italy); Testolin, Alberto (University of Padova, Italy); Zorzi, Marco (University of Padova, Italy)*

In non-symbolic comparison judgements, individuals have shown to be significantly influenced by the perceptual characteristics of the images such as the dimension of the objects or their placement in space. However, while perceptual biases have been extensively studied in the visual and spatial domain, the impact of temporal magnitudes (e.g., duration, rate) on numerosity judgements is still largely unknown. This work investigates the interplay between numerosity and other temporal quantities in visual and auditory domain in a non-symbolic sequential numerosity comparison task designed to estimate the separate contribution of numerical performance from non-numerical biases. When asked to indicate which between two streams of events contained more events, adults showed a performance primarily based on the numerical information. However, in both visual and auditory modalities, participants presented a significant non-numerical bias, particularly related to the rate of presentation of the events and the duration of the sequences. These preliminary results offer an interesting parallelism with corresponding effects in visual parallel tasks and open the debate for the use of cross-modal presentations.

Symposia: 4:30pm - 6:00pm

Probing the Interplay between Early Attention, Executive Functions and Numeracy

Chair: Gaia Scerif

University of Oxford, United Kingdom

Multiple studies have reported robust correlations between executive skills and emerging numerical cognition, but a mechanistic understanding of these correlations remains elusive. In the proposed symposium, we discuss the need to explore complementary objectives, to better probe the executive/numeracy interplay:

1. Understanding the implications of changes in domain-general and domain-specific processes over early childhood;
2. Exploring children's emerging attitudes and affect in the context of maths learning;
3. Understanding the learning environment provided by early years practitioners and steps towards optimising it via practitioner development;
4. Testing correlations across diverse socio-cultural environments in which young children come to learn number.

Keywords: attention, executive functions, early numeracy

Presentation 1: Contrasting theories of change for early executive and maths interventions

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Scerif, Gaia (University of Oxford)*

Gaia Scerif will begin by overview correlational data and different ways in which EF and maths may interplay to generate these relationships. A wealth of research has suggested robust correlations between executive function skills and early cognitive development, including emerging numerical cognition, language and literacy, but an understanding of these correlations remains elusive. Intervention studies offer the opportunity of testing causality. However, a number of recent executive functions interventions have failed to transfer to improvements in known correlated educational outcomes. This is problematic from theoretical and applied perspectives alike: if early execution functions training does not transfer reliably, should we forfeit it entirely? She will detail and contrast distinct theories of change behind executive functions and maths interventions, detailing the case for integrated, as opposed to isolated, interventions and a pre-registered study testing this hypothesis. Having overviewed these distinct theories of change, she will outline differential hypotheses about how domain-general (attentional), domain-specific (numerical) and multi-level processes (child-level, adult-level, environment-level) interact over early numeracy development and conclude on why explicitly operationalizing these mechanisms is important if we want to develop more effective interventions.

Presentation 2: Regulation, attention and early numeracy: Child-level factors

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Gattas, Sylvia (University of Oxford)*

Sylvia Gattas will discuss early mechanisms of regulation and their influence on attentional control and numeracy. Early cognitive development is a large predictor of future mathematical education success and careers. Importantly, developing regulatory mechanisms is essential for the development of foundational executive abilities at pivotal stages in early childhood which set the stage for later mathematical success and prospective career choices. Math anxiety (MA), one's negative feelings of worry about math, often limits one's mathematical development. MA has a significant impact on cognitive, emotional, physiological and behavioural responses. While many believe ability is a result of performance and practice, this view bypasses the underlying mechanisms affected essential to practice and maintenance of such abilities. Consequently, it is important to study the underlying mechanisms of MA and early regulatory processes, how they influence attention and how they might later work as a shield and resilience catalyst against maths anxiety. This presentation will centre around emerging relationships between regulation, attitudes and early numeracy development.

Presentation 3: Environmental factors influencing the executive / numeracy interplay

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O'Connor, Rosemary (University of Oxford)*

Rosemary O'Connor will move the emphasis from the child to the environment provided by supporting adults and peers in preschool. Inequalities in both mathematical and executive performance are already well-established by the time children start primary school. Given that all children in the UK are eligible for at least 15 hours of government-funded childcare from the age of three, preschool is in many ways an ideal environment for an intervention programme designed to optimise the interplay between executive functions and mathematics. However, preschool environments tend to be highly variable: at the level of the child (home environment, socio-economic status, special educational needs), at the level of the staff (training level and experience, attitudes towards maths, engagement, time commitment), and at the level of the setting itself (size, mix of age groups, time and funding dedicated to training opportunities, ethos). This talk will outline the reasons why preschools offer an ideal environment for an early maths and executive intervention programme. Next, the challenges associated with designing an intervention for such a variable group of settings will be discussed, as well as the measures used to gain a greater understanding of the differences between settings. The speaker will outline the steps taken to ensure that the intervention is acceptable and feasible as well as effective, from the early planning stages, through to piloting and collaborating with nursery schools to co-develop an informative and accessible set of training materials, through to the measures used to assess the feasibility of the programme.

Presentation 4: Executive functions and numeracy: Investigating bidirectionality in low-income South African children

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Cook, Caylee (University of The Witwatersrand)*

Caylee Cook closes with an exploration of the interplay between executive and numeracy skills for children in low-income communities in South Africa who do not access preschool facilities, and for whom number learning opportunities differ from those of children in typical higher income settings. Via a longitudinal study of emerging EF and numeracy, she will test whether there are bidirectional or unidirectional relationships across these emerging skills, in highly understudied communities and settings.

Single and Comorbid Difficulties in Math - Development, Underlying Factors, and Long-term Predictors

Chair: Tuire Koponen, Minna Torppa

University of Jyväskylä, Finland

The symposium explores the issue of comorbid and single difficulties in mathematics. It includes four studies covering various populations in terms of culture (Netherland, Finland) and age (Kindergarten, lower grades, and intermediate grades), three large-scale data sets (a twin data and two longitudinal follow-up data), and wide set of underlying and predictive factors (genetic, environmental, cognitive, and non-cognitive). Symposium brings together studies examining questions of underlying factors of comorbidity, relations between learning difficulties and ADHD as well as emergence and development of single and comorbid math and reading difficulties and their predictive factors.

Keywords: Comorbidity, genetic, environmental, cognitive/non-cognitive predictors

Presentation 1: Comorbidity and causality among ADHD, dyslexia, and dyscalculia

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van Bergen, Elsje (Vrije Universiteit Amsterdam); Hart, Sara (Florida State University); Boomsma, Dorret (Vrije Universiteit Amsterdam); de Zeeuw, Eveline (Dutch Inspectorate of Education); de Geus, Eco (Vrije Universiteit Amsterdam); Kan, Kees-Jan (University of Amsterdam)*

Purpose – ADHD, dyslexia and dyscalculia are comorbid. Also, the full ranges of the associated traits are correlated. There is evidence of shared aetiological factors (i.e., genetic and environmental) and shared cognitive factors (e.g., processing speed). These shared factors may fully explain the covariation among the symptom dimensions. Alternatively, there may be causal effects at the behavioural level. That is, children with ADHD might not be able to attend to the teacher's instruction and develop learning difficulties, or, children with learning difficulties might find the instructions too difficult and show ADHD symptoms.

Method - Children in the Netherlands Twin Register were assessed at ages 7 and 10 on ADHD symptoms (teacher reports) and academic skills (tests of reading fluency, spelling, and math). We have (partial) data for 19,125 twin children and 2,150 siblings.

Results - Twins and singletons had similar levels of ADHD symptoms and academic skills. Compared to children without ADHD, those with ADHD were more than 2 times as likely to have a learning disorder in addition (and vice versa). Children with one learning disorder were 3-4 times as likely to have the second learning disorder too. All traits showed high heritabilities and moderate genetic correlations. Longitudinal twin-difference correlations were small and many close to zero. Finally, cross-lagged models, that allowed for shared genetic influences, indicated small significant effects only for ADHDàmath, readingàspelling, and readingàmath.

Conclusions - Together, the analyses suggest that the ADHD-achievement association is mostly due to shared genetic aetiology. Additionally, ADHD-symptoms might hinder math development.

Presentation 2: Parental influences on the development of single and co-occurring difficulties in reading and arithmetic fluency across Grades 1–9

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Khanolainen, Daria (University of Jyväskylä); Koponen, Tuire (University of Jyväskylä); Eklund, Kenneth (University of Jyväskylä); Gerike, Georgia (University of Jyväskylä); Lerkkanen, Marja-Kristiina (University of Jyväskylä); Torppa, Minna (University of Jyväskylä)*

International assessments show that many teenagers struggle with reading simple texts and solving basic mathematical problems; nevertheless, longitudinal research on reading and mathematical skill development mostly focuses on early childhood and primary school education, rarely extending into education during adolescence. What is more, reading and mathematical skills are closely related and difficulties in these domains often co-occur. In this study we investigated how single and co-occurring difficulties in reading and arithmetic fluency developed among Finnish children from Grade 1 onward (N = 2614; 391 among these had at least one type of fluency difficulties in Grade 9). Distinct trajectories of poor fluency development were identified using latent profile analysis: reading difficulties profile (N = 176), mathematical difficulties profile (N = 94), and comorbid difficulties profile (N = 121). Analysis of variance and chi-square tests were employed to compare the latent profiles of learners with fluency difficulties and typical performers on parental reading and mathematical difficulties, parental education, the home learning environment, and assistance with homework. Results showed that children's reading and mathematical difficulties often co-occur—almost 50% of all children with difficulties demonstrated co-occurring difficulties in the other domain. Moreover, the early home environment (when children were in Kindergarten) did not differentiate the profiles. However, parents were sensitive to their children's academic weaknesses providing significantly more deficit-specific homework assistance across all grades compared to parents of typical performers. At the same time, the amount of assistance gradually declined and the performance gap between the profiles increased.

Presentation 3: Cognitive and motivational markers of persistently low arithmetic and/or reading fluency

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Pulkkinen, Jenni (University of Jyväskylä); Eklund, Kenneth (University of Jyväskylä); Koponen, Tuire (University of Jyväskylä); Heikkilä, Riikka (Niilo Mäki Institute); Georgiou, George (University of Alberta); Salminen, Jonna (City of Jyväskylä); van Daal, Victor (University of Amsterdam); Aro, Mikko (University of Jyväskylä)*

For some children, establishing fluent arithmetic and reading skills as tools for further learning requires substantial amount of time and effort. Regardless of importance of early identification, knowledge about early markers indicating single and comorbid fluency problems in arithmetic and reading is still scarce.

We approached this issue by following Finnish children's (n=197) development in arithmetic, reading and cognitive skills as well as their academic self-beliefs semi-annually from Grade 1 to Grade 3. Based on children's performance in reading and arithmetic fluency composite scores at third-grade fall and spring, children were classified into four groups using a cut-off z-score of −0.7: persistently low fluency in arithmetic (n=16), reading (n=14), both (n=25) and neither (n=142).

Group comparisons of ANCOVA showed that consistently low rapid automatized naming and verbal counting were common to all three groups with low fluency, while problems in symbolic magnitude comparison, processing speed and working memory were related to low arithmetic fluency, with and without low reading fluency. Associations between academic skills, self-efficacy and academic self-concept showed domain-specific pattern, low self-beliefs differentiating the three groups from their peers without fluency problems by the end of Grade 2 at the latest.

The results suggest that weakness in processing serial information could be common to arithmetic and reading fluency problems, while low numerical and general cognitive skills might indicate need for monitoring children's arithmetic development more closely. Low confidence in learning academic skills in turn highlights importance of supporting children's self-beliefs alongside mathematical and reading skills across early school years.

Presentation 4: Math development from Grade 1 to 9 and their early identification

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Psyridou, Maria (University of Jyväskylä); Torppa, Minna (University of Jyväskylä); Poikkeus, Anna-Maija (University of Jyväskylä); Lerkkanen, Marja-Kristiina (University of Jyväskylä); Koponen, Tuire (University of Jyväskylä)*

Purpose: We examine the developmental profiles of math skills from Grade 1 to Grade 9 and their early predictors.

Methods: The present study is part of the large-scale Finnish longitudinal First Steps Study, a follow-up of a total of 2,518 children from kindergarten to Grade 9. Math skills were assessed at end of Grades 2, 3, 4, 6, 7, and 9 with two tasks, an arithmetic task and a multiplication task. The predictors assessed in kindergarten (age 6) included gender, parental factors (parental math difficulties, education level, socio-economic status), home numeracy environment, task-avoidant behavior, interest in math, math self-concept, arithmetic strategies, and kindergarten cognitive skills (number counting, number concepts, spatial relations, RAN, phonological awareness, letter knowledge, reading words, vocabulary, listening comprehension).

Results: Data analysis is underway and will include a latent profile analysis to examine the development of math skills across grades. In addition, in order to analyze the relative contributions of gender, parental factors, home numeracy environment, task-avoidant behavior, interest in math, math self-concept, arithmetic strategies, and kindergarten cognitive skills to the developmental profiles, we will conduct a hierarchical regression analysis in a structural equation modeling framework by applying a Cholesky model.

Conclusions: The identified profiles and the effects of the kindergarten-age predictors on the children's math skills development are discussed.

Brain Correlates of Mathematics: the Role of Language Modality, Expertise, and Effective Factors

Chair: Ilaria Berteletti (1), Macarena Suárez-Pellicioni (2), Venera Gashaj (3), Juan-Antonio Álvarez-Montesinos (4)

1: Gallaudet University, United States of America; 2: University of Alabama; 3: Swiss Federal Institute of Technology (ETH) Zurich and University of Tuebingen; 4: Universidad de Málaga, Spain

The symposium's objective is to investigate the role of experience broadly defined on the neurocognitive mechanisms supporting arithmetic and mathematical reasoning. The work presented in these talks identifies the brain mechanisms explaining the role of language modality (i.e. signers vs. hearing non-signers), expertise (i.e. different fluency levels; novice vs. experts), and affective factors (i.e. math attitudes) in math achievement using different neuroimaging approaches (fMRI and ERPs), and populations spanning different age groups (children and adults). The discussions will be geared toward the translational relevance of the findings for education.

Keywords: arithmetic processing, mathematical reasoning, variability, neural correlates, experience

Presentation 1: The role of language modality on the neurocognitive mechanisms supporting arithmetic processing

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Berteletti, Ilaria (Gallaudet University, United States of America); Sullivan, SaraBeth J. (Gallaudet University); Kimbley, Sarah E. (Gallaudet University)*

The role of language modality has been overlooked in the field of numerical cognition. However, language plays a prominent role in arithmetic operations. It is also known that sign languages recruit both the same left-lateralized perisylvian areas as spoken languages but also rely more on visuospatial and premotor processes. It remains an empirical question whether the areas supporting proficiency in arithmetic are language-modality specific or amodal. We will present two neuroimaging studies (EEG and fMRI) on data collected with adult Deaf early signers and hearing non-signers solving subtraction and multiplication problems. In the EEG study, we compare hearing non-signers with Deaf early signers in an operation judgment task. The ERPs for both groups show similar early attentional dissociation with operation type and a later quantity magnitude modulation for subtraction problems. However, now significant differences were observed across groups. This finding suggests that a similar dissociation exists between language modalities for the two types of operations. In the fMRI study, including only Deaf native signers, we found activation in the IFG and STG to be greater for multiplication problems and that the modulation of activation was correlated with greater sign language and arithmetic proficiency. This is the first study to show the functional role of sign language proficiency in supporting arithmetic problem-solving. These results will be discussed within the current theories of arithmetic processing as well as in relation to the translational impact for the Deaf signing community.

Presentation 2: Neurocognitive mechanisms explaining math attitudes' role in predicting children's multiplication improvement

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Suárez-Pellicioni, Macarena (University of Alabama); Demir-Lira, Ö. Ece (The University of Iowa); Booth, James R. (Vanderbilt University)*

Enhancing students' math achievement is a significant educational challenge. Numerous studies have shown that math attitudes can predict improvement in math performance, but no study has yet revealed the underlying neurocognitive mechanisms explaining this effect. To answer this question, 50 children underwent functional magnetic resonance imaging (fMRI) when they were 11 (time 1; T1) and 13 (time 2; T2) years old. Children solved a rhyming judgment and a single-digit multiplication task inside the scanner at T1. The rhyming task was used to independently define a verbal region of interest in the left inferior frontal gyrus (IFG). We focused on this region because of previous evidence showing math attitudes-related effects in the left IFG for children with low math skills (Demir-Lira et al., 2019). Children completed standardized testing of math attitudes at T1 and of multiplication skill both at T1 and T2. We performed a cluster-wise regression analysis to investigate the interaction between math attitudes and improvement in multiplication skill over time while controlling for the main effects of these variables, intelligence, and accuracy on the task. This analysis revealed a significant interaction in the left IFG, which was due to improvers with positive math attitudes showing enhanced activation. Our result suggests that IFG activation, possibly reflecting effort invested in retrieving multiplication facts, is one of the possible neurocognitive mechanisms by which children with positive math attitudes improve in multiplication skill. Our finding suggests that teachers and parents can help children do better in math by promoting positive math attitudes.

Presentation 3: Individual differences in multiplication fluency elicit different ERPs responses in single-digit multiplications

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Álvarez-Montesinos, Juan Antonio (Universidad de Málaga); Avancini, Chiara (Center for Neuroscience in Education); García-Orza, Javier (Universidad de Málaga); Szücs, Dénes (Center for Neuroscience in Education)*

Individual differences in learning and solving multiplications facts remain unexplained. In this study, we used event-related potentials (ERPs) to examine the EEG pattern of two groups of healthy adults: one group of participants with high fluency multiplication skills (N=16) and one group of participants with low multiplication fluency skills (N=12). Subjects were asked to do a verification task: They were presented with a single-digit multiplication and then asked to decide whether a number displayed later was the correct result, or not. The results showed smaller amplitude in the N2b component in the high fluency group compared with the low fluency group when they decide correctly that the number was the correct result of the multiplication. However, this difference was absent when faced with an incorrect result. This effect was found together with a longer latency in the N2b component in the low fluency group than in the high fluency group in central and right-side electrodes, in line with previous studies. No between-group differences were observed in the N400. These results suggest low fluency participants suffer more interference than high fluency participants when they had to decide whether a number is the correct result of a single-digit multiplication. Further studies should be carried out to reveal the origin of these between-group differences.

Presentation 4: Oscillatory dynamics during sense-making of symbolic and nonsymbolic mathematical proofs

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Gashaj, Venera (Swiss Federal Institute of Technology (ETH) Zurich and University of Tuebingen); Tobler, Samuel (Swiss Federal Institute of Technology (ETH) Zurich); Trninić, Dragan (Swiss Federal Institute of Technology (ETH) Zurich); Formaz, Cléa (Swiss Federal Institute of Technology (ETH) Zurich); Poikonen, Hanna (Swiss Federal Institute of Technology (ETH) Zurich); Kapur, Manu (Swiss Federal Institute of Technology (ETH) Zurich)*

Research indicates that symbolic and nonsymbolic reasoning involves distinct processes, despite both recruiting overlapping networks in the parietal cortex (fMRI), at the same time (250 ms after stimulus onset; ERP). Recent work suggests that symbolic and nonsymbolic processing are segregated by means of different frequency ranges: high gamma (above 50 Hz) over frontocentral regions for symbolic processing, and lower beta (12–17 Hz) over parietal regions for nonsymbolic processing, a finding supporting the existence of functional dissociation in EEG oscillatory dynamics. We tested this hypothesis with more natural and longer-lasting stimuli, namely mathematical demonstrations (essentially, informal proofs). In our EEG-oscillations study, we investigated the differences in beta and high gamma waves between 24 mathematics experts and 24 novices, while they watched mathematical demonstrations in either symbolic (algebraic) or non-symbolic (geometric) formats. In addition, we asked them to rate how well they understood the proof, if they had enough time, and how familiar they were with each of the proofs. Contrary to our expectations, the only significant difference we found was between Experts and Novices in beta waves, but no difference in format (symbolic vs. nonsymbolic). This might be due to the duration and complexity of the mathematical proofs requiring various processes happening simultaneously.

Using Large-scale Educational App Data to Investigate Mathematical Learning Processes

Chair: Camilla Gilmore (1), Lucy Cragg (2)

1: Loughborough University, United Kingdom; 2: University of Nottingham, United Kingdom

Teachers and families increasingly use educational apps to support children's mathematics learning, and this was particularly seen during recent periods of school closures. These apps collect large amounts of data on children's mathematics practice and provide an opportunity to study learning processes outside of the lab. This symposium will present analyses of data on children's mathematical practice collected from online learning platforms. These analyses have implications for theories of mathematical cognition as well as informing the design of effective apps. Presenters will also discuss the practical and methodological challenges and opportunities of working with this type of large-scale data.

Keywords: Educational apps, large-scale data, arithmetic, educational technology

Presentation 1: Error monitoring and processing metrics in a mathematical online learning environment

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de Mooij, Susanne (Birkbeck College, University of London and Radboud University); van der Maas, Han L.J. (University of Amsterdam); Dumontheil, Iroise (Birkbeck College, University of London); Kirkham, Natasha (Birkbeck College, University of London); Raijmakers, Maartje E.J. (University of Amsterdam)*

When answering mathematical questions, students inevitably make mistakes and need to detect and learn from them to improve their performance. Optimal teaching tools would support children by gathering information about the type of errors they make or uncertainties they have, and how they respond to errors, and sharing these with the children. Online learning environments provide the platform to collect frequent intraindividual data that could be used in this way, however little research has focused on developing robust metrics of error processing in these systems. In two studies in independent samples, we investigated new measures of error processing collected in Math Garden, an adaptive learning environment for practising mathematical skills played daily by more than 100,000 primary school students. First, tracking mouse movements was found to be an interesting tool to reveal indirect children's consideration of alternative answers when not many errors are made (N = 1,590, age 5 – 13 years). Second, we found that when making an actual error, children tend to slow down their performance afterwards, also known as post-error slowing (N = 149,747, age 5-13 years). This work highlights how large datasets can be used to provide insight into children's learning of mathematics. The identification of these behavioural markers before, during and after making mistakes will help to optimise support tools for individual learners within learning environments.

Presentation 2: Investigating the types of errors made by children playing an online multiplication production game

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Britton-Drewry, Emily (Loughborough University); Gilmore, Camilla (Loughborough University); Cragg, Lucy (University of Nottingham)*

Fluent access to multiplication facts is an important characteristic of people who achieve well in mathematics. Models of multiplication fact knowledge (e.g. Verguts & Fias, 2005) propose that facts are stored in a network where problems are associated with several possible answers. Examining the types of errors that learners frequently make can tell us more about how this network is structured. However, typical lab studies may only produce low levels of error responses.

This study investigated errors made by children playing Times Tables Rock Stars, an online educational game. In total, 95,071 error responses were analysed from 14,996 children. Data from educational apps generates large real-life datasets that provide new research opportunities but require a different analysis approach than experiments, where data collection is tightly controlled.

Previous research has suggested that operand errors, where the given answer is the correct answer to another problem in the same times table, are frequently made. But it is unknown whether table errors - non-operand errors which are still answers to simple multiplication problems - are more frequent than answers which are not from the multiplication table. We investigated how frequently operand errors were made, compared with matched table errors and matched non-operand, non-table errors.

Operand errors occurred significantly more frequently than table errors and other errors. Table errors were made significantly more frequently than non-operand, non-table errors. These findings align with previous research, add new evidence from real-life large data and inform how we can conceptualise models of multiplication fact retrieval.

Presentation 3: How does Calcularis influence the development of numerical skills in children with Dyscalculia? Analyses of children's interaction within the game

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Chan, Jenny Yun-Chen (Worcester Polytechnic Institute); Santos, Flavia H.* (University College Dublin)*

Prior work has revealed that the ways in which children interact with educational technology games impact their learning outcomes. Calcularis, a computer-based math game, has been found to effectively improve numeracy in Brazilian children with Developmental Dyscalculia. Here, we asked how children's interaction within Calcularis influenced aspects of their numerical development. Using the pretest and posttest numeracy performance and children's progress data within the game (N=23), we examined whether the number of exercises and content areaschildren completed as well as their percent correct responses on the exercises predicted their posttest (1) general numerical cognition as measured by Zareki-R, (2) number sense, number comprehension, number production, and calculation factors as identified by Santos et al. (under review), and (3) numbering, relations, and arithmetic skills as identified by Purpura and Lonigan (2013). First, we found that the three in-game predictors did not predict children's overall posttest numerical performance beyond their pretest and gender. Second, the number of exercises children completed ($\boldsymbol{\beta}$ =.39, BF10=3.69, p=.033) predicted their posttest number production beyond the covariates. Third, the in-game predictors did not predict children’s numbering, relations, or arithmetic skills beyond the covariates. The findings suggest that the positive impacts of Calcularis on numerical performance may be specific to aspects of number production, such as verbal counting, number dictation, and reading numbers. Further, doing more exercises in Calcularis may improve number production among children with Dyscalculia. The findings have implications for using data within educational technologies to inform research and instruction.

Presentation 4: Tracing students' systematic errors in large-scale online multiplication practice

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Savi, Alexander O. (University of Amsterdam); Deonovic, Benjamin E. (ACTNext); Bolsinova, Maria (ACTNext); van der Maas, Han L. J. (University of Amsterdam); Maris, Gunter K. J. (ACTNext)*

Diagnosing students' cognitive processes, such as multiplication strategies, is a major challenge in adapting education to the individual. Systematic errors hold a key to such latent processes, as these may signal students' misconceptions. In this talk, I will discuss the various challenges involved with diagnosing misconceptions, and introduce a new method to identify and trace systematic errors. Serving as a recommendation system, this method provides probability estimates for a student's potential misconceptions. The method is derived from the Ising model originating in physics, and exploits a theoretical mapping between latent misconceptions and manifest errors. I evaluate the performance of different model configurations, using single-digit multiplication data from a large-scale adaptive practice system, and key metrics for recommendation systems. The results show that the Systematic Error Tracing (SET) model outranks a majority vote baseline model when two or more recommendations are considered. Also, for some misconceptions it improves the adaptation of recommendations to individual students. I discuss the opportunities of SET in real-world large-scale learning applications.

Homing in on Measurement: Novel Approaches to Scoring, Measuring, and Conceptualizing the HME

Chair: Lauren Westerberg

Purdue University, United States of America

Exploring different methodologies for measuring families' home mathematics environments (HME) is a critical step for both measurement refinement and understanding how aspects of the HME relate to the development of children's mathematics knowledge. The four studies in this symposium explore different approaches to measurement of the HME. The first study examines different methodologies for scoring a traditional HNE scale. The second and third studies consider various dimensions of the HME (e.g., parental beliefs) and how they relate to parent reported home mathematics activities. The final study examines and compares time diaries as an alternative measure to traditional HME surveys.

Keywords: measurement, home mathematics environment, parental involvement, methods

Presentation 1: Exploring Different Methodologies for Scoring Families' Home Numeracy Engagement

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Westerberg, Lauren (Purdue University); Zippert, Erica L. (Purdue University); Cosso, Maria J. (Purdue University); Schmitt, Sara A. (Purdue University); Purpura, David J. (Purdue University)*

Evidence demonstrates that parent-child numerical interactions in the home (i.e., the home numeracy environment [HNE]) are related to children's mathematical understanding (Daucourt et al., 2020). However, studies have found positive (Skwarchuk et al., 2014), both positive and negative (Blevins-Knabe & Musun-Miller, 1996), and non-significant relations (Missall et al., 2015) between the HNE and children's mathematics performance. Composite scores on HNE surveys are generally used to examine these relations which is problematic because these scores may insufficiently capture nuanced relations (e.g., varied item content) that may differentially promote early mathematics skills. The goal of this study was to examine and compare different mechanisms for scoring families' home numeracy engagement. Participants included 428 3- to 6-year-old children and their parents. Parents were asked to rate the frequency with which they engaged their children in twelve numeracy activities using items adapted from an existing survey (LeFevre et al., 2009). Children's numeracy skills were assessed via The Preschool Early Numeracy Screener—Brief Version (PENS-B; Purpura et al., 2015). Classical test theory, factor analysis, and item response theory were used to generate average, latent, and adjusted (i.e., different point values assigned to items based on item difficulties) scores for parents' responses on the HNE survey and their relations to children's numeracy performance were examined. Findings revealed that the average ($\beta = .11$, $p = .008$), latent ($\beta = .12$, $p = .010$), and adjusted ($\beta = .13$, $p = .002$) scores performed similarly. Refinement and further investigation of differential relations for unique populations is warranted.

Presentation 2: Examining the Relationship Between the Home Math Environment and Child Math Outcomes

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Burrell, Nandrea (Florida State University); Daucourt, Mia (Florida State University); Ganley, Colleen M. (Florida State University); Hart, Sara A. (Florida State University)*

The home math environment (HME) is defined as various math-related activities that parents engage in with their children at home. Through formal and informal numeracy activities, the HME plays an important role in the development of children's foundational math skills. Factors such as family composition, income, and parental beliefs and expectations when it comes to education, are some factors that have been seen to impact the quality of the home math environment provided by parents. We will examine how three different aspects of the HME relate to one another and, after accounting for parent factors such as socioeconomic status and math anxiety, test how these relate to child math anxiety and math skills.

In a sample of 120 7-11-year-old children and their parents, we measured the HME in three different ways: 1) a 17-item traditional parent-report questionnaire of frequency of math activities in the home, 2) a 5-item survey of parents' emotional experience while helping their child with math homework, and 3) a math book checklist, which included a list of 26 math-related children's books to assess familiarity with children's math books. Parents reported on their child's math skills on a scale from 0-100 and reported their child's math anxiety using a parent version of the Math Anxiety Scale for Young Children-Revised. We will use structural equation modeling to examine relations between these three aspects of the HME and child math anxiety and math skills, while covarying out parent factors. Data analysis will be completed before the conference.

Presentation 3: Relations Among Caregivers' Math Engagement Anxiety, Math Attitudes, Math Skills, and Home Mathematics Activities with Preschoolers

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Hornburg, Caroline Byrd (Virginia Tech); Kim, Jisun (Virginia Tech); Begley, Caroline V. (Virginia Tech); McGregor, Casey M. (Virginia Tech); Carrazza, Cristina (NORC at the University of Chicago)*

Caregiver beliefs can influence the structure of the home math environment (Douglas et al., 2021); however, less research has examined caregivers' anxiety when engaging in math activities with their children or caregivers' own numeracy skills (Hornburg et al., 2021). The present study examined caregivers' math attitudes, skills, and frequency of engagement in math activities with their preschoolers (ages 3-5, M=4.17, 53% girls). Seventy-two caregivers (94% mothers; 92% White) completed a home math environment (HME) survey. An 11-item measure of caregivers' math engagement anxiety (e.g., "Doing math activities with my child makes me anxious"), adapted from prior work (Boyd et al., 2014; Carrazza, 2021), exhibited good internal consistency (α=.87). Caregivers' math engagement anxiety was distinct from caregiver math anxiety (r=.43) and other caregiver-specific math attitudes such as competence (r=-.58) and value (r=-.55). Caregivers' subjective numeracy skill (Fagerlin et al., 2007; α=.80) was also significantly related to caregiver-specific math attitudes such as competence (r=.75) and value (r=.59), as well as math engagement anxiety (r=-.44). However, neither caregiver numeracy skill nor caregiver-specific math attitudes were significantly related to the frequency of HME activities caregivers reported. Subsequent analyses (to be completed before the conference) will examine caregivers' descriptions of math engagement with their child given specific scenarios in an effort to measure quality, not just quantity, of HME activities. Future research is needed with more diverse samples to examine the complexity of these relations, including observations of parent-child engagement in HME activities and potential relations to direct assessments of children's math skills.

Presentation 4: Using Time Diaries to Measure the Home Math Environment

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Elliott, Leanne (University of Pittsburgh); Coulanges, Linsah (University of Pittsburgh); Votruba-Drzal, Elizabeth (University of Pittsburgh); Miller, Portia (University of Pittsburgh); Libertus, Melissa (University of Pittsburgh); Bachman, Heather (University of Pittsburgh)*

The home math environment is often measured through parent surveys addressing the frequency of engaging in different activities at home, despite methodological concerns regarding parental biases and memory limitations. Recent calls for research in this area underscore the need for multimethod approaches and more consideration of spatial skills (Hornburg et al., 2021). In this study, we explore an alternative measure based on daily reports of parents' time use. Parents of four-year-olds (N = 95) completed an online survey probing how frequently they engaged in 24 different numeracy and spatial activities with their children over the past month (LeFevre et al., 2010). Once on a weekday and once on a weekend, parents also completed a daily time diary where they indicated whether each of those same 24 activities had occurred on the previous day, which was used to calculate the number of overall math activities as well as numeracy and spatial activities across the two days. At age five, children completed several numeracy and spatial assessments. Math activities reported on the online survey were unrelated to numeracy and spatial skills, whereas activities reported on time diaries predicted numeracy and spatial skills, controlling for math skills at age 4, SES, and age. Furthermore, time diary measures of numeracy activities were significantly related to numeracy but not to spatial skills, whereas measures of spatial activities only significantly predicted spatial skills. Thus, time diary measures may be a more ecologically valid and domain-sensitive measure of children's exposure to math activities at home.

FRIDAY 3 JUNE 2022

List of abstracts
(chronologically in order of the program)

Symposia: 9:00am - 10:30am

Mathematical Words: When Do They Count?

Chair: Jo-Anne LeFevre

Carleton University, Canada

Mathematics involves a range of domain-general and domain-specific skills. In this symposium, presenters will provide evidence about how and when knowledge of mathematical vocabulary (vs. receptive language skills in general) predict individual differences in a range of mathematical outcomes for students in the US, Canada, and Chile. Participants included US preschoolers who were Spanish-English bilinguals, and three different groups of grade 3 students; Spanish-speaking students in Chile, English-speaking students in Canada, and English-speaking US students with math difficulties. Across these diverse groups, the presenters discuss the role of mathematical language in predicting numeracy and word-problem solving performance.

Keywords: mathematical vocabulary, word-problem solving, mathematics difficulty, mathematics language

Presentation 1: The Relation Between Mathematical Language and Numeracy Performance for Spanish-English Dual Language Learners

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Purpura, David J. (Purdue University); Cosso, Jimena (Purdue University); Beltran Grimm, Susie (Purdue University); Schmitt, Sara (Purdue University)*

Mathematical language—children's understanding of mathematical terms and concepts such as more, similar, few—is consistently one of the strongest predictors of children's numeracy skills across development (Purpura & Logan, 2015; Toll & van Luit, 2014; Ünal et al., 2021). However, most of the work on mathematical language has focused on English or Dutch speaking populations. Given that there are differences in mathematical language terms across languages such as English and Spanish (e.g., some terms do not have clear translations across languages; Purpura et al., 2018) and that Spanish speaking are the largest minority group in the U.S. (Lopez et al., 2018), there is a need to replicate findings on the relation between mathematical language and numeracy with Spanish-English dual language learners (DDLs). In this study, sixty-two 3- to 5-year-old Spanish-English DLLs children completed assessments on their mathematical language, numeracy, vocabulary, and cognitive flexibility. Regression analyses predicting numeracy skills were conducted that included mathematical language and vocabulary as independent variables and age, sex, and parent education as covariates.

Results indicated that the independent variables and covariates accounted for a significant proportion of variability in numeracy skills ($R2 = .65$). Notably, the only significant predictors were mathematical language ($\beta = .51$, $p < .001$) and age ($\beta = .33$, $p = .002$). These findings replicate prior findings with English and Dutch speaking populations and suggest that mathematical language is a strong predictor of numeracy performance for

Presentation 2: The Roles of General Cognitive Skills and Domain-Specific Mathematical Language Skills in the Mathematical Performance of Chilean Students in Grade 3

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Susperreguy, Maria Ines (Pontificia Universidad Catolica de Chile); Xu, Chang (Carleton University); Di Lonardo Burr, Sabrina M. (University of British Columbia); Douglas, Heather (Carleton University); LeFevre, Jo-Anne (Carleton University); del Rio, M. Francisca (Universidad Diego Portales de Chile); Salinas, Viviana (Pontifica Universidad Catolia de Chile)*

According to the Pathways to Mathematics model (LeFevre et al., 2010), in the early years of mathematics learning, students' cognitive skills (i.e., language, working memory, quantitative) will predict their concurrent and future mathematics achievement. As they progress through formal schooling, however, students' domain-specific mathematical language knowledge may mediate the relations between cognitive skills and mathematics outcomes. In the present study, we tested these predictions for Spanish-speaking Chilean students in Grade 3 (N = 159; M = 8:11 years, SD = 0:5; 51% girls). Students completed measures of general cognitive skills (i.e., receptive vocabulary, backward digit span, and number comparison), domain-specific mathematical language skills (i.e., mathematical vocabulary and mathematical orthography), mathematical outcomes (i.e., word problems, written calculations, and arithmetic fluency), and a reading outcome (i.e., reading comprehension). Path analyses showed that the three cognitive skills explained a significant proportion of the variance in word problems ($R2 = .36$), written calculations ($R2 = .32$), arithmetic fluency ($R2 = .43$), and reading comprehension ($R2 = .40$). When the domain-specific mathematical language skills were added to the model, they explained additional variance (ranging from 2-7%) in all four outcomes. Moreover, mathematical language skills mediated some of the relations between the cognitive skills and outcomes. Our findings support the Pathways to Mathematics model and further suggest that, although these grade 3 students are acquiring domain-specific mathematical language skills, they also continue to rely on their general cognitive skills to solve mathematical problems.

Presentation 3: Relations Between Mathematical Vocabulary and Mathematical Performance for English-speaking Canadian Students in Grade 3

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Song, Charlene Shujie (Carleton University); Douglas, Heather (Carleton University); Skwarchuk, Sheri-Lynn (University of Winnipeg); Xu, Chang (Carleton University); Osana, Helena P. (Concordia University); Simms, Victoria (Ulster University); Wylie, Judith (Queen's University of Belfast); Lafay, Anne (Université Savoie Mont Blanc); Maloney, Erin A. (University of Ottawa); LeFevre, Jo-Anne (Carleton University)*

Mathematical vocabulary comprises terms that have mathematical meanings and which people use to communicate mathematical concepts (e.g., large, digit, circle, equal sign). Students' general vocabulary and their mathematical vocabulary are both correlated with their mathematical skills. We asked whether mathematical vocabulary fully or partially mediates the relation between general vocabulary and mathematical performance. Canadian students in grade 3 (N = 234, mean age = 8.67 years) completed measures of general and mathematical vocabulary and several different mathematical outcomes (i.e., arithmetic fluency, pre-algebra, and word-problem solving). Students were either learning mathematics in English or in French; the latter group were in immersion schools and thus had English as their first language. We expect that students' mathematical vocabulary will partially mediate the relation between general vocabulary and mathematical skills after controlling the immersion status and mother's education level; and second, that students' domain-general cognitive skills (e.g., working memory, nonverbal reasoning) will partially mediate the relation between mathematical vocabulary and mathematical skills. These analyses will provide information about how individual differences in domain-specific and domain-general skills are related to students' mathematical performance.

Presentation 4: Language Predictors of Word-Problem Performance Among Grade 3 Students With Mathematics Difficulties

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Lariviere, Danielle O. (University of Texas at Austin); Powell, Sarah R. (University of Texas at Austin); Fall, Anna-Maria (University of Texas at Austin); Roberts, Greg (University of Texas at Austin)*

Word-problem solving is a critical component of students' mathematics proficiency. Students employ a multitude of language skills to solve word problems, including word reading, vocabulary knowledge, and reading comprehension. Applying language skills to word-problem solving can present a significant challenge to students, particularly among those who experience difficulty with mathematics (Powell et al., 2019). For instance, students may encounter difficulties differentiating a vocabulary term's use in a generalized context from its meaning in a mathematics-specific context (e.g., the foot of a bed vs. a foot as 12 inches; Riccomini et al., 2015). In this study, we examined how both generalized and mathematics-specific language skills predicted the word-problem performance of students with mathematics difficulties. Participants included 325 Grade 3 (ages 8–9) students in the southwestern United States who all performed below the 25th percentile on a word-problem measure. We assessed students' generalized language skills in word reading, sight word efficiency, generalized vocabulary knowledge, and passage comprehension. Additionally, we measured students' mathematics-specific vocabulary knowledge. We utilized unconditional quantile regression to examine the differential predictive capacity of each of these skillsets on students' word-problem performance. Results revealed that mathematics vocabulary knowledge significantly predicted students' word-problem performance at all quantiles ($p < .01$), with strongest predictive capacity at the highest quantiles. In contrast, students' generalized language skills did not demonstrate significant predictive capacity for word-problem performance. Given the unique relationship between mathematics vocabulary knowledge and word-problem solving, educators should prioritize assessing and explicitly teaching mathematics vocabulary to improve students' word-problem solving skills.

Similar Mathematics Anxiety Levels, Different Outcome Effects in Different Domains

Chair: Krzysztof Cipora, Iro Xenidou-Dervou

Loughborough University, United Kingdom

Mathematics Anxiety (MA) has been consistently shown to affect mathematics performance and various decisions individuals make regarding their engagement with mathematics-related activities, including how they support their children in learning mathematics. However, a growing body of evidence shows that the link between MA and those outcome variables is not as straightforward as it was initially believed. In this symposium, we wish to bring together studies which demonstrate that MA alone is not sufficient to explain these effects and highlight that amore fine-grained approach is needed.

Keywords: Mathematics anxiety, anxiety, individual differences

Presentation 1: Emotions and mathematics: Anxiety profiles and their influence on arithmetic performance

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Rossi, Serena (Loughborough University); Xenidou-Dervou, Iro (Loughborough University); Cipora, Krzysztof (Loughborough University)*

Beyond Mathematics Anxiety (MA) (Barroso et al., 2021), other forms of anxiety, such as General (GA) and Test Anxiety (TA) seem to play a role in mathematics performance. However, it is unclear how the simultaneous presence of different forms of anxiety influences the relationship between MA and mathematics performance. Also, to the best of our knowledge, studies that have categorized participants based on their level of different types of anxiety and investigated the influence of each anxiety profile on mathematics performance have so far only been conducted with children (Carey et al., 2017; Mammarella et al., 2018).

This study uses Latent Profile Analysis (LPA) to examine whether distinct individual profiles based on the level of different forms of anxiety can be identified in adulthood and specifically in UK university students, and if the pattern of results is similar to those found in children. Furthermore, we investigate whether these profile groups perform differently in an arithmetic task, and a non-mathematics task (grammatical reasoning task), as well as whether the profile groups differ in neuroticism, state anxiety, and positive aspects/beliefs, such as mathematics self-concept and mathematics self-efficacy. Outcomes will provide an additional tool for identifying students in need of anxiety interventions, and for creating interventions more tailored to individuals' unique profiles and specific types of anxiety. Results will be discussed in light of the existing literature by considering potential practical implications.

Presentation 2: Too anxious to be confident?: Mathematics anxiety, metacognition and executive functions in arithmetic achievement

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Bellon, Elien (KU Leuven); Fias, Wim (Ghent University); De Smedt, Bert (KU Leuven)*

Mathematics anxiety, metacognitive monitoring and executive functions have been identified as associated with or predictive of individual differences in arithmetic in primary school children. Although there are various theoretical reasons for an association between these variables, on the empirical level, it is unclear how they are interrelated and whether their interrelation impacts their respective associations with arithmetic achievement. The current longitudinal panel study investigated the interplay of mathematics anxiety with metacognitive monitoring and executive functions in 127 typically developing 7-8-year-olds (second grade) and followed them up one year later (in third grade). To measure mathematics anxiety, we adapted the mathematics anxiety questionnaire developed by Suinn and Edwards (1982). Metacognitive monitoring was measured within an arithmetic task, by asking children on a trial-by-trial basis to report their confidence in the accuracy of their answer on the arithmetic item. Different aspects of executive functioning were measured with tasks that tap into inhibition, shifting and updating skills. Our results indicate that, at different ages, there are different interrelations between mathematics anxiety, monitoring and executive functioning, and a differential impact of the interrelations on their respective associations with and predictive value for arithmetic. These findings, their relevance and their implications will be discussed.

Presentation 3: Replication and extension of the factor structure of parents' math anxiety

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Cosso, Jimena (Purdue University); Ellis, Alexa (Purdue University); O' Rear, Connor (Purdue University); Purpura, David (Purdue University)*

Most of the work investigating parents' math anxiety has considered it as a unidimensional. One recent study with preschool children and their parents (N = 155), found that the best fitting model of parents' math anxiety was a bifactor model (Cosso et al., 2021). This model had a general factor representing parents' math anxiety, and two orthogonal-specific factors, one representing parents' math anxiety when engaging in mathematics on their own and the other representing anxiety when engaging in mathematics with their child. The goal of this study was to replicate these findings in a larger sample (N=842) and extend these results to examine whether parents' math anxiety is related to their home mathematical environment (HME) activities. Parents' math anxiety was assessed as part of a larger study about the general home learning environment conducted on Prolific. The replication suggested that both the two-factor model and a bifactor model adequately fit the data. The more parsimonious two-factor model was used to examine the relation between parents' math anxiety and HME activities. After controlling for child age, child gender, parent education, parent relation, and household income, neither the factor of parents' anxiety when engaging themselves in mathematics ($r = -.04$, $p = .29$), nor the factor of parents' math anxiety when engaging with their children in math ($r = -.03$, $p = .43$) was significantly related to their HME activities. The multidimensionality of parents' math anxiety, and the relation to HME activities will be discussed.

Presentation 4: Parent's math homework helping style partially mediates the effect of parents' MA on their childrens' mathematics performance

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Retanal, Fraulein (University of Ottawa); Johnston, Nicole B. (University of Ottawa); Di Lonardo Burr, Sabrina M. (University of British Columbia); Storozuk, Andie (University of Ottawa); Di Stefano, Michaela (University of Ottawa); Maloney, Erin A. (University of Ottawa)*

Previous research has shown that math homework help of higher-math-anxious parents impedes children's math learning and facilitates the development of math anxiety (Maloney et al., 2015). In the present study, we explored a possible explanation for this phenomenon by examining the relations between parents' math anxiety, their math homework-helping styles (i.e., autonomy- and controlling-supportive), and their child's math achievement. Parents of children ages 11 to 14 completed an online survey. Using path analysis, we examined the relations among parental factors (i.e., math anxiety, math ability, and homework-helping styles) and child math achievement. Parents' math anxiety was positively related to both autonomy-supportive and controlling-supportive math homework-helping styles. Notably, controlling-supportive style partially mediated the relation between parents' math anxiety and their children's math achievement. Thus, it is possible that the use of a controlling-supportive math homework-helping style may explain why the homework help offered by higher-math-anxious parents is detrimental to their children's math learning. Identifying negative relations between parent factors and children's math outcomes is crucial for developing evidence-based math learning interventions.

Arithmetic Fluency and Fact Retrieval: Typical and Atypical Processing Patterns

Chair: Elise Klein (1), Liane Kaufmann (2)

1: CNRS, LaPsyDÉ, Université de Paris, Paris Sorbonne Cité, Paris, France; 2: Department of Psychology, University of Innsbruck, Austria

Arithmetic fluency, the ability to quickly and effortlessly solve simple arithmetic problems (e.g., 2+3), is foundational for learning mathematics and mathematical skills. It has been suggested that arithmetic fluency may be either achieved through increasing reliance on arithmetic fact retrieval or through automatization of procedures that have been repeatedly practiced, such as counting. In this symposium, Elise Klein (Paris), an expert on the neurofunctional correlates of arithmetic fact learning/retrieval and Liane Kaufmann (Innsbruck), an expert on typical/atypical arithmetic fluency, will guide through talks addressing these issues, from how arithmetic fluency can be measured to neurocognitive patterns of typical/atypical fact retrieval.

Keywords: Arithmetic fluency, arithmetic fact retrieval, dyscalculia, acalculia

Presentation 1: Introducing the Math-4 Speed – a normed speeded test of arithmetic fluency

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Nuerk, Hans-Christoph (Brain and Number Group Tuebingen, University of Tuebingen, Tuebingen, Germany); Loenneker, Hannah (Brain and Number Group Tuebingen, University of Tuebingen, Tuebingen, Germany); Huber, Julia (Brain and Number Group Tuebingen, University of Tuebingen, Tuebingen, Germany); Artemenko, Christina (Brain and Number Group Tuebingen, University of Tuebingen, Tuebingen, Germany); Cipora, Krzysztof (Mathematics Education Centre, Loughborough University, Loughborough, United Kingdom)*

A large range of measures evaluating arithmetic fluency is currently used, differing in definitions and operationalizations of the underlying construct. Therefore, we introduce the Math-4 Speed, assessing performance in the four basic operations graded by difficulty (addition: carry/ non-carry, subtraction: borrow/ non-borrow, multiplication: 2-/ 1-digit operands, division: 2-/ 1-digit results). We administered this paper-and-pencil test to a sample of young neurotypical adults (n = 131 English, n = 134 German, n = 102 Polish, and n = 61 Belgian).

We provide norms and criterion validity measures for subscales (4 operations x 2 difficulties) and an overall score. Regarding the construct of arithmetic, associations of addition with subtraction and multiplication with division were the highest. Concerning convergent validity: correlations of Math-4 Speed and elementary number processing were higher for processing 2-digit than 1-digit numbers. Descriptively, magnitude comparison was stronger related to Math-4 Speed than different types of parity judgments. Self-reported math grade, math anxiety, and non-verbal intelligence were stronger related to performance in complex items, indicating the necessity to cover a range of item difficulties. None/very weak correlations of Math-4 Speed to self-reported language grades provided evidence for discriminant validity. Differences between cultures in overall performance (Polish > German > English > Belgian) and genders (male > female) for subtraction and division were adapted in our norms.

The Math-4 Speed will be openly available to provide a speeded arithmetic fluency test, which can quickly be employed by researchers to control for math performance in adult samples from different cultural backgrounds.

Presentation 2: Impaired arithmetic fact retrieval in an adult with developmental dyscalculia: Evidence from behavioral and functional brain imaging data

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Goebel, Silke M. (Department of Psychology, University of York, York, United Kingdom); Klein, Elise (CNRS, LaPsyDÉ, Université de Paris, Paris Sorbonne Cité, Paris, France); Terry, Rebecca (Department of Psychology, University of York, York, United Kingdom); Hymers, Mark (York Neuroimaging Centre and York Biomedical Research Institute, University of York, U.K); Kaufmann, Liane (Department of Psychology, University of Innsbruck, Austria)*

Developmental dyscalculia (DD) is a developmental disorder characterised by arithmetic difficulties. Recently, it has been suggested that the neural networks supporting procedure-based calculation (e.g., in subtraction) and left-hemispheric verbal arithmetic fact retrieval (e.g., in multiplication) are partially distinct.

Here we compared the neurofunctional correlates of subtraction and multiplication in a 19-year-old student (RM) with DD to 18 age-matched controls. Behaviorally, RM performed significantly worse than controls in multiplication, while subtraction was unaffected. Neurofunctional differences were most pronounced regarding multiplication: RM showed significantly stronger activation than controls not only in left angular gyrus but also in a fronto-parietal network (including left intraparietal sulcus and inferior frontal gyrus) typically activated during procedure-based calculation. Region-of-interest analyses indicated group differences in multiplication only, which -however– did not survive correction for multiple comparisons.

Our results are consistent with dissociable and processing-specific neurofunctional networks. Procedure-based calculation is not only associated with subtraction but also with (untrained) multiplication facts. Only after rote learning, facts can be retrieved quasi automatically from the retrieval network. We suggest that this learning process and the associated shift in activation patterns has not fully occured in RM, as reflected by her need to resort to procedure-based strategies to solve multiplication facts.

Presentation 3: Left angular gyrus disconnection impairs multiplication fact retrieval

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Smaczny, Stefan (Centre of Neurology, Division of Neuropsychology, Hertie-Institute for Clinical Brain Research, University of Tuebingen, Tuebingen, Germany); Sperber, Christoph (Centre of Neurology, Division of Neuropsychology, Hertie-Institute for Clinical Brain Research, University of Tuebingen, Tuebingen, Germany); Jung, Stefanie (Leibniz-Institut fuer Wissensmedien Tuebingen, Tuebingen, Germany); Moeller, Korbinian (Mathematics Education Centre, Loughborough University, Loughborough, United Kingdom); Karnath, Hans-Otto (Centre of Neurology, Division of Neuropsychology, Hertie-Institute for Clinical Brain Research, University of Tuebingen, Tuebingen, Germany); Klein, Elise (CNRS, LaPsyDÉ, Université de Paris, Paris Sorbonne Cité, Paris, France)*

Arithmetic fact retrieval has been suggested to recruit a left-lateralized network comprising perisylvian language areas, parietal areas such as the angular gyrus (AG), and subcortical structures such as the hippocampus. However, the underlying white matter connectivity of these areas has not been evaluated systematically so far.

Using simple multiplication problems, we evaluated how disconnections in parietal brain areas affected arithmetic fact retrieval following stroke. We derived disconnectivity measures by jointly considering data from n=73 patients with acute unilateral lesions in either hemisphere and a white-matter tractography atlas (HCP-842) using the Lesion Quantification Toolbox (LQT). Whole-brain voxel-based analysis indicated a left-hemispheric cluster of white matter fibers connecting the AG and superior temporal areas to be associated with a fact retrieval deficit. Subsequent analyses of direct grey-to-grey matter disconnections revealed that disconnections of additional left-hemispheric areas (e.g., between the superior temporal gyrus and parietal areas) were significantly associated with the observed fact retrieval deficit.

Results imply that disconnections of parietal areas (i.e., the AG) with language-related areas (i.e., superior and middle temporal gyri) seem specifically detrimental to arithmetic fact retrieval. This suggests that arithmetic fact retrieval recruits a widespread left-hemispheric network and emphasizes the relevance of white matter connectivity for number processing.

Presentation 4: Patterns of sustained attention and anxiety in predicting school-aged children's arithmetic fluency

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Orbach, Lars (Department of Psychology, Federal University Minas Gerais, Belo Horizonte, Brazil); Fritz, Annemarie (Department of Psychology, University Duisburg-Essen, Duisburg, Germany)*

Although the interaction between anxiety and attention is considered crucial for learning and performance in mathematics, less studies have examined these cognitive and affective predictors in one framework and explored the role of sustained attention in promoting children's arithmetic performance, using traditional linear analyses and latent profile analysis (LPA). In this paper, state anxieties (in a math test and in an attention test situation), general anxiety traits, sustained attention (performance-based test and ADHD self-ratings) and math achievement of 403 fourth and fifth graders (55.8% girls) are assessed. A negative correlation between state anxiety prior to the math test and arithmetic performances was identified, even when controlling for other non-math related state anxieties and general anxiety. Sustained attention was a strong predictor of arithmetic performance and functioned as moderator in the anxiety-performance link. LPA identified six distinct profiles that revealed complex relations with arithmetic fluency. The weakest performances were found for a specific math anxiety subgroup. The findings highlight the important role of the interplay between anxiety and sustained attention in children's ability to perform math and allow new conclusions about the specific nature of math anxiety. Implications for future research are discussed.

Evolutive Changes in Numerical Cognition and Cross-cultural Differences

Chair: Avishai Henik

Ben-Gurion University of the Negev Beer-Sheva, Israel

Abilities related to numerical cognition change throughout the life cycle.

In this symposium we dicuss some changes in numerical cognition that occur due to ontogenetic development, as well as differences related to cultural context.

Specifically, we present the evolutive development of the ability to integrate spatial and numerical information, as well as the development of math fluency in relation to verbal fluency. We also present a cross-cultural comparison of symbolic and finger-based number representations on Magnitude, Distance and SNARC effects, and neural bases of number and hand action interactions.

Keywords: Numerical cognition, Development, Math Fluency, Magnitude processing, Finger counting

Presentation 1: Math Fluency During Life: Evidence from Primary School, Young Adults and Old Adults

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Gliksman, Yarden (Ruppin Academic Center, Emek Hefer, Israel)*

Math fluency is the ability to answer quickly and accurately on known math exercises (math facts). This ability is important for academic achievements and in everyday life. Recently, we developed the BGU-MF (Ben-Gurion University Math Fluency) test, a 3-minutes computerized tool to assess math fluency. Participants are presented with arithmetic exercises and asked to type in their answers. BGU-MF provides measures of number of solved items, accuracy rates and response times (RT) per exercise and per operation (addition, subtraction, multiplication, and division). In the current work I examined the performance of math fluency among children in primary school (6-11 years old), young adults (23-26 years old) and old adults (68-72 years old). Performance of math fluency improved in all measures from primary school to young adults. Performance decreases in older adults in measures of number of exercise and RTs but remains stable in accuracy rates. Old adults presented similar performance to six grade students in measure of number of exercise, but presented better performance in the other measures. Importantly, proficiency of math fluency differed by operations, and automaticity of math facts was acquired in different grades. Addition exercises reached high performance early in primary school (third grade), and was the most reserved operation among old adults. Division exercise did not reach automaticity in accuracy rates and RTs in primary school, and were the slowest RT for operation in old adults. The results can shed light on the developmental trajectory of arithmetic abilities during life.

Presentation 2: The ability to integrate spatial and numerical quantitative information in children and young adults: a cross-sectional study

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García-Sanz, Sara (Universidad de La Sabana. Colombia); Arévalo Jaimes, Yesenia (Universidad de La Sabana. Colombia); Muñoz Aguilar, Nicolas (Universidad de La Sabana. Colombia)*

There is currently an intense debate on whether numbers are processed using a number specific system or a general magnitude processing system, shared with other non-numerical magnitudes such as size, length, or duration. There are many studies that analyze how these magnitudes interfere with number processing, but the specific ability to convert and integrate spatial and numerical quantitative information has hardly been addressed.

In this cross-sectional study, we analyzed the ability to integrate spatial and numerical information in three age groups: 7-year-old, 12-year-old and 20-year-old.

For this purpose, we used seven computerized magnitude comparison tasks: three numerical comparison tasks (pure symbolic, pure non-symbolic and mixed-format), two spatial comparison tasks (comparing continuous areas of both regular and irregular-shaped areas), and two spatial-numerical tasks. The spatial-numerical tasks were a comparison between continuous and discrete areas (also for both options regular and irregular shapes). On one side of the screen a continuous area is presented, and on the other side a number of discrete areas are presented. Participants must decide which of the two has a greater total surface area. These tasks require integrating numerical quantitative information (number of elements) and spatial quantitative information (size).

We currently analyze data of 96 participants we collected. For each of the tasks, the relationship between the ratio and the accuracy will be analyzed (following Leibovich (2017) we use 8 different ratios). Then, the results of the three age groups will be compared.

Presentation 3: Embodied numbers and numerical hands: A cross-cultural comparison of symbolic and finger-based number representations

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Felisatti, Arianna (Department of Psychology, University of Potsdam, Potsdam, Germany); Li, Xin (Department of Psychology, University of Potsdam, Potsdam, Germany); Fischer, Martin H. (Department of Psychology, University of Potsdam, Potsdam, Germany)*

Fingers support the acquisition of numeracy skills and contribute to the construction of the mental-number-line [1]. While finger counting is spontaneous and universal, counting habits reflect learning and culture: Western cultures use a sub-base-five system, requiring a full hand to express numbers larger than "5"; instead, Chinese culture adopts a partially symbolic system, involving only one hand to reproduce numbers larger than "5" [2]. So far, the influence of the finger-based representation on basic signatures of numerical cognition has been documented only within the Chinese culture [3]. This study aims to directly compare the differential impact of finger-based and symbolic number representations on number processing, in Western and Chinese cultures.

46 German and 44 Chinese adults performed two versions of the Magnitude classification task: Numerical magnitudes were presented as Arabic digits (Digit-magnitude classification) or as finger configurations, consistent with cultural finger-counting habits (Finger-magnitude classification).

Participants judged whether a target numerical value was smaller or larger than “5” by pressing one of two horizontally aligned response buttons.

The results revealed that: 1) The advantage for small numbers (Magnitude effect) was stronger with finger configurations, especially for Chinese participants; 2) the advantage for numbers far from the reference (Distance effect) was stronger with finger configurations in both cultures; 3) the association between left/right side and small/large numbers (SNARC effect) was stable across representations and populations.

Our study documents the differential contributions of embodied and symbolic number representations to signatures of numerical cognition and the mediating role of cultural finger-counting habits.

Presentation 4: Symbolic number, hand reach and grasp: common and number-specific brain areas

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Ranzini, Mariagrazia(University of Padua, Italy); Radua, Joaquim (IDIBAPS, Barcelona); Cutini, Simone (University of Padua, Italy); Semenza, Carlo (University of Padua, Italy); Zorzi, Marco (University of Padua, Italy); Scarpazza, Cristina (University of Padua, Italy)*

A large body of empirical evidence supports the idea that the mental processing of number recruits mechanisms involved in planning and executing hand actions, in line with embodied cognition theories. In a recent study we investigated the brain networks common to symbolic number comparison and to the hand action of reach and grasp by means of a meta-analytic approach (seed-based d mapping with permutation of subject images meta-analytic method: SDM-PSI). We analysed 42 studies on symbolic number comparison and 58 studies on hand reach and grasp actions. We found that symbolic number comparison, and reach and grasp actions shared cerebral regions within a fronto-parietal brain network, specifically within the parietal lobes bilaterally, the left precentral gyrus, and the supplementary motor area. These findings strongly support the view that number processing is embodied in action-based mechanisms. However, it has also been suggested that number processes and the motor system specialize and differentiate between each other during lifespan. Considering this, we re-analysed the data from our meta-analysis to investigate the existence of brain areas involved in number processing outside the reach and grasp networks. The analysis contrasting the number and the grasp network revealed a number-specific involvement of a region within the left superior parietal gyrus, while the analysis contrasting the number and the reach network revealed small number-specific areas within the right supramarginal gyrus and the right inferior frontal gyrus. These results will be discussed considering inter-individual variability in number-action interactions, and the potential role of expertise.

Symposia: 11:00am - 12:30pm

Neurodivergent Perspectives on Mathematical Cognition

Chair: Emily K. Farran

University of Surrey, United Kingdom

This symposium explores mathematical cognition and developmental changes in four neurodivergent groups. The research identifies patterns of mathematical cognition in people with autism, Down syndrome, Williams syndrome, and adolescents born very preterm. The first three presentations focus on people with autism, Down syndrome, and very preterm adolescents, incorporating a range of domain-specific and domain-general factors. The final presentation focusses on the perspectives of parents and teachers who support people with Down syndrome and Williams syndrome. Together, these findings contribute to a wider discussion about differing needs identified in neurodivergent individuals, and how to maximise the impact of interventions and support.

Keywords: Autism, Down syndrome, Williams Syndrome, Preterm

Presentation 1: Variability and development of mathematical abilities in the autistic population

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Ranzato, Erica (UCL Institute of Education); Van Herwegen, Jo (UCL Institute of Education)*

Although the number of studies focusing on general academic achievement in the autistic population is increasing, there is fragmented and conflicting findings on mathematical abilities in this population and its comparison with the typically developing (TD) population (e.g., Dowker, 2020). Moreover, very few studies have applied a developmental approach to investigate the distinct contribution of domain-specific abilities to mathematical skills at different stages of development in the autistic population.

In this study we examined whether symbolic and non-symbolic domain-specific abilities are related to overall mathematical skills in autistic children as well as the individual differences within these abilities, such as gender differences. Symbolic abilities were measured by means of verbal counting and digit recognition, non-symbolic abilities were measured by means of the non-symbolic ANS task, and the overall mathematical skills were assessed using the Numerical Operations sub-test from the Wechsler Individual Achievement Test.

Cross-sectional data from 40 autistic participants aged 5 to 18 years (20 males, 20 females) and 40 TD participants matched for mental age (MA, N=20) and chronological age (CA, N=20) were analysed. Preliminary mixed ANOVA analyses showed a significant difference between the groups in overall mathematical skills, with the autistic group performing significantly below the CA group. However, no significant differences for the three groups were found for the symbolic abilities, while the autistic group performed significantly below both groups for the non-symbolic task. The impact of individual differences and further implications of the findings will be discussed.

Presentation 2: Exploring relative strengths in Down syndrome: Spatial thinking and its role in mathematics

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Morris, Su (University of Surrey); Farran, Emily K. (University of Surrey); Gilligan-Lee, Katie A. (University of Surrey)*

There is convincing evidence that mathematics outcomes can be improved through training spatial abilities in typically developing (TD) children (Hawes, Gilligan-Lee & Mix, 2022). However, at present, a lack of information on mathematical development and spatial-mathematics associations in people with Down syndrome (DS) hinders the translation of these interventions. Here, we compare profiles of mathematics ability, establish developmental trajectories of mathematics, and explore whether spatial ability predicts attainment on different mathematics measures. Participants with DS (N=36; 10-35 years) and TD children (N=131; 4-11 years) completed spatial tasks assessing different sub-domains of spatial thinking, mathematics tasks assessing early mathematics skills, mathematical reasoning, arithmetic, and geometry, and IQ tasks.

The profile of mathematics performance was largely similar for the DS and mental-age matched TD groups. For all three mathematics measures, developmental trajectories revealed similar developmental onset and similar rates of development for DS and TD groups. After controlling for verbal skills, spatial skills explained between 5.8% and 18.1% of the variation in mathematical performance across different mathematics tasks, and the pattern of spatial-mathematics relations was similar for DS and mental-age matched TD groups. This shows that mathematical development in DS groups appears to mirror that of mental-age matched TDs. However, what is unknown is why this development appears to hit a ceiling. Strong spatial-mathematics relations were observed for the DS group, similar to those seen for TD participants. This is the vital knowledge needed to support the use of spatial intervention for improving mathematics in individuals with DS.

Presentation 3: Understanding number line estimation in very preterm born adolescents

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Simms, Victoria (Ulster University); Clayton, Sarah (Oxford University); Cragg, Lucy (University of Nottingham); Gilmore, Camilla (Loughborough University); Jones, Samantha (University of Leicester)*

Previous literature has consistently identified a significant relationship between number line estimation (NLE) skills and broader mathematical attainment, with multiple explanations as to why this association may exist (Schneider et al., 2018). One potential reason is that NLE task completion may rely on similar cognitive skills as more complex mathematics tasks. Participants who struggle with mathematics also may have particular difficulties in NLE (e.g. van't Noordende, et al., 2016). In recent work, Simms et al. (2020) established differing patterns of predictors of NLE skills for individuals with Down Syndrome (i.e. visuo-spatial skills) and those with Williams Syndrome (i.e. number familiarity), indicating that different populations may rely on varied skills to complete the task.

The current study aims to replicate the previous paper with adolescents born very preterm (<32 weeks' gestation). Adolescents (very preterm, N=127; term born, N=94) completed a 0-1000 NLE task along with a battery of domain-general and domain-specific skills assessments. Very preterm adolescents displayed significantly poorer NLE performance than the term born adolescents, $t(220)= -2.63$, $p= .009$. Linear regression analyses indicated that visual-spatial processing, visual-spatial working memory, and verbal working memory skills were unique predictors of very preterm adolescents' NLE performance (R2= .25, p<.001). For term-born adolescents, working memory was the only unique predictor of NLE performance (R2= .21, p<.001). These data will be discussed in the context of the debate around the approaches that different populations take when completing this task and explanations for the relationship between NLE and mathematics attainment.

Presentation 4: Teaching mathematics to children with Down syndrome and children with Williams syndrome: Parent and teacher views

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Taiwo, Unta (UCL Institute of Education); Thomas, Michael S. C. (Birkbeck, University of London); Simms, Victoria (Ulster University); Van Herwegen, Jo (UCL Institute of Education)*

Mathematical interventions to support children with Down syndrome (DS) and those with William syndrome (WS) are scarce. Little is known about teaching practices used in the school and home setting to support mathematical development for both populations (Ranzato et al., 2021). The current study is the first to triangulate the views of parents and teachers using a mixed-methods research design firstly to obtain a better understanding of the current practices used by teachers and parents to support mathematical abilities of children with DS and WS aged 5-11 years, and secondly to explore the teaching needs of those who support them.

Parents and teachers of children with DS and WS will participate in an online survey in March 2022. This survey will investigate participant views on the strengths and difficulties in mathematical abilities for those with DS and WS, along with issues relating to teaching approaches, strategies and interventions, homework and resources. This study will further examine the expectations of parents and teachers regarding progress in maths for individual children, and levels of confidence to support mathematical learning in primary school-aged children. In follow-up focus group, parents and teachers will discuss specific interventions, and elaborate on barriers and facilitators for implementing maths interventions in the home or school setting. Both quantitative and qualitative methods will be used to analyse findings from the survey and focus group. Preliminary findings from this study and how they can inform the future design of mathematical interventions for children with DS and WS will be discussed.

FMRI of Numerical Responses in the Human Brain

Chair: Ben Harvey

Utrecht University, The Netherlands

Neural responses to numerosity and symbolic numbers are an important basis for mathematical cognition. Over the last 15 years, increasingly advanced functional MRI methods have been used to characterise these numerical responses in the human brain. This symposium will bring together experts in fMRI of numerical responses to present recent results that address longstanding questions for mathematical cognition. How is numerosity estimated from visual images? How are responses to numerosity and symbolic numbers related? How does the brain represent mathematical calculations and their results? This will give an integrated overview of the biological basis of humans' unique mathematical cognition.

Keywords: fMRI, numerosity, symbolic numbers, neuroscience

Presentation 1: Numerosity tuning in human association cortices and local image contrast representations in early visual cortex

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Paul, Jacob (Melbourne School of Psychological Sciences, University of Melbourne, Australia); van Ackooij, Martijn (Department of Experimental Psychology, Helmholtz Institute, Utrecht University, Netherlands); Harvey, Ben (Department of Experimental Psychology, Helmholtz Institute, Utrecht University, Netherlands)*

Humans and many animals perceive visual numerosity (object number) and neurons showing numerosity-tuned responses have been found in several species. However, it remains unclear how the brain estimates numerosity from visual images while disregarding object size and spacing. Recent results show that human early visual cortex responses monotonically increase following numerosity, regardless of object size or spacing. This is surprising because numerosity is typically considered a high-level visual or cognitive feature while early visual responses are normally thought to follow image contrast in the spatial frequency domain. We therefore asked whether these early visual responses could be explained by the spatial frequency content of numerosity displays. We found that aggregate Fourier power (contrast at all orientations and spatial frequencies) followed numerosity closely but nonlinearly, with little effect of object size, spacing or shape. This would allow straightforward numerosity estimation from spatial frequency domain image representations. Using 7 Tesla fMRI, we showed monotonic responses originate in primary visual cortex (V1) at the stimulus's retinotopic location. Responses here and in neural network models followed aggregate Fourier power more closely than numerosity. Truly numerosity tuned responses emerged after lateral occipital cortex and were independent of retinotopic location. We propose numerosity's straightforward perception and evolutionarily preserved neural responses may result from the pervasive spatial frequency analyses in early visual processing throughout the animal kingdom.

Presentation 2: Linking numerosity selective responses to natural images and symbolic numbers

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Hofstetter, Shir (Spinoza Centre for Neuroimaging, Netherlands Institute for Neuroscience, Amsterdam, Netherlands); Cai, Yuxuan (Spinoza Centre for Neuroimaging, Netherlands Institute for Neuroscience, Amsterdam, Netherlands); Dumoulin, Serge (Spinoza Centre for Neuroimaging, Netherlands Institute for Neuroscience, Amsterdam, Netherlands)*

Numerosity is the number of items in a scene and thought to underlie our mathematical abilities. Virtually all studies investigating numerosity use well-controlled artificial stimuli typically consisting of dots in order to remove sensory confounds that go along with changes in numerosity. Here we challenge the ecological validity of the numerosity stimuli and findings. An important development in studying numerosity perception was the discovery of numerosity-selective neurons in animals and humans. Imaging studies in humans showed that the populations of numerosity-selective neurons are organized in a network of topographic maps. First, we evaluate whether numerosity-tuned neurons also respond to the items contained in natural scenes. The results of the first study provide evidence that the numerosity-tuned neural populations show numerosity-selective responses when viewing images from a real visual scene. These findings provide an important link between numerosity selective neurons and their role in perception of numerosity in real world settings. Second, we queried a longstanding debate on whether numerosity and symbolic numbers are represented in a common abstract coding scheme, using a symbolic number experiment and a number-detection task. We found that out of the network of topographic numerosity maps, only the maps at the temporal-occipital cortex (NTO) also respond to symbolic numbers. These findings show the numerosity maps respond to numerosity in real world scenes and support the suggested link between non-symbolic numerosity and symbolic numerical processing.

Presentation 3: On the impact of expertise, format, and modality the representation of number in the intraparietal sulcus of sighted Braille readers

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Knops, André (Laboratory for the Psychology of Child Development and Education, University of Paris, Paris, France); Rączy, Katarzyna (Institute of Psychology, Jagiellonian University, Krakow, Poland); Szewczyk, Jakub (Institute of Psychology, Jagiellonian University, Krakow, Poland); Paplińska, Małgorzata (Maria Grzegorzewska University, Warsaw, Poland); Jednoróg, Katarzyna (Laboratory of Language Neurobiology, Nencki Institute of Experimental Biology, Polish Academy of Sciences, Warsaw, Poland); Marchewka, Artur (Laboratory of Brain Imaging, Nencki Institute of Experimental Biology, Polish Academy of Sciences, Warsaw, Poland); Guido Hesselmann, Guido (Institute of Psychology, Jagiellonian University, Krakow, Poland); Szwed, Marcin (Institute of Psychology, Jagiellonian University, Krakow, Poland)*

The Triple-Code Model stipulates that numerical information from different formats and modalities converges on a common magnitude representation in the Intraparietal Sulcus (IPS). It remains unsolved to what extent the representations for all numerosity forms overlap. Some argue that the representation of symbolic numerosities (for example, Arabic digits) is sparser and is grounded in an existing representation that codes for non-symbolic numerosity information (i.e. sets of objects). Others argue that numerical symbols represent a separate number category that emerges only during education. Here, we tested a unique group of sighted tactile Braille readers with numerosities 2, 4, 6 and 8 in three number formats: Arabic digits, sets of dots, tactile Braille numbers. We showed a consistent overlap in activations evoked by the three number formats. This result shows that all three used formats are represented in the IPS which may suggest at least partial overlap between the representations of three formats used in this experiment. Using MVPA, we found that only non-automatized number information (Braille and sets of dots) allowed successful number classification that did not significantly generalize across formats, however. These results suggest that the IPS may host independent number codes in overlapping cortical circuits. They also highlight that the level of training in encoding a given piece of number information - often confounded with the non-symbolic-symbolic distinction - represents an important factor determining the amount of exploitable information and needs to be controlled for in order to identify the neural code underlying numerical information per se.

Presentation 4: From stimulus-evoked to internally computed representations of quantity in the human brain

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Eger, Evelyn (Cognitive Neuroimaging Unit, CEA, INSERM, Université Paris-Saclay, NeuroSpin center, France)*

Different neuroscientific methods have converged on demonstrating codes for numerical quantities in occipito-parietal and frontal brain regions, most often during perceptual tasks. Numbers, however, are not only perceptual objects, but also internally transformed during mental computations (in both concrete and more abstract form). It remains open to what extent representations of such internally computed numerical contents overlap with those found during perception. Here, we imaged adult human subjects' brain activity at 7 Tesla during a non-symbolic calculation task requiring them to perform either multiplications or divisions on visually presented numerosities, and compare their internally computed results with probe numerosities appearing after a prolonged delay period. Multivariate pattern analysis was used to disentangle the contributions of several predictors (reflecting the different sample numbers, operations, operands, and result numbers) to brain activity patterns at different points of the delay. The visually presented sample numbers were most strongly distinguishable during middle parts of the delay period, in dorsal visual stream/parietal, prefrontal and occipito-temporal brain regions. Representations of the internally generated result numbers were found in subregions of lateral prefrontal cortex as well as in the left angular gyrus during the late delay, before the appearance the probe number. In addition, representations of the symbolically presented operands were detectable in the left inferior frontal sulcus. Our results provide a first demonstration of codes for purely internally generated numerical contents in the human brain, showing that these are found predominantly in higher-level areas on top of the sensory processing hierarchy, in contrast with stimulus-evoked ones.

Development of Math Skills - The Role of Parents and Home Environment

Chair: Jenni Elina Salminen, Tuire Koponen

University of Jyväskylä, Finland

Home learning environment has been acknowledged as a quintessential factor for the development of literacy and mathematical skills. However, research continues to be rather scant and fragmented in understanding how different characteristics of home learning environments independently and jointly impact skill development, particularly so for math skills. This symposium contributes to the understanding of how the mechanisms and characteristics within the home learning environment (e.g., parent-child interactions, informal and formal activities at home; parental learning difficulties, attitudes and emotions toward math and literacy) contribute to the development of math and literacy skills in early childhood and later in school.

Keywords: home learning environment, home learning practices, math skills, literacy skills, attitudes

Presentation 1: Role of Home Environment and Familial Risk for Reading and Math Difficulties on Children's Numeracy and Literacy Skills in Early Childhood

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Salminen, Jenni (University of Jyväskylä); Khanolainen, Daria (University of Jyväskylä); Koponen, Tuire (University of Jyväskylä); Torppa, Minna (University of Jyväskylä); Lerkkanen, Marja-Kristiina (University of Jyväskylä)*

This study examines the direct and indirect effects of home numeracy and literacy environment, and parental factors (parental reading and math difficulties, and parental education) on the development of several early numeracy and literacy skills. The 265 participating Finnish children were assessed four times between ages 2.5 and 6.5. Children's skills in counting objects, number production, number sequence knowledge, number symbol knowledge, number naming, vocabulary, print knowledge, and letter knowledge were assessed individually. Parents (N = 202) reported on their education level, learning difficulties in math and reading (familial risk, FR), and home learning environment separately for numeracy (HNE) and literacy (HLE) while their children were 2.5 years old and again while they were 5.5 years old. The results revealed both within-domain and cross-domain associations. Parents' mathematical difficulties (MD) and reading difficulties (RD) and home numeracy environment predicted children's numeracy and literacy skill development within and across domains. An evocative effect was found as well; children's skills in counting, number sequence knowledge, number symbol identification, and letter knowledge negatively predicted later home numeracy and literacy activities. There were no significant indirect effects from parents' RD, MD, or educational level on children's skills via HLE or HNE. Our study highlights that parental RD and MD, parental education, and the home learning environment form a complex pattern of associations with children's numeracy and literacy skills starting already in toddlerhood.

Presentation 2: Mothers and Fathers Count: Relations between Home Learning Practices and the Cognitive and Academic Skills of Eight-Year-Old Canadian Children

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Cahoon, Abbie (Ulster University); Douglas, Heather (Carleton University); LeFevre, Jo-Anne (Carleton University); Xu, Chang (Carleton University); Maloney, Erin A. (University of Ottawa); Osana, Helena (Concordia University); Wylie, Judith (Queen's University Belfast); Simms, Victoria (Ulster University); Susperreguy, María Inés (Pontificia Universidad Católica de Chile); Lafay, Anne (Savoy Mont Blanc University); Song, Charlene Shujie (Carleton University); Di Lonardo Burr, Sabrina (University of British Columbia); Skwarchuk, Sheri-Lynn (University of Winnipeg)*

Across the world, studies have shown that parents' reports of home learning practices and their attitudes toward literacy and mathematics are related to their 4- to 6-year-old children's early academic skills. In the current study, we asked whether parents' home learning practices, occurring when children are in elementary school (i.e., Grade 3, aged 8 to 9 years), contribute to unique variance in children's academic outcomes. Canadian parents, 50 mothers and 31 fathers, completed a home learning survey on their attitudes, home mathematics and literacy practices, and homework involvement. Their children (n= 81) completed cognitive and academic assessments. Both mothers and fathers reported providing literacy, mathematical (i.e., operational and mapping) and spatial activities for their children. Fathers reported more positive attitudes toward mathematics than mothers whereas mothers reported more positive attitudes toward literacy than fathers. The frequency of operational activities (i.e., practicing arithmetic) and parents' attitudes toward mathematics predicted children's arithmetic fluency. Consistent with literacy research, parents' knowledge of children's books was related to their children's vocabulary knowledge. Parents reported spending little time helping with homework and homework helping was not related to Grade 3 achievement. In summary, some home experiences were related to variance in cognitive and academic skills for older children.

Presentation 3: Exploring Parent-Child Interactions around Math Homework of 8–12-year-old Canadian Children

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Retanal, Fraulein (University of Ottawa); Di Lonardo Burr, Sabrina (University of British Columbia); Xu, Chang (Carleton University); Bureau, Jean-Francois (University of Ottawa); DiStefano, Michela (University of Ottawa); Douglas, Heather (Carleton University); Hunt, Thomas (University of Derby); Lafay, Anne (Université Savoie Mont Blanc); LeFevre, Jo-Anne (Carleton University); Osana, Helena P. (Concordia University); Simms, Victoria (Ulster University); Song, Charlene Shujie (Carleton University); Skwarchuk, Sheri-Lynn (University of Winnipeg); Trepiak, Philip (University of Ottawa); Wylie, Judith (Queen's University Belfast); Maloney, Erin A. (University of Ottawa)*

One critical component of the home math environment is the interaction that parents have with their children around math homework. In the current study, we had 41 parent-child dyads complete questions of their perceptions of the math interaction at home and engage in a math task as they would at home. We provide a descriptive analysis of parent-child interactions surrounding math using a combination of parents and their children's self-report ratings of their emotional experiences (i.e., levels of confidence, conflict, stress, frustration, and feelings of being distant) during math homework-

helping interactions and observational measures of the in-lab math task interactions. We also provide insights into how this relates to both parent and child math achievement and math attitudes.

Presentation 4: Early Home Numeracy Activities and Chinese Children's Third-Grade Nonsymbolic and Symbolic Math Skills

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Zhang, Xiao (Faculty of Education, The University of Hong Kong); Zou, Xinzhuo (Faculty of Education, The University of Hong Kong); Hu, Bi Ying (University of Macau)*

Based on a sample of 196 Chinese children (101 girls and 95 boys; age at the first wave of assessment: $M \pm SD = 5.10 \pm 0.35$ years) and their parents followed from preschool to third grade (age 9), this study examined the longitudinal relations of early home numeracy activities with children's later symbolic and nonsymbolic math skills. The results showed that the frequency of parent-child number book activities predicted children's third-grade nonsymbolic math skills. The frequencies of parent-child number game and application activities were predictive of children's third-grade symbolic math skills. More important, the predictive relations between early number application activities and later symbolic math skills and between early number book activities and later nonsymbolic math skills remained statistically significant even after controlling for earlier math skills, the other types of home numeracy activities, positive and negative parenting styles, and demographic variables. In contrast, the frequency of parent-child number skill activities was not related to children's symbolic or nonsymbolic math skills in third grade. The findings highlight the potential role of enhancing early parent-child numeracy activities in engendering long-lasting effects on children's math skill development.

Behind the Curtain: Exploring Factors Associated with Intervention Response

Chair: Ben Clarke

University of Oregon, United States of America

Despite the growing number of effective math and STEM related intervention programs, there remains a subset of students who do not respond to these targeted interventions. If the needs of all learners are to be met, additional research is needed to find mechanisms to increase the efficacy of interventions and decrease non-responsiveness (Miller et al, 2014). The purpose of this symposium is to examine student level variables associated with response to four efficacious math and STEM intervention programs. Presenters will share results from four independent large scale research projects to provide greater insight into factors associated with intervention effectiveness.

Keywords: math, stem, intervention, moderation, response

Presentation 1: Examining the Impact of a First Grade Math Intervention

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Clarke, Ben (University of Oregon, Eugene); Sutherland, Marah (University of Oregon)*

The importance of a successful start in mathematics is widely recognized. To support that goal, we developed and studied the efficacy of a first grade math intervention program, Fusion. The current study used a randomized control trial design (blocking on classrooms). The research team randomly assigned 10 eligible students per classroom to one of three conditions: (1) a FUSION-large group (5:1 student-teacher ratio), (2) a FUSION-small group (2:1 student-teacher ratio), and (3) a no-treatment control group. Three research questions were investigated as part of this study: (1) What was the overall impact of the treatment, FUSION, compared to control?, (2) Was there a differential impact on student outcomes between the two treatment conditions?, and (3) Did students benefit differentially from the Fusion intervention by initial mathematics skill? and did that relationship vary by group size? The final analytic sample consisted of 459 students: Fusion-large (n = 230), Fusion-small (n = 91), and no-treatment control group (n = 138). Analyses found positive effects on four outcome measures favoring Fusion groups over control with two of the differences statistically significant. Results between Fusion groups found positive effects favoring the Fusion 2:1 group compared to the Fusion 5:1 group on all four outcome measures with two of the differences statistically significant. Moderation analyses for research question 3 are ongoing and will be presented. Results will be contextualized within similar research conducted with a kindergarten intervention program. Implications for curriculum design, instructional supports in schools, and future research will be shared.

Presentation 2: The Association Between a Whole Number Math Intervention and Kindergarten Students' Approaches to Learning

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Turtura, Jessica (University of Oregon); Smolkowski, Keith (Oregon Research Institute)*

Approaches to learning (ATL) is an umbrella term encompassing a set of learning-related skills that reflect children's enthusiasm for and engagement in educational activities. Research suggests that children who demonstrate positive ATL behaviors have stronger academic skills and that children's ATL at kindergarten entry significantly predict later achievement. However, research examining the role of ATL for students with or at-risk for math difficulties is limited. To address this need we examined ATL in the context of a kindergarten mathematics intervention designed to support students struggling in mathematics (Clarke et al., 2020). Specifically, this study examined how intervention receipt affected student ATL, whether fall math performance and fall-to-spring gains in math performance predicted spring ATL, and whether condition moderated the relationship between gains in math performance and spring ATL. Results show that teachers reported higher ATL scores for students who received the math intervention than for students in the comparison condition. We found that students with lower fall math performance and lower gains in math performance scored lower on ATL in the spring, while students with higher fall math performance and higher gains in math performance scored higher on spring ATL. Condition moderated the relationship between gains in math performance and spring ATL for one math outcome measure. Results suggest a potential causal link between a kindergarten math intervention and student ATL. Implications will be discussed in terms of how specific features of math intervention can work to improve student learning-related behaviors, including persistence and the ability to work independently.

Presentation 3: Exploring the Role of Initial Mathematics and Reading Skills in Early Science Instruction: A Moderation Analysis

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Doabler, Christian (University of Texas); Gersib, Jenna (University of Texas); Rojo, Megan (University of Texas); Longhi, Maria (University of Texas)*

Many students continue to face learning difficulties in early science. To promote science literacy among all second-grade students, we designed the Scientific Explorers (Sci2) program to improve students' knowledge and understanding of the disciplinary core ideas and cross-cutting concepts related to Earth's Systems in U.S. national science standards. Findings from a recent, cluster-randomized controlled trial suggested students in Sci2 classrooms significantly outperformed their peers in control classrooms on several important science outcome measures (Doabler et al., 2021). While these results are undoubtedly important for building the evidentiary basis of Sci2, alone they are insufficient for understanding why and for whom the program was found to work. Therefore, the purpose of the current study was to explore whether the Sci2 program acted as an effective mechanism for improving equitable access to high quality, early STEM instruction for all students. Specifically, this study examined a set of student-level pre-treatment academic performance factors (i.e., initial skills in mathematics and reading) to determine whether and to what extent they predicted differential response to the Sci2 program. Results indicated differential response to Sci2 based on initial performance in whole numbers and word reading skills such that treatment effects were more pronounced for students with higher initial skills in these areas. These findings highlight the national challenge to provide all students with access to high-quality STEM education. Implications for designing early science interventions for students who demonstrate academic risk are discussed.

Presentation 4: Differential Response as a Function of Student-Level Factors for Students with Mathematical Difficulties

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Gersib, Jenna (University of Texas); Doabler, Christian (University of Texas); Rojo, Megan (University of Texas); Longhi, Maria (University of Texas)*

Limited exposure to measurement and data analysis concepts may hinder students' opportunities to strengthen their understanding of whole number concepts and operations. As such, it is imperative that students with mathematical difficulties (MD) work with foundational concepts in these areas of mathematics. To meet this need, our team developed the Precision Mathematics (PM) intervention. Designed to increase first-grade students' conceptual understanding and problem-solving skills in measurement and data analysis, PM is a small-group intervention that incorporates both print and technology-based materials. Findings from a recent randomized controlled trial that included approximately 100 first-grade students with MD found statistically significant positive effects on an early measurement curriculum-based measure and nonsignificant, albeit positive, effects on the four other measures administered (Doabler et al., 2019). Researchers also examined whether and to what extent students' academic risk statuses based on initial skill levels in mathematics and early literacy moderated the effects of the PM intervention. Results indicated both student-level variables resulted in differential gains in mathematics outcomes. Initial early numeracy and early literacy skills were found to moderate the effects of PM such that mathematics gains were greater among students at more significant academic risk compared to those considered less at risk. Findings suggest the utility of exploring initial academic skills, such as pre-treatment mathematics skills, to understand response variation among well-designed mathematics interventions. Implications will be discussed in terms of designing and implementing mathematics interventions that address areas of mathematics beyond whole number concepts and operations.

Poster session 3: 12:30pm - 2:30pm

1. Bayesian reasoning with analogous mental representations: Are proportions more natural than probabilities?

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Bayesian reasoning tasks require the processing of data in probabilistic situations to revise risk estimations. Research has shown that such tasks are difficult when data is presented in terms of single-event probabilities (Gigerenzer & Hoffrage, 1995; McDowell & Jacobs, 2017). The multiplicative combination of priors and likelihoods can be missed, resulting in erroneous strategies such as prior neglect or averaging heuristics (Cohen & Staub, 2015; Shanteau, 1975). Proportions (i.e., relative frequencies, part-whole ratios) are computationally equivalent to probabilities because they also require the multiplicative combination which is characteristic of normalized data. However, proportions are connected to natural mental representations (so-called ratio sense, Matthews & Ellis, 2018). More specifically, mental representations of nested proportions (e.g., 70% of 20%) allow for a mental operation that corresponds to a multiplicative combination of percentages.

In our study, we systematically varied the conceptual framing by adapting the wording across two conditions (e.g., “proportion of…” vs. “probability of …”). We aimed to avoid procedural calculations with percentages and instead focused on the conceptual understanding underlying Bayesian reasoning by utilizing graphical representations without numbers (cf. Leuders & Loibl, 2020).

Our results showed that participants in the proportion framing condition tended to apply a valid Bayesian strategy while participants in the probability framing condition tended to combine the prior and conditional probabilities additively (by averaging priors and likelihoods as opposed to multiplicatively combining them).

Thus, proportions can be regarded as a natural view on normalized Bayesian situations which may support the learning and understanding of formal Bayesian reasoning.

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Keywords: Bayesian Reasoning, Nested Proportions, Averaging Heuristics, Mental Representations

2. An exploratory study of the instrumental use of finger counting in adults

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1: Psychological Sciences Research Institute, UCLouvain, Belgium; 2: CNRS, Institut de Neurosciences Cognitives et Intégratives d'Aquitaine (UMR 5287), Université de Bordeaux, France.; 3: Institute of Neuroscience, UCLouvain, Belgium

Fingers offer a practical tool for learning to count but little is known about their use in adults performing numerical activities, in particular how often and for what reason they would use them. The way adults use their fingers for counting is typically assessed by asking them to show how they count from 1 to 10, but such an assessment might reveal a different pattern than the one exhibited in daily activities, because this "show me" task is devoid of any numerical purpose. We surveyed finger counting in 594 French-speaking adults who estimated the frequency of finger use in different contexts and described their manner of counting in a demonstrative "show me" task and in an instrumental "keep track" task where the use of fingers was kept implicit. Results showed that finger counting is frequently used by adults, especially when they communicate numbers or count invisible elements, with higher percentages for math-anxious participants. The finger counting patterns slightly differ between the "keep track" and "show me" tasks. Results suggest that anatomical factors (i.e., hand dominance and mirror movement) play a greater role in the instrumental than in the demonstrative condition, the latter being further influenced by spatial factors (i.e., left-to-right mapping of numbers on the ten fingers). In conclusion, finger counting remains instrumental to adults in daily life, and a systematic evaluation is important to fully capture the heterogeneity of finger counting practices.

Keywords: finger counting, large-scale survey, embodied cognition, math anxiety

3. Variation in parents' number talk with their preschool-aged children: A cluster analytic approach

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Recent work suggests that number talk (NT) is not a unitary construct (e.g., Bachman et al., 2020). The extent to which parents and children engage in NT does not consistently relate to children's math depending on how NT is operationalized, e.g., number statements vs. questions, basic (e.g., counting) vs. advanced (e.g., cardinality or arithmetic) NT, small vs. large (numerals > 4) NT. Given that parents employ and balance various forms of NT with their children, the present study used cluster analysis to uncover patterns of parental input based on combinations of NT measures during pretend grocery shopping with their young children (n = 123; Child age: M = 4.40 years, SD = 3.60 months) and the relations to children's math skills. None of the parent NT measures were independently linked to children's math. In contrast, a k-means cluster analysis, using the proportion of parents' number Qs, large NT, and advanced NT, revealed three groups of parents who provided low NT overall (n = 63), greater proportions of large vs. advanced NT (n = 37), and greater proportions of advanced NT than large NT and Qs (n = 23). Children's standardized math scores differed by parent cluster, (F(1, 3747.12) = 4.91, p = .03). In general, parents who used more advanced NT relative to other forms of NT had children with higher scores. Thus, parents' relative allocation of different forms of NT, not each type of talk by itself, may matter for children's developing math abilities.

Keywords: number talk, math talk, parent-child interactions, informal learning

4. Visual and auditory quantities processing in children aged from 5 to 8 years old

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The approximate number system is a primitive system essential to symbolic mathematic skills. Humans can process quantities in the visual, cross (i.e., dots and tones sequences; Barth et al., 2005, 2006), and haptic modality (Gimbert et al., 2016). Little is known about quantity processing in the auditory modality. We aimed to investigate the development of quantities processing in visual and auditory modalities in 5-8-year-old children. French children in Kindergarten (n = 118), grade 1 (n = 124), and grade 2 (n = 97) were assessed with comparison tasks. In the visual task, two dot sets were presented to children who were asked to select the one with the most dots. In the auditory task, two clowns were playing drums one after the other, and children were asked to select the one who played the most drum tones. Results showed that kindergartners were better to compare visual than auditory quantities, while first and second graders were successful in the two modalities. Children were better to compare small (1-4) than large quantities (5-13), but the gap was bigger for kindergartners. When children compared large quantities, they were better to compare visual than auditory quantities. Therefore, the development of quantities processing was linked to the modality: The auditory quantities seemed more complicated to process, especially when the quantities were large. The sequentiality of the auditory modality may require more working memory and attentional skills. Also, the results could come from a more frequent exposure to visual than auditory stimuli (e.g., in games).

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Keywords: non-symbolic quantities, auditory, child

5. Implications of Neural Integration of Spatial and Mathematical Comprehension for Math Ability and Math Anxiety

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Current literature suggests that increased spatial ability relates positively to mathematical ability. This is supported by evidence from both behavioral and the neural domains. Much of this evidence is derived from classic laboratory-based experimental methods utilizing visual stimuli, despite most individuals experiencing mathematics in a variety of verbal contexts, such as in conversation or while listening to a lecture. The current study investigated neural integration of mathematical and spatial processing in a semi-naturalistic setting – namely listening to statements whose comprehension required one engage in spatial or mathematical thinking. We then tested whether regions showing such integration predict enhanced or impaired mathematical processing. We used a multivariate, neural similarity-based approach to directly assess the extent of neural integration between spatial and mathematical neural activity, while controlling for activity due to basic auditory processing and verbal-listening. Whole-brain results indicated a significant positive relation between spatial and mathematical activity in bilateral anterior hippocampus, an area previously implicated in both mathematics and spatial processing. We next used behavioral measures to test the degree to which greater neural integration of math and space in the anterior hippocampus may be beneficial or deleterious for mathematical processing. The behavioral data indicated that greater integration was associated with poorer math skills and higher anxiety about math. Overall, the results provide evidence for neural integration between mathematics and spatial processing even in semi-naturalistic listening contexts. However, from a behavioral standpoint, this integration is not necessarily beneficial, thus highlighting the importance of contextualizing brain data with behavioral measures.

Keywords: spatial processing, mathematical processing, verbal comprehension, fMRI, neural integratio

7. Adults and children's strategy selection and execution in multi-digit subtraction: The role of executive functions

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1: Center for Instructional Psychology and Technology, KU Leuven, Belgium; 2: Parenting and Special Education Research Unit, KU Leuven, Belgium

We present two closely related studies in which we examined the frequency, efficiency and adaptivity of adults' (N = 140; Mage = 19y11m) and children's (N = 150; Mage = 10y11m) use of direct subtraction (DS; e.g., 712–346=?; 712-300=412, 412-40=372, 372-6=366) and subtraction by addition (SBA; e.g., 712–346=?; 346+54=400, 400+300=700, 700+12=712 and 54+300+12=366) in mental multi-digit subtraction, in relation to their executive functions (EFs). The above-mentioned subtraction strategy parameters were examined by means of the choice/no-choice method (Siegler & Lemaire, 1997). Participants were offered subtractions in one choice condition (free choice between DS and SBA) and two no-choice conditions (mandatory use of either DS or SBA). Multiple tasks (adjusted to the participants' age) were used to examine three EFs: updating, inhibition and shifting (Miyake et al., 2000).

For the adult sample, results showed that SBA was used as frequently as DS, and that DS was most accurate on subtractions with a large difference (e.g., 502–18), while SBA was fastest on subtractions with a small difference (e.g., 903–886). Two-thirds of the adults were adaptive to task characteristics, and adults were generally adaptive for their personal speed characteristics. In line with our hypothesis, updating was related to strategy efficiency. But, inhibition and shifting were unexpectedly not related to strategy adaptivity. The data from the children's sample are currently being analyzed. Detailed results for the latter sample, and conclusions for the whole dataset, will be presented at MCLS 2022.

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Keywords: Subtraction by addition, Mental multi-digit subtraction, Choice/no-choice method, Strategy adaptivity, Executive functions

8. Why Does Fractions Knowledge Support Algebra Knowledge? Investigating Multiple Paths

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Two distinct lines of research show that fractions knowledge supports students' success in algebra. However, it remains unclear why. Have quantitative fractions-algebra studies (e.g., Barbieri et al., 2021; Booth et al., 2014) and qualitative studies (e.g., Hackenberg & Lee, 2015) captured the same connection, or do they represent separate pathways by which aspects of fractions knowledge may support aspects of algebra?

We will investigate these alternatives by assessing fractions and algebra knowledge, and general cognitive skills, of 60 U.S. 8th graders. Fractions measures include both those favored by psychologists (i.e., fraction estimation, comparison, and arithmetic) and those favored by math education researchers (i.e., drawing tasks to measure fraction schemes). Algebra items measure various aspects of algebraic concepts, procedures, and flexibility. Covariates include fluid intelligence, whole number estimation and arithmetic, working memory, proportional reasoning, and math anxiety.

We will model whether fraction magnitude, arithmetic, and schemes uniquely predict students' algebra scores, when controlling for each other and for general skills. We expect each fraction measure to explain unique variance in students' overall algebra scores. Using structural equation modeling, we will test whether specific aspects of fractions knowledge more closely relate to particular aspects of algebra. For example, we hypothesize that fraction arithmetic will more strongly predict procedural knowledge than other aspects of algebra.

This interdisciplinary study will support a more comprehensive model of relations between fractions and algebra knowledge. Our findings, expected by June, will identify specific causal mechanisms to be tested in future longitudinal studies.

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Keywords: fractions, algebra, interdisciplinary, preregistered, student thinking

9. Mathematics Writing Profiles for Students with Mathematics Difficulty

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Students must increasingly demonstrate knowledge in mathematics through mathematics writing, yet research aimed at understanding how students perform and how to support the development of students' mathematics writing is limited. Most of the available research on mathematics writing focuses on typically achieving students without narrowing to students who experience mathematics difficulty (MD; Hebert & Powell, 2016; Powell et al., 2017). We evaluated the mathematics writing performance of 144 third-grade students (ages 8-9) with MD on an explanatory mathematics writing measure. We sought to identify features they included most within their mathematics writing samples. On average, students with MD scored 6.38 points on a mathematics writing rubric out of 25 points. This rubric scored mathematics writing according to mathematics content, mathematics vocabulary, organization of math ideas, writing grammar, and clarity and precision. When compared to a normative sample of students who responded to the same mathematics writing prompt (Namkung et al., 2019), this score for students with MD was significantly lower. Students with MD wrote on average 33.3 words with an average of 8.7 mathematics vocabulary terms. Of the mathematics vocabulary terms used, students most frequently used technical mathematics vocabulary and symbolic numbers. They included symbolic symbols and general vocabulary less frequently. In conclusion, this study demonstrates that students with MD experience difficulty with mathematics writing, and future research is needed to develop mathematics writing supports for students with MD.

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Keywords: mathematics, mathematics writing, explanatory writing, mathematics difficulty

10. Integration of Symbolic and Non-symbolic Numerical Information in Children: Task-Dependence and its Link to Math Abilities

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From birth, children have access to the approximate number system, which allows them to represent and transform approximate estimates of numerical quantities. As children learn to count and acquire symbolic numbers, they develop a symbolic number system to represent exact numerical information. In this study, we investigated how these two number systems are integrated in middle childhood, and if this integration relates to children's formal math abilities. To this end, we tested 70 children (9 to 10 years old) on two tasks: a number comparison task and a number-letter discrimination task. For the number comparison task, children judged the larger of two sequentially presented stimuli that were either presented in the same number format (dot-dot or numeral-numeral) or in a mixed format (dot-numeral or numeral-dot). For the number-letter judgement task, children identified Arabic numerals or letter pairs superimposed on dot arrays that either matched or mismatched the quantity denoted by the Arabic numerals. In the number comparison task, children were significantly slower when comparing mixed-format stimuli than same-format stimuli, which suggests an estrangement between symbolic and non-symbolic numerical information. In contrast, in the number-letter discrimination task, children were significantly faster in discriminating numerals when they matched the quantity of dots, suggesting an immediate integration between symbolic and non-symbolic numerical information. Thus, we conclude that when children process numbers, whether symbolic and non-symbolic numerical information are integrated or estranged is task-dependent. Additionally, correlational analyses suggested that children with greater symbolic estrangement tend to have greater math abilities.

Keywords: Symbolic number, non-symbolic number, numerical estrangement, numerical integration, math

11. Spontaneous focusing on regularities in preschool predicts reasoning about randomness four years later

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The concept of randomness is difficult to grasp. Coin-tossing tasks, in which participants have to predict the next toss after a given sequence of tosses or have to judge the likelihood of given sequences of coin tosses, have been popular to investigate the understanding of randomness (e.g., Falk & Konold, 1997). The systematic errors observed in these tasks are often believed to be caused by the use of the representativeness heuristic (Kahneman & Tversky, 1972). When thinking representatively about randomness, one evaluates how well a set of random events resembles the prototype for random events in one's mind. The representativeness heuristic is explained by our tendency to seek for patterns in our surroundings. Recent findings confirm that the tendency to spontaneously focus on patterns (SFOP) is already observed in preschool (e.g., Wijns et al., 2020). In the present study, a SFOP-task was presented to 302 preschoolers. Four years later these children completed a coin-tossing task. Regarding coin-tosses, findings suggest that children make rational judgements but intra- and inter-individual differences exist. Moreover, children with a spontaneous focus on patterns in preschool make more representativeness-based judgment errors four years later. Our conclusion is twofold: (a) previous studies might have underestimated children's abilities to reason about randomness in coin-tossing contexts and (b) errors in reasoning about randomness are associated with pattern-based thinking tendencies in children.

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Keywords: mathematical development, randomness, representativeness heuristic, patterns

12. Math computerized games in the classroom: a Number Line Training in Primary School Children

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Several studies have shown that the number line can be a useful tool to support early numeracy development. Here, we conducted a school-based training study to evaluate the effectiveness of the software “The Number Line” (“La Linea Dei Numeri”; Tressoldi and Peroni, 2013) in improving children’s mathematical skills. We randomly allocated ten classes of first, second and third graders (N=183) to one of three experimental groups: one group played with The Number Line; the second group played with Labyrinth, a computerized game designed to train attention skills; the third group had no intervention (business-as-usual). At the end of the first training phase, children in The Number Line group completed another training phase playing with Labyrinth, whereas the other two groups played with The Number Line. After playing with The Number Line, all groups displayed more accuracy when placing numbers in the number line task. However, we observed no evident improvement in other mathematical skills. These results suggest that specific training effects emerge even in the school context, although transfer to other numerical skills may be harder to achieve.

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Keywords: number line, training, arithmetic, primary school, mathematical cognition

13. Prior home numeracy environment is associated with adaptation to homeschooling during COVID lockdown.

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The emerging COVID-19 crisis led to exceptional measures throughout the world to contain the spread of the virus. In France, schools were closed for several weeks. A growing number of studies suggest that socio-economic status might be an important predictor of how families adapted to homeschooling during lockdown. However, socio-economic status is a distal factor that does not necessarily inform on the specific characteristics of the home learning environment that may more directly influence parental adaptation to homeschooling during lockdown. Using more proximal indicators of the home learning environment, we aimed to evaluate whether and how parental adaptation to homeschooling during lockdown was related to their prior beliefs about math learning as well as to the frequency of numeracy activities that were already present at home before lockdown. The present study involves 52 families who participated in a study about the home learning environment in 2018. At the end of the first French lockdown in 2020, they were asked again to complete a questionnaire assessing homeschooling conditions during lockdown as well as parental confidence towards academic domains. Over and above a range of background variables, correlation analyses revealed that parental expectations towards math learning as well as frequency of prior shared numerical activities were related to daily homeschooling time during lockdown. Both parental attitudes and expectation towards numeracy were also related to parental confidence in homeschooling. Our results suggest that several aspects of the home learning environment may have influenced how family adapted to homeschooling during the 2020 COVID lockdown.

Keywords: COVID, homeschooling, home numeracy environment

14. Young children's proportional vocabulary knowledge and its association with proportional reasoning abilities

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Proportional reasoning is a stumbling block for many children (Resnick & Singer, 1993). It has been suggested that an absence of appropriate language skills could be underlying these difficulties (Vanluydt et al., 2021). This is not surprising because proportional reasoning abilities are frequently measured in language-embedded tasks containing specific mathematical vocabulary (e.g., double, three times more, …). In a first step, we developed a reliable and valid instrument to measure specific mathematical vocabulary related to proportional reasoning in second and third graders. This test instrument included 44 items, representing eleven proportional reasoning concepts. In a second step, this instrument was used to investigate whether second graders' (n = 146) proportional vocabulary knowledge is associated with (1) proportional reasoning abilities and (2) performance on additive and proportional word problems. First, the results indicated a positive association between children's proportional vocabulary knowledge and proportional reasoning abilities ($r = .527$, $p < .001$). Second, as expected children's proportional vocabulary knowledge positively correlates with performance on proportional word problems ($r = .287$, $p < .001$), and apparently also with additive word problems ($r = .275$, $p < .001$). Nevertheless, performance on additive word problems is not correlated with performance on proportional word problems ($r = .033$, $p = .696$). Overall, these findings indicate that specific mathematical vocabulary knowledge is important for proportional reasoning. It is advised to investigate whether explicit language instruction improves proportional reasoning abilities and whether mathematical abilities in other highly content-specific mathematical areas are also associated with specific mathematical vocabulary knowledge.

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Keywords: Proportional reasoning, Specific mathematical vocabulary, Proportional vocabulary, Word problems

15. Learning artificial number symbol systems with training

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How numerical symbols gain semantic meaning has interested researchers for many years. Different proposals have been made, yet it is still unclear which types of information are involved in the learning of numerical symbols.

Using an artificial symbol learning paradigm, we investigated whether ordinal (symbols presented as sequence), magnitude (symbol-dot array pairs) or a combination of ordinal and magnitude (ordinal+magnitude) information (full sequence with symbol-dot pairs for some symbols) allows adults (N=306) to learn the numerical meaning of 12 symbols which are part of a base-3 place-value system (Study 1). We also tested adults' (N=204) ability to learn different types of artificial symbol systems (place-value or sign-value) with ordinal training (Study 2).

Results of Study 1 showed that ordinal, magnitude and ordinal+magnitude training allowed for accurate ordinal- and magnitude-based judgements about the numerical symbols. Thus, participants can attach numerical meaning to these, and even infer the meaning of symbols never encountered during training. When making magnitude-based judgements, the magnitude and ordinal+magnitude groups performed significantly better than the ordinal group. Study 2 showed that ordinal training allows the learning of both place-value and sign-value systems, and that the meaning of symbols not encountered previously can be inferred. Learning a sign-value system may be easier, as indicated by better performance on a symbolic comparison task.

These studies demonstrate that magnitude and ordinal information can be used to attach numerical meaning to artificial symbols within a number system, which can shed light on the types of information that give meaning to numbers.

Keywords: Artificial symbol learning, Symbol systems, Approximate magnitudes, Ordinality

16. Strategy choices and individual differences in computational estimation

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Our study evaluated the strategy inventories of young adults making computational estimates, and whether their strategy choices are associated with mathematical achievement. We built on Levine's (1982) Test of Estimation Ability (TEA) and Dowker's (1996) use of this measure to identify two classes of strategies. We modified the TEA, developing the Test of Estimation Strategies (TES). The TES consists of five sets of four problems each where the problem features in each set align with one of five strategies. These include three of Dowker's Class One strategies, which are "all-purpose" and "school-taught": (1) Proceed Algorithmically, (2) Round One, and (3) Round Two. These also include two of her Class Two strategies, which require more conceptual knowledge: (4) Fractions and (5) Known-and-Nice Numbers.

Our 55 participants had 4 minutes to type their estimates to the 20 problems. We divided them into high and average performance groups based on the number of correct estimates they made (i.e., within 10% of the actual answer). The high performance group made more correct estimates ($t(50) = 3.85$, $p < .001$) while, surprisingly, the two groups attempted a comparable numbers of problems ($t(50) = 1.71$, $p = .094$). The high performance group utilized more of the conceptually-driven Class Two strategies ($t(50) = 2.51$, $p = .015$) whereas the average performance group used more procedural Class One strategies ($t(50) = -4.97$, $p = .030$). Last, individual differences in estimation accuracy and mathematical achievement (on the ACT or SAT) were correlated ($r = 0.53$, $p < .001$).

Keywords: arithmetic strategies, strategy choice, mathematical achievement, individual differences, test of estimation strategies

17. The Automatic Processing of String Lengths and Digit Identities in Multi-Digit Number Comparisons

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In the Arabic number system, multi-digit numbers represent a numerical value via digits' shapes, and their position in the number's string. This system associates number length with its value so that the longer the number is, the larger its value. We hypothesized that the digits' identity and the overall string length are both processed automatically when comparing multi-digit numbers from different scales, resulting in a Stroop-like congruity effect. To test this, eight groups of participants compared pairs of numbers which differed in digit identity and string length. Groups 1-4 were shown numbers composed of a repeated digit (e.g., 333 vs. 77). Group 1 chose the string composed of the largest repeating digit, while ignoring the strings lengths. Group 2 chose the longest string, while ignoring the digits' values. Group 3 chose the string that contained the most digits, while ignoring the digits' values. Group 4 chose the largest multi-digit number. Groups 5-8 received similar instructions to groups 1-4, but with stimuli composed of multiples of 10 and 100 (e.g., 300 vs. 70). The results revealed a significantly larger congruity effect when the string lengths were processed automatically, rather than the repeated digit identity. Moreover, for all groups, the size congruity effect increased linearly as the numerical distance increased, but this modulation was more pronounced in the "Largest Digit" conditions. These findings reveal that comparisons of multi-digit numbers from different scales are not solely based on differences in the numbers' lengths. We discuss these findings considering multi-digit number processing models.

Keywords: multi-digit, automaticity, sice

18. Exploring the dynamic, longitudinal relationships between 'general' cognitive abilities, numeracy and literacy from kindergarten to second grade

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The development of cognitive and early academic abilities has been the subject of much investigation throughout the last few decades. Still, a comprehensive framework of the interrelations between math, reading, and general cognitive abilities across early development is lacking. In our upcoming project, for which data collection will start in September of this year, we plan to conduct a longitudinal investigation of early cognitive, numerical and literacy development over a period spanning from kindergarten to the second grade of primary school.

By repeatedly administering the same battery of tasks at five different time points (across two years), we will obtain sufficient temporal resolution to investigate the ways in which EF, WM and fluid intelligence dynamically develop over time, and how they interact mutually (i.e., bidirectionally) with number sense, early numeracy, and literacy development. School and parental factors will be included as well, in order to examine the role of environmental factors during these developments. Taken together, this approach will improve our understanding of (individual differences in) the dynamic relationships between early math and reading development.

We will recruit a large sample (n=200) of kindergartners, showing ample variation in terms of (early) literacy and numeracy abilities. More specifically, we will include a majority of typically developing children, as well as a substantial group of precocious (i.e., ‘gifted’) learners. This will allow us to not only investigate the dynamic/mutual learning trajectories in the general population, but also within the population of precocious children, who have been largely underinvestigated in the existing literature.

Keywords: numeracy, literacy, mutualism, intelligence, longitudinal

19. The Role of Gestural and Spatial Input in Children's Early Spatial Skills

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Previous literature has shown that spatial language input and gestural input are independently implicated in the development of children's spatial skills. However, few studies have examined the effect of spatial and gestural input in tandem on children's spatial skills. The current study investigated whether spatial language accompanied by gesture during parent-child interactions was predictive of preschoolers' spatial skills above and beyond spatial language unaccompanied by gesture. Parents and their 4-year-old children (N = 105 dyads) were observed completing a puzzle activity together. Each instance of spatial talk, utterances about spatial concepts employed by a parent or child, was coded, as well as each instance of gesture that accompanied this spatial talk (e.g., pointing while talking about a shape). Children were then administered three spatial assessments to test their spatial mental transformation, geometric sensitivity, and patterning skills respectively. Parent spatial talk and gestures were entered into one regression model predicting a composite of the three spatial assessments, and child spatial talk and gestures were entered into a separate model. We found that parents' spatial talk with gesture was significantly and negatively correlated with children's spatial skills. However, parents' spatial talk without gesture or children's spatial talk with and without gesture were not predictive of children's spatial skills. These findings suggest that parents whose children have lower spatial skills may use gestural input as an additional learning aid in their interactions with their children.

Keywords: parent-child interactions, spatial talk, gestures

20. Evidence for the graded nature of human geometric and topological cognition

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Dehaene et al. (2006) found evidence of sensitivity to geometric and topological (GT) concepts in adults and children, even those without explicit mathematical instruction, using a odd-one-out task. Participants saw 5 images that embodied a GT concept interspersed with one violation and had to pick the odd-one-out. Participants' proficiency at the task was interpreted as suggesting the presence of GT concepts even early in life. However, it could instead be measuring more general cognitive abilities, as models of this task often use domain-general cognitive abilities such as analogical inference to induce the odd-one-out. We developed a new 2-alternative forced choice (2-AFC) version of the task where the role of general cognitive abilities is minimized. Replicating the original finding, 88 American participants showed above-chance sensitivity to 41 of the 43 concepts tested. Performance was not strongly associated with two general cognitive abilities and mathematical achievement as measured by a fluid intelligence and mental rotation tests, and the ACT/SAT. Performance on the 2-AFC task was highly correlated with similar past studies. We aggregated the 43 concepts into seven classes and derived an aggregate score for the "domain centricity" of each class using accuracy, reaction time, and correlations with the general cognitive ability and mathematical achievement measures. We found a graded structure, where classes such as Geometric transformations were more reliant on domain-general cognitive abilities than others (for e.g. Euclidean geometry). These results challenge existing models of geometric cognition that suggest that people use domain-general abilities such as induction to solve this task.

Keywords: geometry, intuitive concepts, topology

21. Do Arithmetic Effects Depend on the Paradigm?

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In arithmetic studies, researchers may choose different paradigms. However, effects and their impact on mathematical cognition theories are usually interpreted generally, i.e., without consideration of the specific paradigms used. For instance, while most neuroimaging studies adopt verification or choice reaction paradigms to ensure less noise and movement for neural signals, production paradigms are more ecological valid. This raises the general question whether results obtained with one paradigm (e.g. choice reaction) can be generalized to other paradigms (e.g., production) or more generally, whether arithmetic effects are general or paradigm-dependent.

This preregistered study aims at investigating mental arithmetic in six different paradigms (verification, choice reaction, delayed choice reaction, computerized production, verbal production with button press, and verbal production with voice key), which are commonly used interchangeably in arithmetic research without further consideration of paradigm-specific modulations of effects. In the mental arithmetic task, the operation (addition/subtraction) and difficulty level (with/without carry/borrow) are varied. We expect better arithmetic performance in verification and choice reaction paradigms than in production paradigms. Furthermore, we evaluate whether the operation effect and the carry/borrow effects are influenced by the paradigms. Due to the COVID-19 pandemic, data collection will start as soon as the current situation permits. We expect to present and discuss the results and implications of the preregistered analyses at the MCLS.

Keywords: paradigms, arithmetic, operation, difficulty

22. Caregivers’ Number Application Talk and Young Chinese Children’s Number Skills and Interest

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Introduction: A growing body of research has found the relation between caregivers’ number talk and children’s number skills. However, the question of what type of number talk is more effective than others remains understudied. In the present study, we proposed a new type of number talk, namely number application talk, and explored the association between caregivers’ number application talk in a shopping context and children’s number skills and interest.

Method: Ninety-three children (mean age = 67.08 months and SD = 3.77 months) and their caregivers were recruited from China. The speech of caregivers and children when shopping in a local supermarket was audio recorded. The researchers coded caregivers’ number application talk and non-application talk. Children completed spontaneous focusing on numerosity (SFON) tasks, numerical interest interviews, and number skill tests. Caregivers filled out questionnaires regarding children’s numerical interest.

Results: The results from multivariate multiple regressions showed that caregivers’ application talk about calculation positively correlated with child-reported numerical interest. Caregivers’ application talk solely referring to money was positively linked to caregiver-reported child numerical interest. Moreover, caregivers’ application talk about cardinal values positively correlated with children’s SFON. Finally, caregivers’ total amount of number application talk positively related to children’s performance in arithmetic word problems.

Conclusion: The findings highlight the positive relations between caregivers’ number application talk and children’s number learning. The study not only adds a useful classification to caregivers’ number talk, but also offers important insights for designing family math intervention programs.

Keywords: number talk, application, number skills, number interest, shopping

23. Context effects in adults' attention to numerosity extend to new stimuli and online administration

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The Attention to Number (AtN) task (Chan & Mazzocco, 2017; Mazzocco et al., 2020) was created to assess whether children's focus on numerosity is affected by the context in which numerical stimuli appear. In prior AtN research, participants chose more numerosity-based matches when number was pitted against features of lower salience (e.g., pattern, location) versus higher salience (e.g., color, shape). Also, both children and adults demonstrated an order effect: when numerosity-based matches first appeared against less (vs. more) salient features, participants made more numerosity-based matches overall. Given the relative infrequency of numerosity-based responses, we considered whether the AtN underestimates attention to numerosity because, unlike competing features, numerosity is a property of an entire set of AtN stimuli, not a feature of each object in the set. We created new stimuli with numerosity represented within a single holistic object (e.g., number of dots on a ladybug, not the number of ladybugs). Additionally, we adapted the AtN from a paper-and-pencil task to online administration, and counterbalanced original and revised stimuli. Among 282 adults who completed both AtN versions, we replicated both the main effect of salience (numerosity-based matches are more common against lower salience features), and the order effect for more numerosity-based matches when paired with lower salience features first. These effects were obtained both for the original and new stimuli, providing validation for online AtN administration and consistency across stimulus types. Post-assessment survey items provide further validation for features adults focus on in the AtN.

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Keywords: numerosity, attention to number, spontaneous focus on numerosity, contextual effects

24. Exploring the Early Years Numeracy Environment in the UK

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Many children spend a substantial amount of their time in Early Years (EY) settings (e.g., nurseries and preschools). These facilities are essential for children's personal, social, and emotional development and also for individual attainment in, for example, literacy and numeracy. However, relative to research on home numeracy, the EY numeracy environment has received limited attention. Therefore, to foster our understanding of the EY numeracy environment, we adapted a home numeracy environment questionnaire to EY settings. In this study, 158 EY practitioners indicated how often they used certain numerical activities with the children in their care. EFA revealed five types of numeracy tasks: counting, informal practitioner-led, manipulative focused, Arabic digits focused, and advanced activities. Practitioners with higher academic expectations were found to use more Arabic digit focused tasks, while higher education levels were associated with advanced activities. Our results suggest that practitioner beliefs and experiences influence the types and frequency of numerical activities used with the children in their care. Further research is needed to investigate how numerical activity types and practitioner characteristics affect children's numerical abilities. Currently, we are running a follow-up study with a revised numeracy questionnaire to elaborate on the extent to which practitioner beliefs and experiences influence the EY numeracy environment.

Keywords: Early Years, Numeracy development, Practitioner-child interactions, Practitioner's expectations

25. What constitutes an effective manipulative? A comparative judgement study investigating the views of researchers, teachers, and parents.

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Manipulatives, such as counters or toy animals, are often used by teachers and parents to teach mathematical concepts to children. Although these objects draw children's attention and make learning fun, there is conflicting research concerning their efficacy for learning. A key aspect of contention is the concreteness of an object, which is defined as the amount of information an object provides. This information can relate to an object's perceptual richness (how colourful/textured an object is), established knowledge (the pre-existing knowledge activated by an object), iconicity (how similar an object is to its real-world referent) and homogeneity (whether objects are all the same or all different). To date research has explored these different dimensions of concreteness in isolation, resulting in conflicting outcomes and guidance for practice. We conducted a study to unpick which dimensions of concreteness influence what individuals choose to teach children. Researchers (n=32), teachers (n=31), and parents (n=31) completed a comparative judgement task comparing images of objects varying in different dimensions of concreteness, with participants deciding which they would choose to teach arithmetic to children. Overall, the findings indicated homogeneity and iconicity were the main dimensions of concreteness influencing whether an object was chosen, with homogeneous, 3-dimensional models being the most preferred across all groups. This contradicts the common research recommendation to avoid concrete objects in teaching due to their distractive qualities. Some concrete features may in fact be seen as beneficial by practitioners for capturing children's attention in busy classroom contexts.

Keywords: Manipulatives, arithmetic, comparative judgement, concrete objects, practitioners

26. Relationship between Cognitive Control and Mathematics Achievement: A Pilot Study

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Error monitoring which is associated with meta-cognition and inhibitory processes of cognitive control also plays a role in academic achievement (Hirsh & Inzlicht, 2010). However, it has not been investigated yet if error monitoring is specifically related to mathematical achievements. In this study 20 adults and 48 children took part. Two different kinds of executive function tasks (non-numeric and numeric) were developed to measure post-error slowing (PES) and post-error improvement in accuracy (PIA). Later PES and PIA were correlated with participants' math fluency scores. It was shown that PES is modulated by response-stimulus intervals (RSI; Danielmeier & Ullsperger, 2011), therefore, a short and a long RSI (200 and 750 ms) were used. Results showed that adults, but not children, showed significantly more PES in the numeric task than in the non-numeric task and PES was larger for the short R SI. Adults' post-error accuracy for short RSIs, but not for long RSIs, was decreased in Simon task, in the math task it was decreased for both RS Is. Childrens' post-error accuracy was decreased in both RSIs and both tasks. The correlations indicated that only children, but not adults, showed a positive correlation between PES from the short RSI condition in the numeric task and math fluency. PIA in the long RSI condition of the math task was positively correlated with math fluency only for adults. The findings indicate that the relationship between PES, PIA, and maths achievement is sensitive to the RSI and the age of the participants.

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Keywords: Cognitive Control, Error Monitoring, Mathematics Achievement

27. Arithmetic and word problem-based procedural flexibility measures as predictors of middle-schoolers' differential algebra skills

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Procedural flexibility, or the ability to adaptively apply strategies to solve problems, is an important skill for advanced math learning. Previous studies (Durkin et al., 2021; Rittle-Johnson et al., 2020) measure students' procedural flexibility through their ability to efficiently apply strategies to solve arithmetic problems (e.g., 2½ x 4 = __). However, students are often tasked with solving other problem-types, such as word problems, that may also promote problem-solving flexibility. In the current study, we measure middle schoolers' procedural flexibility with both fraction arithmetic problems and word problems. Using a coding scheme informed by Newton (2008), we examined and coded students' use of efficient strategies on fraction arithmetic and word problems to create flexibility scores for each. We establish the relationship between these flexibility measures ($r = .525$, $p < .001$) and then examine their relative predictive utility in simultaneously predicting students' improvements in algebraic feature knowledge and equation solving skills over the course of the school year. We find that the overall flexibility measure, collapsed across problem-type, predicts end-of-year (EOY) algebraic feature knowledge and equation-solving skills, controlling for corresponding start-of-year (SOY) algebra measures ($p < .001$). When split by problem-type, flexibility displayed on word problems at SOY predicts EOY algebraic feature knowledge ($p = .040$) whereas flexibility displayed on arithmetic problems at SOY predicts EOY equation-solving skills ($p = .049$). These preliminary results suggest flexibility displayed on word problems may have a distinct role in the development of mathematical knowledge.

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Keywords: Procedural flexibility, word problems, algebra

28. Symbolic and non-symbolic numerals do not interact in the SNARC effect

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Extensive evidence shows that both symbolic (digits) and non-symbolic (dots) numerals are spatially represented, with small numbers eliciting faster left key responses and large numbers eliciting faster right key responses (Spatial-Numerical Association of Response Codes). A format independent SNARC effect has been used to support the existence of a common system for symbolic and non-symbolic numerical representations. This study aims at investigating whether symbolic and non-symbolic numerals interact in the SNARC effect when both information is presented simultaneously. Participants were presented with dice-like patterns with digits being displayed instead of dots. In two separate magnitude classification tasks, participants had to respond either to the number of digits being present on the screen or to their numerical size. In the non-symbolic task, they had to judge whether the digits on the screen were more or less than three, irrespective of the numerical value of the digits. In the symbolic task, participants had to judge whether the digits on the screen were numerically smaller or larger than three, irrespective of the number of digits being present. The results show a consistent SNARC effect in the symbolic task and no effect in the non-symbolic one. Furthermore, congruency between symbolic and non-symbolic numerals did not modulate the response patterns, thus supporting the idea of independent representations and questioning some propositions of current theoretical accounts, such as the Approximate Number System (ANS) and A Theory of Magnitude (ATOM).

Keywords: SNARC, digit, numerosity, Approximate Number System, A Theory of Magnitude

29. The effects of parietal and prefrontal neuromodulation (by means of tDCS) on the ability to integrate spatial and numerical quantitative information

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Introduction: There is currently an intense debate about whether numbers are processed using a number-specific system or a general magnitude processing system, shared with other non-numerical magnitudes such as size, length or duration . There are many studies that analyze how these magnitudes interfere with number processing, but the specific ability to convert and integrate spatial, and numerical quantities has hardly been addressed.

In this study, we analyze the effects of neuromodulation of right prefrontal and parietal cortices by means of anodal tDCS, in the ability to integrate spatial and numerical information.

Methods: Randomized single-blinded sham-controlled trial, stimulation site as between subjects condition, and stimulation as within subjects condition.Multifocal tDCS administered on-line during the execution of the magnitude comparison tasks.

Results: (Experiment in progress: data are being collected).

The parsimonious hypothesis is that parietal stimulation will affect performance in pure numerical and pure spatial comparison tasks, while prefrontal stimulation affects mixed comparison tasks, whose execution requires the integration of numerical and spatial information.

Nevertheless, if the ATOM theory is valid, then there will be no differences between performance in pure and mixed task in both stimulation groups, since all the formats are processed by a single magnitude processing system.

Discussion: Prefrontal and parietal anodal tDCS can improve arithmetic and numerical learning and also can impair arithmetic .Our results will provide evidence about the possible use of tDCS as a cognitive enhancer in numerical cognition.

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Keywords: Numerical cognition, Space-number processing, ATOM, NIBS

30. Strategies for remediating math anxiety in high school classrooms

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Math anxiety, or negative thoughts, feelings, and avoidance associated with mathematics, is associated with underperformance in mathematics. Math anxiety has been characterized by intrusive and distracting thoughts and is also associated with maladaptive study skills, such as avoidance. Math anxiety is not only associated with negative feelings and experiences, but is also associated with decreases in math performance in the lab, decreased grade performance, and decreased interest in taking math classes or choosing quantitative careers. To combat these behaviors, we introduced two interventions into two samples of high school math classrooms: one intervention focused on regulating anxiety using cognitive reappraisal, and the other encouraged students to improve their study habits. Across both school samples, students in the study skills (SS) intervention improved their math performance, whereas students in the emotion regulation (ER) intervention were relatively unaffected by the intervention. Across two samples of high school students, even controlling for past class performance, the SS intervention encouraged the most anxious students to incorporate self-testing and overcome avoidant behaviors, ameliorating the performance deficits associated with increased anxiety. This strategy results in better performance, allowing students who are challenged by feelings of anxiety to more fully reach their potential.

Keywords: Math Anxiety, Intervention, Self-Testing, Cognitive Reappraisal, Class Performance

31. Using the Curriculum Research Framework to Design and Develop Word Problem Solving Instruction to Reduce Cognitive and Linguistic Demands

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The importance of word problem solving (WPS) to students' educational success is well-established, given its ties to critical thinking skills, applicability to everyday life, and frequent appearance on high-stakes standardized tests (Powell, 2011). Students with mathematics difficulties (MD) often struggle disproportionately with WPS due to the unique intersection of required language, executive functioning, and computational skills (Fuchs et al., 2016). For example, WPS involves identifying relevant and irrelevant information, determining what component to solve for, generating an equation to solve for the missing information, as well as calculating the answer and checking the reasonableness of the outcome.

Mathematics intervention programs should be developed using a scientific approach that draws from existing research on effective instructional practices and utilizes cycles of development, field-testing, analysis, and revision. One validated framework to guide the development of new curricular programs is the Curriculum Research Framework (CRF; Clements, 2007). The current proposal will discuss the design and development of the WPS strand within a second-grade, NSF-funded Tier 2 mathematics intervention. We utilized the CRF to design WPS activities that reduced cognitive and linguistic demands by incorporating schema-based instruction, self-regulated strategy development, an integrated concrete-representational-abstract framework, and a focus on precise and consistent mathematical language. Discussion will center on how curriculum developers can incorporate research related to cognition and language development to design and test of the efficacy of mathematics interventions.

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Keywords: mathematics intervention, curriculum design, cognitive and linguistic demands

32. Ecological factors shape quantitative decision-making in coyotes

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Much research has focused on the development and evolution of cognition in the realm of numerical knowledge in human and non-human animals but often fails to take into account ecological realities that, over time, may influence and constrain cognitive abilities in real-life decision-making. Seasonal variations drive many differences in animal behavior and cognition (e.g., hibernation, breeding, food resource availability). Cognitive abilities such as enumerating and timing are central to many psychological and ecological models of behavior, yet our knowledge of how these are affected by environmental fluctuations remains incomplete. Our research bridges the gap between basic cognitive research and ecological decision-making. We used coyotes (Canis latrans) as a model animal system to study decision-making about quantities in foraging tasks, testing a large number of animals across their four biological seasons to examine effects of ecological factors such as breeding status and environmental risk on quantitative performance. Results show that coyotes, similar to other species, spatially discount food rewards while foraging. The degree to which coyotes are sensitive to the risk of obtaining the larger food reward, however, depended on the season in which they completed the foraging task, the presence of unfamiliar humans, and the presence of conspecifics.

Keywords: decision-making, ecology, enumeration, foraging, risk

33. Characterizing the associations between parent-child neural synchrony and child math processing

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Parent-child interactions are often marked by interpersonal neural synchrony (INS), the temporal coordination of neural responses linked to interpersonal cooperativity.1 Mental processes underlying INS are associated with learning,1 but little is known about relationships between parent-child INS and early mathematical processing.

Neural structure and function change significantly across development.2 Thus, if neurophysiology during parent-child INS showed similarities in spatial location and/or frequency band, it could suggest processes reflected by INS play some moderating role in cognitive function.

EEG was recorded for 20 dyads of parents and elementary-aged children during an arithmetic flashcard task. We evaluated relative scale-averaged power per participant across five frequency bands, and established the proportion of total synchronous activity within dyads. We calculated the effect of INS proportion and power per frequency band on whether power in an electrode surpassed a subject-specific threshold. We accounted for fixed-effects of electrode identity, a proxy for spatial location.

INS was significantly associated with total electrode power (B= 11.752, p=.036). Power in the alpha band (8-16Hz) was significantly associated with INS (B= 19.196, p<.01). Power in other frequency bands did not significantly affect electrode power or INS. Alpha band activity dominates during wakefulness, and is associated with cortical excitability and attention.3 Our results thus suggest spatial localization of activity during periods of INS was tied more to baseline regional excitability than an INS-moderation effect.

Our analysis shows that processes reflected by parent-child INS may benefit learning primarily through domain-general effects, facilitating cognitive function irrespective of the particular neural process.1, 2

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Keywords: interpersonal neural synchrony, EEG, parents, child learning

34. Cognitive and Non-Cognitive Factors Explaining Responsiveness to Arithmetic Fluency Intervention

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The aim of the study was to search for factors influencing school-aged children’s response to an arithmetic fluency intervention by analyzing associations between intervention response, cognitive and non-cognitive pre-intervention attributes, and gender. Participants were 69 elementary school children with low performance in calculation fluency participating in manualized arithmetic fluency intervention with and without self-efficacy support implemented in schools for 12 weeks. Analyses based on continuous and categorical variables revealed that cognitive and non-cognitive pre-intervention attributes predicted 21% to 50% of the variation in intervention response. Cognitive skills were associated with the intervention response mainly among the boys whereas the non-cognitive attributes explained more of the response among the girls. Thus, both cognitive and non-cognitive factors and their interaction with gender should be considered when identifying possible non-responders who are likely in need of more individually tailored support at school.

Keywords: Response to intervention, arithmetic fluency, cognitive and non-cognitive predictors

35. The unique and shared contributions of verbal and nonverbal relational reasoning to mathematical problem solving

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Previous research suggested that the manifestation of relational reasoning differs across representational systems (verbal and nonverbal). However, the contribution of relational reasoning ability in the two distinct representations to mathematics learning has not been investigated. In the current study, a sample of 230 sixth graders completed the nonverbal Test of Relational Reasoning-Junior (TORR-jr), the newly developed verbal Test of Relational Reasoning-Junior (vTORR-jr), and a mathematical problem solving measure. The vTORR-jr showed good internal consistency and validity. Regression analyses revealed that relational reasoning ability in both nonverbal and verbal representations uniquely predicted children's mathematical problem solving, after controlling for their prior nonverbal intelligence, working memory, receptive vocabulary, and reading comprehension. The findings highlight the significance of both verbal and nonverbal relational reasoning abilities in mathematics learning. Meanwhile, the development of vTORR-jr opens a window to understand children's relational reasoning in verbal representations.

Keywords: Relational reasoning, representation, mathematical problem solving, higher-order thinking

36. Math Anxiety, Students and Teachers' Perception of School Climate: What Relationship with Math Performance in Primary School Children?

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Math skills are fundamental in both everyday life and education (Dowker, 2019). Extensive literature indicates that children's math-anxiety is related to their math performance and that both individual and contextual factors have a substantial role in modulating this relationship (Chang & Beilock, 2016). To our knowledge, however, no previous research has examined the relationship between contextual factors related to the perceived school climate evaluated from both students and teachers' perspectives, students' math-anxiety and their math performance (Selen Demirtas-Zorbaz et al., 2021).

In this study, 583 typically-developing children (287 M; MAgeMonths = 126.38) were tested with questionnaires on their math-anxiety, relationship with teachers, and academic support. Math teachers completed questionnaires on the school environment, their relationship with students, and their awareness of students' math-related metacognitive beliefs. Children also completed math fluency and calculation tasks. We used Confirmatory Factor Analysis to define latent variables related to students' math-anxiety, the school climate perceived by students and teachers, and students' math performance. Structural Equation Models indicated that teachers' perception of the school climate fully mediated the relationship between students' math-anxiety and their perception of the school climate, on one side, and their math performance, on the other side.

Theoretical and practical implications will be discussed.

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Keywords: Math anxiety, School climate, Contextual factors, Math performance, Primary school

37. The brain goes the distance: a shared numerical magnitude representation revealed by a frequency-tagging multi-code EEG study

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Humans can effortlessly abstract numerical information from various formats, codes, and contexts. However, whether the access to the underlying magnitude information relies on common or distinct brain representations remains highly debated. Here, we recorded electrophysiological (EEG) responses to periodic variation of numerosity (every five items) occurring in rapid streams of numbers presented at 6Hz in randomly varying codes – Arabic digits, number words, canonical dot patterns and finger configurations – thus mixing symbolic and iconic formats. Results demonstrated that numerical information was abstracted and generalized over the different representation codes by revealing clear discrimination responses (at 1.2 Hz) of the deviant numerosity from the base numerosity (both presented in various codes), recorded over parieto-occipital electrodes. Crucially, and supporting the claim that discrimination responses reflected magnitude processing, the presentation of a deviant numerosity distant from the base (e.g., base “2” and deviant “8”) elicited larger right-hemispheric responses than the presentation of a close deviant numerosity (e.g., base “2” and deviant “3”). This finding nicely represents the neural signature of the so-called distance effect, an interpretation further reinforced by the clear correlation with individuals’ behavioral performance in an independent numerical comparison task. Our results therefore provide for the first time unambiguously a reliable and specific neural marker of a magnitude representation that is shared among several numerical formats.

Keywords: numerical codes, numerosity integration, magnitude representation, fast periodic visual stimulation, frequency-tagging

38. Implicit Learning: Verification vs. Generation Tasks

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Participants learned the union set operation using a methodology borrowed from implicit learning experiments. In two experiments, a stimulus in the learning phase consisted of two groups of objects and a group showing the union of the two groups. The participants were not aware of the rule underlying the relation between the two groups and the union group. After learning, they were told that a rule was hidden in what they saw and were asked to perform two additional tasks according to that rule: 1) a verification task (as in most implicit learning experiments) in which the participants were asked to judge if a displayed result was correct or incorrect, and 2) a generation task in which the participants were asked to indicate which objects belong to the correct result.

We hypothesized that partial understanding of the rule would be sufficient to achieve a high accuracy rate in the verification task, but not in the generation task. Hence, we expected a lower accuracy rate in the generation compared to the verification task.

In the first experiment, participants received 64 learning trials. The accuracy rate of both tasks was very high (above 90%) indicating the union rule can be learned using implicit learning. The expected difference between the verification and the generation task was not found, possibly due to a ceiling effect. Accordingly, we conducted another experiment using only 20 learning trials. Preliminary results indicate significant differences between the verification and the generation accuracy rates, as we expected.

Keywords: implicit learning, rule learning, union, verification task, generation task

39. Math Experiences

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Consistent underperformance in mathematics by students in the United States has attracted concern and attention from educators, psychologists, and researchers, seeking to understand factors influencing mathematics learning. Despite the abundance of studies devoted to mathematics aptitude and achievement, research on how individuals experience math has remained relatively fragmented. Herein, we sought to comprehensively characterize and assess individual experiences with math, with a particular focus on negative experiences. Examining the literature on attitudes and anxiety about, cognitive processing of, and physiological responses to mathematics led to the identification of eight potential facets of math experiences: emotional, cognitive, physiological, behavioral, testing, classroom/social performance, self-efficacy, and attitudinal. We generated survey items intended to probe experiences within each of these facets, constructing a preliminary questionnaire of 118 candidate items, comprising positively and negatively framed statements. An exploratory factor analysis of all items revealed two factors aligned primarily according to affective valence, regardless of specific facet. Considering negatively-valenced items separately identified four factors: attitudinal, physiological reactions, educational experiences, and a cognitive/emotional hybrid factor. Contrasting with the somewhat Balkanized literature detailing sub-aspects of math experiences, our results suggest that math experiences tend to organize around several factors, even when examining negatively-valenced experiences in isolation. One unexpected, novel result was that statements about one's physiological responses to math were uniquely identified as an aspect of negative math experiences. Several of these were among the highest loading negative items in the simple bi-valenced factor solution, highlighting the importance of the often-overlooked aspect of self-reported physiological experiences of math.

Keywords: mathematics, math experiences, math anxiety

40. How can 'you' support children's maths word problem solving?

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When information is related to the Self, this prompts processing biases including increased attention and memory. Research has shown that when self-cues are included in educational tasks such as mathematical processing, there can be an increase in children's task performance. We report two experiments that investigated the educational applications of Self in maths . A self-cue, the personal pronoun 'you', was included in maths word problems completed by 7 – 11-year-old (Exp 1) and 9 – 11-year-old children (Exp 2). Task difficulty was manipulated by including addition and subtraction questions (Exp 1, Exp 2), a different quantity of referents (Exp 1), and lexically consistent and inconsistent questions (Exp 2). Accuracy and response time data showed that self-cues tended to facilitate performance, but the effect varied by condition. In Exp 1, self-cues enhanced answer accuracy when problems included a single referent, but had no significant effect on response time. In Exp 2, response time and accuracy were both significantly higher in problems that included a self-cue. Furthermore, unlike Exp 1 the accuracy advantage for self-pronoun problems was greater in higher difficulty questions, with a significant self-advantage emerging in subtraction but not addition questions, and in lexically inconsistent word problems but not consistent problems. The research demonstrates the conditional effectiveness of applying self-cues in maths word problem solving, suggesting that including personal pronouns can significantly facilitate numerical processing in children, but this effect varies by task difficulty.

Keywords: maths, self-cues, attention, self

41. Psychometric Properties of Two Math Anxiety Scales in Norwegian Elementary School Children: Testing Factor Structure and Gender Invariance

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Math anxiety is a phenomenon with considerably negative consequences at all ages, and worldwide it relates to decreased math achievement (Dowker et al., 2016). Over the past years, there has been an increasing interest in understanding the etiology of math anxiety in children. However, there is a lack of consistency and clarity on what dimensions of math anxiety is assessed within different scales. On the one hand, the Abbreviated Math Anxiety Scale (AMAS) consists of two dimensions, math learning anxiety and math evaluation anxiety (Caviola et al., 2017). On the other hand, Achievement Emotion Questionnaire –Elementary school (AEQ-ES) has been specifically developed for children (Lichtenfeld et al., 2012). Specifically, in addition to test- and learning-related math anxiety, the factorial structure of the AEQ-MA presents a dimension on classroom-related math anxiety.

In this study, we translated and adapted the AMAS and AEQ-MA and administrated the scales to 234 Norwegian children in 3rd grade. We compared the psychometric properties of the two scales including their factor structure, internal consistency and measurement invariance across boys and girls. Preliminary results indicates that learning-related math anxiety and classroom-related math anxiety in the AEQ-MA were undistinguishable in our sample, resulting in a 2-factor model. The two-factor model of the AEQ-MA was found to be invariant across gender. The original two – factor structure of the AMAS was confirmed. Both scales show good internal consistency and are significantly negatively related to math achievement. Results will be discussed together with the theoretical and educational implications.

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Keywords: Math Anxiety, Early School Years, Math Performance, Assessment tools, Psychometric properties

42. When Reducing Fractions Hurts and When it Helps Performance

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Students are instructed to always reduce fractions to lowest terms, e.g., to transform 4/6 into 2/3. This raises the question of how people process reducible fractions more generally. We investigated whether people reduce fractions to lowest terms even when it is task-irrelevant to do so, and thus hurts their performance. Forty participants completed a fraction span task where they were they encoded, maintained, and immediately recalled sequences of four fractions. For the 12 experimental sequences, two fractions were reducible and two were irreducible (e.g., 7/6, 4/2, 5/7, 3/9). For the 12 control sequences, all four fractions were irreducible. The results showed that participants reduced the fractions even though it was irrelevant to the task purpose. Their recall was worse for the reducible experimental sequences ($M = 5.85$, $SD = 1.18$) than for the irreducible control sequences ($M = 6.10$, $SD = 1.26$), $t(39) = 2.34$, $p = .025$, $d = 0.21$). We reported this finding at MCLS in 2021. We are currently running a complementary experiment where reducing fractions is task-relevant, and thus doing so should help task performance. The critical change is that the experimental sequences consist of two pairs of fractions where reducing the initial fraction yields the subsequent fraction, e.g., 4/8, 1/2, 6/9, 2/3. We predict that people will reduce the first and third fractions, and this will enable them to chunk pairs of fractions and strategically recall them. Thus, their recall will be better for the experimental sequences than the control sequences.

Keywords: fraction, fraction processing, fraction reduction, span task

43. Where and how many? Toddlers' ability to represent spatial and numerical information separately

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Infants can remember the number of hidden objects and update the representation of the array's numerosity when an object is added or subtracted from the initial set (I). However, this process appears to be modulated by the number of updating operations and the distribution of the objects (II), namely whether two consecutive objects are hidden sequentially in the same location or alternately in two different locations (III). Less is known about the spatial arrangements that infants expect from the hidden arrays and how they influence their numerical representations. Our study adds to this research line by exploring the value that toddlers confer to variations in spatial and numerical arrangements of a hidden set. Toddlers (N=33, Mage=22+3 months) observed the experimenter placing three objects behind two panels located on the left and right side of a stage (e.g. 2 objects in A and 1 in B). In the test, three possible outcomes could be revealed: numerically and spatially expected (e.g. 2 in A and 1 in B), spatially unexpected (e.g. 1 in A and 2 in B), or numerically unexpected (e.g. 1 in both arrays). A mixed effects model revealed that toddlers explored the two arrays more intensively (as measured by the number of shifts from one array to the other) in the numerically unexpected than in the other two conditions. These results confirm previous research by showing that toddlers successfully updated their representations of hidden arrays and suggest that toddlers' memory for numerical information excels memory for spatial arrangements.

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Keywords: Numerical representation, spatial representation, toddlers, memory

44. The Relation Between Home Spatial Activities and Preschoolers' Spatial Skills

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The home mathematics environment (HME) encompasses all math-related interactions, activities, and attitudes parents share with their children in the home that are intended to promote the development of their mathematics knowledge (Daucourt et al., 2021). Studies have generally focused on the numeracy aspects of the HME (i.e., home numeracy environment [HNE]; LeFevre et al., 2009; Skwarchuk et al., 2014); however, much less work has examined home activities targeted at promoting children's spatial skills (Hart et al., 2016; Zippert et al., 2020). The goal of this study was to examine whether families' engagement in home spatial activities (e.g., playing with puzzles, building with Lego blocks) predicted children's performance on a spatial assembly task. Participants included 125 3- to 5-year-old children (59 female) and their parents. Parents reported the frequency of engagement in eight home spatial activities. Children's spatial performance was assessed using the Test of Spatial Assembly (TOSA; Verdine et al., 2014). Multiple regression analyses were used to examine whether families' home spatial activities predicted their children's spatial performance. Covariates included child's age and sex, parent's education, and families' home numeracy activities. Findings revealed that home spatial activities significantly predicted children's spatial assembly ($\beta = .26$, $p = .026$). Beyond numeracy skills, it is possible for parents to assist building their child's spatial knowledge and skills through home spatial activities. Future research should continue to examine spatial activities in addition to numeracy activities within the home setting.

Keywords: spatial skills, home spatial environment, early childhood

45. Computational estimation performance as a predictor for math achievement

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Computational estimation can be defined as providing an approximate answer to an arithmetic problem without precisely calculating the actual answer. This skill involves a complex interplay of various types of mathematical knowledge and skills including conceptual knowledge (e.g., recognizing that there are several ways for obtaining an estimate), procedural knowledge (e.g., being able to modify the problem to arrive at a mentally more manageable problem), and arithmetic knowledge and skills (e.g., mental computation skills) (Sowder, 1992). Given the multi-faceted nature of computational estimation, the present study investigated the extent to which computational estimation performance was predictive for mathematics achievement in third grade of primary school. A group of 316 children was longitudinally followed from the third year of kindergarten until the third year of primary school. Children's computational estimation performance was tested each year in Fall. In third year of kindergarten we also assessed their domain general skills (i.e., WM span and non-verbal intelligence) in the Fall and their basic numerical skills (e.g., number comparison, verbal counting, object counting) in the Spring. A series of hierarchical regressions was conducted in which SES, domain-general and basic numerical skills were always introduced in the first step and computational estimation performance of the respective time point in the second step. It was found that, from the first year of primary school onwards, verbal computational estimation performance was a significant predictor of math achievement above and beyond SES, domain-general and basic numerical skills. The results and their implications will be discussed at the meeting.

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Keywords: computational estimation, math achievement, longitudinal data

46. Relations of ANS Acuity, Visual Spatial Working Memory, Inhibition, and Sustained Attention Across the Range of Math Ability in Preschool Children

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Approximate number sense (ANS) acuity on incongruent trials (in which set magnitude and spatial cues are inversely proportional) have differentiated children with dyscalculia from typical peers (Bugden & Ansari, 2016; Fuhs & McNeil, 2013; Wilkey et al., 2020). Domain-general cognitive abilities (visual spatial working memory, and inhibition), and not ANS acuity, have shown to account for individual differences on these trials (Bugden & Ansari, 2016; Fuhs & McNeil, 2013). However, prior studies relied on cut-points to determine differences between students with dyscalculia and those who are typically developing. We aim to explore relations of ANS acuity, visual spatial working memory, inhibition, and sustained attention, and to examine these relations across the distribution of math ability. Our sample included over 500 children, measured at the end of preschool. Results from the OLS regression found that incongruent trials, visual spatial working memory, and inhibition were all significant predictors of TEMA-3 performance. However, quantile regression models showed that incongruent trial accuracy and domain-general cognitive competencies predicted math ability at different points along the continuum of math ability. Findings for cognitive competencies at different levels of math achievement will also be presented and discussed in relation to previous findings using cut-points for math achievement.

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Keywords: ANS, Cognition, Math, Preschool

47. Middle-school students' preferences for visual features of tape diagrams and their relation to symbolizing equations

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Tape diagrams, an increasingly common visualization in middle school math curricula, represent linear equations by using horizontal bars, or tapes, that are proportional to the values in equations. Additional visual features, such as color or lines at the bar boundaries, are sometimes used in tape diagrams; however, little information is available about peoples' preferences for visual features of tape diagrams and their relation to learning. One study (Bartel et al., 2021) has systematically analyzed teachers' preferences for visual features, but no research has explored the preferences of the middle school students who are learning from tape diagrams. Understanding these preferences and their relation to student learning are important for increasing student achievement in algebra. The current study investigates middle school students' preferences for specific visual features of tape diagrams and analyzes whether these preferences are associated with a greater understanding of how tape diagrams represent equations. Preliminary results from 26 students (15 6th grade, seven 7th grade, six 8th grade) show that students have clear preferences for certain visual features of tape diagrams. Specifically, students prefer tape diagrams with salient visual features (e.g., color, lines, specific location of the constant) and using dashed lines to depict subtraction. These preferences align with preferences held by middle- school teachers (Bartel et al., 2021). Students' accuracy in symbolizing equations did not depend on these preferences. Data collection and analysis is ongoing. These findings inform future designs of tape diagrams for mathematics curriculum and instruction.

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Keywords: Algebra, Visual Representations, Math Cognition

48. Implicit and Explicit Measurement of Math Anxiety

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Math anxiety is defined as distress or anxiety felt with the performance of mathematics. Previously, Rubinsten et al. (2010; 2012) created the Arithmetic-Affective Priming Task (AAPT) to test whether an implicit measure could be used to study math anxiety. During this task, participants are primed with words categorized as negative, positive, neutral, or related to mathematics, and then asked to complete a short math task. Faster reaction time on trials with negative primes has been used as evidence for a negative association with mathematics. The purpose of the current study was to directly test the association between the AAPT and a validated explicit measure of math anxiety. We hypothesized that reaction time on negative prime trials of the AAPT would have a negative association with score on the validated explicit math anxiety measure. A sample of 78 undergraduate students completed the Short Mathematics Anxiety Rating Scale (sMARS) questionnaire to measure explicit math anxiety, the AAPT, to measure implicit math anxiety; the WRAT-5 to measure math skills; and a short demographics survey. The relationship between implicit and explicit math anxiety was the opposite as predicted: negative prime trial reaction time on the AAPT showed a weak positive correlation with explicit math anxiety score ($r = 0.179$). Therefore, the AAPT not detect math anxiety.

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Keywords: math anxiety, affective priming, mathematics, implicit measurement, explicit measurement

49. Parents' approaches to early numeracy support do not match the approach they think is most important

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Parents' beliefs influence the early numeracy support they provide their children (1,2). The current study addresses how well parents' beliefs about the best approach for supporting children's math development align with their use of that approach, whether it varies by parent education, and how this relates to their numeracy support.

Participants were 89 parents (69% mothers) of 3- and 4-year-olds (52% female) who completed an online survey. Most were White (72%) with at least their bachelor’s degree (39% of mothers, 75% of fathers) and had low to middle incomes.

Most parents (40%) reported using the approach of incorporating math during daily routines most often, with 29% incorporating math during activities their child enjoys and 20% providing math-related toys most often. Notably, only 10% of parents reported using the approach of direct teaching most often. However, when a subset of parents (N = 45) were asked to rank the approaches by importance, most parents (60%) chose direct teaching as most important, with 22% choosing math-related toys, 9% choosing daily routine, and 9% choosing activities their child enjoys. At the individual level, most parents (89%) showed a mismatch in the approach they use most often and what they believe is most important. Parents' use and beliefs were unrelated to the frequency of their numeracy support and parents' endorsement of direct teaching over the other approaches did not vary by parent education (bachelor's vs. no bachelor’s degree). Future research is needed on why and how parents use different approaches to home math support.

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Keywords: home math environment, parents' beliefs, early numeracy

50. Fraction Magnitude Understanding Across Learning Formats: an fMRI Study

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Previous research has demonstrated that both children and adults display considerable difficulty working with numbers represented as fractions (Bailey et al., 2015; Stigler et al., 2010; Wortha et al., 2021). The current education curriculum teaches fractions predominantly through the area model and then later introduces number lines as an instructional tool (Gunderson, 2019). Previous behavioural work has demonstrated that training on the number line yields a significant improvement in performance on fraction magnitude tasks in comparison to the area model (Hamdan & Gunderson, 2017). However, it is currently unknown how fractions represented using area and number line models are processed in the brain. Brain imaging has the potential to better explain common and discrete mechanisms underlying the processing of fractions represented using different formats. Thus, the present study aims to fill the aforementioned gap through use of functional brain MRI methods to examine the neural activity of adult participants in response to fractions presented in number line and area model formats. While in the scanner, participants will be asked to complete a verification task to indicate whether the model correctly or incorrectly displays the given fraction. A whole-brain scan will be collected, and a contrast of the models will be run to determine whether there are significant differences in the neural response between the two formats. It is predicted that the number line is a more intuitive model for understanding fraction magnitude, thus, we anticipate to observe greater fronto-parietal activity, namely around the intraparietal sulcus, for number line format tasks.

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Keywords: Fraction magnitude, MRI methods, learning formats

51. Gender Differences in Math Anxiety and positive feelings towards mathematics: evidence from elite STEM students

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It is not only cognitive abilities, but also emotional aspects such as (mathematics) anxiety and feelings towards the subject, which influence mathematics achievement. Several of these factors appear to be particularly disadvantageous for female students. However, the main focus of the existing studies has been on negative feelings, and little is known about positive feelings such as experiencing flow, relaxation, "Eureka" moments, and beauty when dealing with mathematics. In addition, most of the existing studies focus either on students with mathematics difficulties or on samples with unspecified mathematics skills level. Students enrolled in elite STEM programs (and consequently, gender differences in this population) have been neglected. By investigating elite STEM students in one of the most prestigious technical universities worldwide (n>4500), we uncover relatively unexplored aspects of human experience related to mathematics. Preliminary results show that women reported higher anxiety levels than men. At the same time, they also reported more positive feelings about mathematics (except for "experiencing beauty when dealing with mathematics", where men scored higher). These differences held irrespective of the mathematics-heaviness of programs in which students were enrolled. Correlations between anxiety and positive feelings towards mathematics were very similar between men and women. These observations suggest that even though experiencing higher mathematics anxiety, women also experience more positive feelings toward mathematics. Moreover, low correlations between positive and negative feelings towards mathematics suggest that these are not mutually exclusive.

Keywords: Gender differences, mathematics anxiety, positive feelings towards mathematics

52. Preserved retrieval learning and impaired consolidation learning of arithmetic in math anxious individuals

Cynthia Marie Fioriti* (1), Rachel Pizzie (1,2), Ian Lyons (1)

1: Georgetown University, United States of America; 2: Gallaudet University, United States of America

Research has shown that high math anxiety (HMA) detrimentally impacts math performance; however, limited work has examined how math anxiety impacts mathematical learning. One possibility is that HMAs experience a disruption of working memory and attention thereby imposing global limitations on math learning relative to LMAs. Alternatively, HMAs may seek to avoid computationally demanding challenges in exchange for selectively enhancing short-term learning for memorized math facts. To observe possible differences, we examined HMA and LMA learning of math problems requiring either explicit memorization or skills-based consolidation. Adult participants (N=86) completed 648 difficult multiplication trials (123x4=?) in 2 sessions across 2 consecutive days (1 session per day). Feedback in the form of the correct answer was given after each trial. Half of these were repeated problems (6 problems repeated twice per block), and the other half were never repeated. To examine short-term vs consolidation learning, we examined performance improvements within and between sessions. For non-repeated problems, low-math anxious individuals (LMAs) showed significantly greater learning, which was driven by greater consolidation between sessions. For repeated problems, high math anxious individuals (HMAs) showed a learning trajectory comparable to their LMA peers, with both groups showing the largest learning gains within the first session. Together, these results reveal different learning trajectories for LMAs and HMAs depending on the type of information being encoded and provides evidence in support of our selective enhancement hypothesis. In context, this work reveals that learning through repetition may prevent HMAs from falling behind their LMA peers in math fluency.

Keywords: Math Anxiety, Learning, Consolidation

53. Math Anxiety and Emotional Expressivity

Rachel G. Pizzie* (1), Rachel Ann Inghram (1), David J.M. Kraemer (2)

1: Gallaudet University, Washington, D. C., United States of America; 2: Dartmouth College, Hanover, NH, United States of America

Math anxiety is characterized by feelings of nervousness or apprehension when presented with numerical representations or performing mathematical computations. Math anxiety is associated with avoidance of math, causing decreases in math performance, and shying away from taking further math courses and quantitative careers. Past research has implicated social communication as a contributing factor in math anxiety. For example, past research has illustrated that more math anxious parents tend to have more math anxious children, indicating intergenerational communication of math anxious attitudes. Similarly, teachers who have increased anxiety may communicate this anxiety to their students, especially if the students are female. This research explores the role that affective communication may play in math anxiety, investigating how emotional expressions may be way in which math anxiety may become “contagious” from one individual to another. Using an affective priming paradigm, this research investigates how math anxious individuals are affected by negative expressions displayed by peers, thus examining a potential nonverbal mechanism by which math anxiety may be communicated and spread across individuals. In addition to behavior, this research explored how physiological measures of affect an be used to observe how correlates of negative emotion may be influenced by observing and potentially mimicking the negative affect of others. We hypothesize that math anxious individuals will be increasingly sensitive to negative affective stimuli and this will result in decreased performance when negative cues are present. Furthermore, we hypothesize that increased mimicry of negative affect in math anxious individuals will have a detrimental effect on performance.

Keywords: affect, math anxiety, mimicry

Symposia: 2:30pm - 4:00pm

Towards Math Equity for All Students: the Link between Math Anxiety, Match Achievement, Math Avoidance and Career Interests

Chair: Maria Chiara Passolunghi

University of Trieste, Italy

It is well established that math learning is influenced by affective factors such as math anxiety (MA), which is recognized to negatively impact achievement, cognitive resources, and attitudes. Deeper knowledge of MA risk profiles could explain and predict short, middle, and long-term achievement outcomes leading to a better understanding of emotional processes involved. The present symposium links research on different facets of MA shedding light on individuals' cognitive processes, attitudes, behaviors, and even career choices. The presentations will provide meaningful insights into the underlying mechanisms of MA discussing the practical implications and the social disadvantages that this condition poses.

Keywords: Math anxiety, Math achievement, Cognitive abilities, Attitudes toward math, Career choices

Presentation 1: Math Anxiety and Math Abilities: the Moderating Role of Visuospatial Working Memory

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Cuder, Alessandro (University of Trieste, Italy); Pellizzoni, Sandra (University of Trieste, Italy); Passolunghi, Maria Chiara (University of Trieste, Italy)*

It is well established that mathematical achievement is influenced by cognitive and affective factors, while the interaction between them has been scarcely explored. According to the Processing Efficiency Theory (PET), math anxiety (MA) could interfere with working memory (WM) resources through negative intrusive thoughts, leading to poor mathematical performance. However, literature reached inconsistent conclusions on whether higher or lower WM capacity individuals are more influenced by MA. Few studies focused on how the interaction between MA and WM would affect different aspects of math proficiency, especially in younger students. The aim of the present study was to investigate whether visuospatial WM moderates the relationship between MA and math performance examining simple slopes on different math tasks. Participants of the study were 197 primary school students (Mage= 9.69, SDage= 1.19; 98 female). Children were tested on general anxiety, MA, WM and three different math tasks (approximate calculation, math fluency and matrix reasoning). Results showed that visuospatial WM moderates the relationship between MA and math performance only when the approximate calculation and math fluency tasks were considered. Simple slopes revealed that participants high in visuospatial WM capacity were affected more negatively by MA. The interaction between MA and visuospatial WM seemed not to influence the matrix reasoning task. Overall, results suggest that MA and WM interact in determining the performance on different math outcomes and this effect could depend on the task characteristics.

Presentation 2: Math Anxiety and Arithmetic Problem-Solving: the Role of Perceived Difficulty and Gender

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Doz, Eleonora (University of Trieste, Italy); Pellizzoni, Sandra (University of Trieste, Italy); Passolunghi, Maria Chiara (University of Trieste, Italy)*

A crucial component of the mathematics curriculum at all levels of education is represented by arithmetic word problems. Previous studies have extensively investigated the role of cognitive factors underlying arithmetic problem-solving in primary school students. However, more recently it has been reported that also emotional aspects such as math anxiety (MA) could impact arithmetic problem-solving achievement. Some finding suggested that perceiving a task as demanding might result in higher negative affect and anxiety which, in turn, would impair students' performance on a task. However, the relation between perceived difficulty, MA and math achievement has not been explored yet. Moreover, although many studies reported that female students tend to have higher levels of MA compared to males, it is not clear whether this gender difference is present since primary school. Thus, the purpose of this study was to evaluate the role of MA and perceived difficulty of the task on arithmetical problem-solving achievement of Grade 5 students (N=81). In addition, we investigated gender differences in MA, perceived difficulty, and problem-solving proficiency.

The mediation analysis showed that MA fully mediated the relationship between perceived difficulty of the task and problem-solving performance. Moreover, the findings confirmed that female students had higher MA levels, however no gender difference was found in the problem-solving accuracy nor in the perceived difficulty of the problems. Findings are discussed in terms of math educational context, and they underline the need to take into consideration MA and perception of difficulty when developing word-problem interventions.

Presentation 3: Measuring Math Avoidance in Children to Better Understand Its Relation with Math Anxiety and Achievement

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Conlon, Rachel A. (Florida State University, United States); Krentz, Victoria L. (Florida State University,United States); Dasher, Jamie M. (Florida State University, United States); Merritt, Kelsie E. (Florida State University, United States); Ganley, Colleen M. (Florida State University, United States); Hornburg, Caroline B. (Virginia Tech University, United States); Meyer, Alexandria (Florida State University, United States); Hart, Sara A. (Florida State University, United States)*

Theories on the relation between math anxiety and achievement suggest that math anxiety may lead children to avoid math learning situations. This may explain lower math achievement. Math-avoidant behaviors are common in adolescents and adults with higher levels of math anxiety, but less is known about this relation in children. One issue is that measures of avoidance often focus on avoiding pursuits like higher-level math classes or STEM careers. Given that math is compulsory for school-aged children, these measures are not suitable for capturing avoidance behaviors in this population. Thus, we sought to develop a self-report math avoidance measure for children that incorporates more common avoidant behaviors in this age group such as lack of engagement in math class, avoidance of voluntary math activities, and reluctance to do math homework, to allow us to understand how children's avoidance relates to their math anxiety.

We piloted an 8-item measure with 115 children aged 7-10 and found that avoidance was moderately correlated with math anxiety (r=.622). Scale reliability was acceptable (a=.73). Next, we conducted cognitive interviews with 12 children aged 7-9 to assess children's understanding and interpretation of the 8 initial items, along with 9 new items. This allowed us to create a revised 10-item measure that contained items that were understood as intended by children. We are now testing out this new measure in a new sample of elementary school children and will be able to examine how it relates to math anxiety, other math attitudes, and math achievement.

Presentation 4: Math Anxiety is related to Gender Differences in Career Interests during Development

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Levy, Hili Eidlin (University of Haifa, Israel); Rubinsten, Orly (University of Haifa, Israel)*

Poor math performance in middle and high school can lead to lower attainment of math-intensive careers. We asked whether math anxiety, which is strongly related to low math achievement, can also predict enrollment in math-intensive careers. Studies have found math anxiety levels accelerate over the school years, and math anxiety is more common among female students. Thus, we measured whether the links between math anxiety and the math load of desired or selected career change over development and differ by gender. In two studies we examined three research populations: ninth grade students (N=127, 68 females), 10th grade students (N=111, 61 females) and university students (N=100, 53 females). In the first study, 9th grade middle school students performed a computation task and completed math anxiety, trait anxiety and vocational interest questionnaires. In the second study, 10th grade high school students and university students completed math and trait anxiety questionnaires and reported their math achievement and career choice.

Results indicated that for females but not males, math anxiety was associated with both interest and enrollment in studies with a lower math load. Furthermore, math anxiety had a direct effect on interest and career choice for female school students, while math achievement mediated math anxiety and career choice for female university students. We suggest that for females, math anxiety's influence on the math load of a career interest and choice emerges in school and persists into higher education. The findings may shade light on the origins of underrepresentation of females in math intensive careers.

Predicting Early Mathematics Difficulties

Chair: Brianna Devlin

Purdue University, United States of America

Difficulties with mathematics begin early and have far-reaching negative implications for future mathematics achievement (Jordan et al., 2009) and career choices. Beyond academic outcomes, mathematics difficulty can affect daily life, such as tasks like cooking, managing finances, and making healthcare decisions (NMAP, 2009). Determining early predictors of difficulty and areas of need is an important first step to providing effective instruction that promotes mathematics understanding for all students.Focused on varied predictors and ages within the early years, the talks included in this symposium will provide various perspectives on early mathematics difficulties.

References:

1 Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: kindergarten number competence and later mathematics outcomes. Developmental psychology, 45(3), 850.

2 Selden, A., & Selden, J. (2009). Reflections on Foundations for Success: The Final Report of the National Mathematics Advisory Panel.

Keywords: mathematics difficulties, early math, individual differences

Presentation 1: Identifying preschool predictors of kindergarten low mathematics performance with classification and regression tree analysis

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Devlin, Brianna (Purdue University); Ellis, Alexa (Purdue University); Day, Elizabeth (Cornell University, Bronfenbrenner Center for Translational Research); Elicker, James (Purdue University); Duncan, Robert (Purdue University); Schmitt, Sara (Purdue University); Purpura, David (Purdue University)*

Differences in learning mathematics can often be explained by various factors and cognitive skills. Research examining differences in mathematical performance has found domain-general (e.g., working memory), domain-specific (e.g., verbal counting), and overlapping (e.g., mathematical language) skills to be predictive of later mathematical achievement (Koponen et al., 2019; Kroesbergen & van Dijk, 2015; Purpura et al., 2017). However, prior research examining classifiers of risk status has focused on specific developmental periods (e.g., preschool; Purpura et al., 2017) or solely general predictive relations. This study uses classification and regression trees (CART) as a data-based analytic approach to determine preschool classifiers of kindergarten low performance in mathematics. In the fall of preschool, children (N = 506) were assessed on a battery of skills including executive functioning, mathematical language, numeracy, global school readiness, receptive vocabulary, and mathematics. These skills, along with demographics variables, were used to predict kindergarten low mathematics performance. CART analysis uses step-wise partitioning to create increasingly similar sub-groups using the multiple predictor variables. Results indicated that the most consistent classifiers of kindergarten low mathematics were preschool mathematics and mathematical language skills. Findings are aligned with past work showing that early mathematical language is a strong predictor of mathematical skill within the preschool year (Purpura et al., 2017), and demonstrate its importance as a predictor of low mathematics performance as children enter kindergarten.

Presentation 2: Exploring growth in number competencies among students at risk for mathematics learning difficulties

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Zhang, Haobai (University of Delaware); Devlin, Brianna (Purdue University); Beliakoff, Amber (WestEd); Miller-Cotto, Dana (University of Delaware); Klein, Alice (WestEd); Jordan, Nancy (University of Delaware)*

Early number competence predicts mathematics achievement across elementary school. The present study used the validated Screener for Early Number Sense (SENS) to examine growth in number competencies for children designated at-risk for mathematics learning difficulties (MLD) at kindergarten-entry. Normal Curve Equivalent scores (NCEs) allow for comparison across parallel grade-level SENS forms. Children (N = 150) were assessed in the fall of kindergarten and a year later in first grade, using the appropriate grade-level form and designated as at-risk of later MLD based upon d-based cut-scores (Jordan et al., 2022).

Children were categorized into one of four groups by whether their performance fell below the cut-score: a) at both time points (n = 54), b) in kindergarten only (n=26), c) in first grade only (n =8) and, d) at neither time point (n = 62). Of particular interest were groups a and b, who both entered kindergarten at-risk, but for whom some improved after a year of formal schooling (group b) while others did not (group a). Examining growth, group b grew an average of 16.46 NCEs ($t(25)= -7.2184$, $p< .01$), while group a grew an average of only 2.44 NCEs ($t(53) = -1.43$, $p = 0.16$). Both groups started with the same level of knowledge in number operations, but group b gained significantly more than group a. Logistic regression including the demographic variables of age, gender, income-level, and home language showed that children who were from families with lower-incomes and younger children were more likely to be in group a.

Presentation 3: Exploring the relations between children’s executive functions, math abilities, and their use of gesture in arithmetic contexts

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Gordon, Raychel (University of Maryland, College Park); Ramani, Geetha (University of Maryland, College Park)*

Hand gestures support young children’s math learning. Specifically, they reduce the user's working memory (WM) load during math contexts (Goldin-Meadow &Wagner, 2005). Gestures are one of several observable strategies children use to solve math problems, and with age the type and frequency of these behaviors shift from more basic to more advanced and efficient (Siegler, 1987). For example, younger children typically use more overtly observable strategies (e.g. finger counting), whereas older children use more implicit strategies (e.g. memory retrieval of math facts, Geary et al., 1991). However, less is known about how individual differences in children’s WM and affiliated cognitive capacities (e.g. inhibitory control; IC) relate to the strategic use of gesture during arithmetic problem solving.

Two sets of data will be considered here. First, children ages 5- to 8-year-olds (n=97, Mage=7.04) participated in a Zoom study, where their unprompted arithmetic strategies were recorded, and WM assessed. Overall, children’s individual WM level and age correlated to their use of gesture during arithmetic problem solving. The second involves ongoing replication and extension efforts, including the addition of IC measures. Here, structural equation modeling will be employed to better represent how underlying cognitive factors (e.g. WM, IC, math knowledge) relate to differences in children's observable use of gesture strategies in math contexts. Preliminary results will be discussed in relation to how a child's use of gesture-based strategies at different stages of arithmetic learning may either help or hinder them to overcome early math difficulties.

Discussant remarks

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Clarke, Ben (University of Oregon)*

Instead of a fourth research presentation, we will conclude with remarks by an expert discussant. Dr. Ben Clarke is an associate professor of School Psychology at the University of Oregon. His extensive body of research focuses on early instruction and assessment with the goal of identifying and preventing later mathematics difficulties.

Stimulating and Examining Multiplicative Reasoning

Chair: Jo Van Hoof, Jake McMullen

University of Turku, Finland

Previous studies show that a good understanding of multiplicative reasoning is crucial for learners' numerical development. Accordingly, both in primary and secondary education it forms an essential part of the mathematics curriculum. Nonetheless, ample studies show the struggles learners have with multiplicative reasoning in several domains of mathematics, such as proportional reasoning, fractions, probabilistic reasoning, etc.

The objective of this symposium is to highlight the need for and investigate the effectiveness of supporting and stimulating learners in their development of multiplicative reasoning, starting from the early phases of proportional reasoning to the more advanced fraction understanding.

Keywords: multiplicative reasoning, proportional reasoning, fractions, games, intervention

Presentation 1: Stimulating early proportional reasoning: An intervention study in second graders

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Vanluydt, Elien (KU Leuven); De Keyser, Laure (KU Leuven); Verschaffel, Lieven (KU Leuven); Van Dooren, Wim (KU Leuven)*

Not only children, but also adolescents and adults encounter great difficulties in learning how to reason proportionally. Despite these difficulties, research increasingly shows that proportional reasoning emerges early, before the start of formal instruction in it. There have however been very few attempts to stimulate proportional reasoning at a younger age than is currently done. The aim of the present study was to stimulate proportional reasoning in second graders. We developed a seven-lesson-four-week intervention program focusing on quantitative reasoning, i.e. introducing children to the different kinds of relationships that can exists between quantities and promoting different strategies to solve proportional reasoning missing-value problems. The effectiveness of this program was evaluated in a pretest-intervention-posttest with control group design (n=139). Results showed a large significant effect of the intervention program on children's proportional reasoning abilities as well as a moderate significant effect on the proportional vocabulary that was explicitly used in the intervention program. There was no significant effect on proportional vocabulary that was not explicitly used in the program. We did, however, observe a small but significant effect on word problem solving. During this presentation we will give an overview of the intervention program and zoom in on the results of the intervention study. Moreover, theoretical implications and implications for practice will be discussed.

Presentation 2: Math glasses versus math game. Two interventions for promoting multiplicative relation and fraction knowledge

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Määttä, Saku (University of Turku); Hannula-Sormunen, Minna (University of Turku); Kiili, Kristian (Tampere University Finland); Halme, Hilma (University of Turku); Koskinen, Antti (Tampere University Finland); McMullen, Jake (University of Turku)*

Students' encounter quantitative relations such as multiplicative relations and fractions through their life in formal and informal settings. Although early multiplicative reasoning can support fraction learning (Nunes & Bryant, 2015) and understanding of fractions is seen as integral part of getting by in life and society (Siegler et al., 2012), students' are found to struggle in learning of fractions (NMAP, 2008; Obersteiner et al.; 2013; Ni & Zhou, 2005). Prior research encourages the development of practical ways to support teachers and students in teaching and learning of multiplicative relations and fractions.

This study compares two separate intervention programs including four intervention lessons surrounded by pre- and posttest. First intervention was based on Spontaneous Focusing on Quantitative Relations (SFOR) (McMullen, 2014) with intervention activities in which the aim was to support students' ability to recognize and describe quantitative relations (i.e. multiplicative relations or fractions) in example tasks and their school surroundings. In the second intervention students played a digital Number Trace game (Kiili et al., 2018) which is a highly configurable digital learning environment that is developed to be used in rational number instruction.

The two intervention studies were compared in their effectiveness to support 5th grade students' (ages 11-12) development on tendency to spontaneously focus on quantitative relations (SFOR), multiplicative relations, and fraction knowledge. Pre-registered analysis for the study can be found in https://osf.io/86xku.

Presentation 3: Aspects of fraction understanding are associated selectively with performance on a fraction learning game

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Thoma, Georgios (Loughborough University); Bahnmueller, Julia (University of Tübingen and Loughborough University); Lindstedt, Antero (Tampere University Finland); Kiili, Kristian (Tampere University Finland); Moeller, Korbinian (IDeA Centre, Frankfurt am Main); Ninaus, Manuel (University of Graz)*

Fraction understanding seems a double-edged sword. On the one hand, it is an important predictor of later mathematical achievement. On the other hand, it also is one of the topics students struggle most in secondary math education. To complement traditional instruction, digital learning games were developed and found to successfully foster fraction understanding. However, so far, it is not known which aspects of fraction understanding (e.g., fraction magnitude, part-whole relations, fraction arithmetic) are conveyed by such a game and which may not. The current study evaluated selective associations of in game performance on Semideus (a fraction learning game) with specific aspects of fraction understanding assessed using a comprehensive paper-pencil test. In Semideus, participants are to find gold coins buried along a number line whose location is indicated by fractions. Results replicated previous findings showing that in-game performance was significantly associated with mathematics achievement (i.e., math grades). Moreover, we observed significant associations for aspects closely matching mechanics of the learning game such as fraction ordering and magnitude understanding. This pattern of results was observed for accuracy on the game's fraction learning task (e.g., estimation accuracy on the number line) but also generalized to game-based metrics such as virtual incentives (i.e., stars or coins awarded in the game). This implies that a learning game's mechanic may specifically convey aspects of fraction understanding, substantiating ideas of intrinsic integration in game design.

Discussant

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Obersteiner, Andreas (Technical University of Munich)*

The discussant of the symposium will be professor Andreas Obersteiner, from the Technical University of Munich. His main research topic is understanding and supporting mathematical thinking and learning processes. He has a lot of experience with investigating learners' multiplicative reasoning from the very early stages to even mathematics experts. Therefore, he will be an excellent discussant to address the ways in which we can support the development of learners' multiplicative reasoning and to touch the gaps in the literature that should be addressed by future research.

Eye Tracking in Mathematical Cognition Research

Chair: Gabriella Daroczy, Hans-Christoph Nuerk

University of Tuebingen, Germany

Eye tracking is increasingly used to study the underlying mechanisms of mathematical cognition. Nevertheless, it is still a challenge to properly link eye movements to the assumed cognitive processes during mathematical tasks. This symposium presents findings from eye tracking methodology in various topics of mathematical cognition: from number line estimation, basic arithmetic to more complex word problems. We aim to provide a platform to discuss the potential of using eye tracking in mathematical cognition.

Keywords: Eye Tracking, number line estimation, artimetic, word problems

Presentation 1: Do hatchmarks affect strategy use on number line estimation tasks with fractions? An eyetracking study

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Strohmaier, Anselm R. (Technical University of Munich, Germany); Obersteiner, Andreas* (Technical University of Munich, Germany); Wagner Alibali, Martha (University of Wisconsin-Madison, United States); Marupudi, Vijay (Georgia Institute of Technology, United States)*

Estimating the position of symbolic fractions on number lines is an important facet of fraction competence. Research suggests that providing visual hatchmarks on number lines can improve performance on number line estimation tasks with fractions, but it is less clear how hatchmarks influence strategy use. We recorded eye movements of 34 adults in a number line estimation task with fractions. Items were presented in three hatchmark conditions that varied within-subjects: a no-hatchmark condition (empty number line), a thirds-hatchmark condition (hatchmarks at 1/3 and 2/3), and a quartile-hatchmark condition. In each trial, participants saw a symbolic fraction on the top of the screen and were asked to fixate their eyes on the correct position on the number line at the bottom of the screen. Participants' average accuracy, measured in terms of deviation of their final eye fixation from the correct position, did not vary between the three conditions. However, participants were more accurate and faster when hatchmarks corresponded to the fraction denominators, that is, when denominators were a multiple of the provided hatchmarks (e.g., 5/9 in third-hatchmark condition) than when hatchmarks did not correspond (e.g., 5/9 in the quartile-hatchmark condition) or when there were no hatchmarks. The total numbers of fixations and saccades (rapid eye movements) were larger on items with hatchmarks than on items without hatchmarks, suggesting that participants made use of hatchmarks for orientation. Further analyses of eye movements (in progress) will allow characterizing strategy use in more detail.

Presentation 2: The predictive role of eye movements in mental arithmetic

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Andres, Michael (Psychological Sciences Research Institute, Université de Louvain, Belgium)*

Eye movements provide an interesting window into the mathematical mind. We have developed a method that allowed us to detect subtle gaze deviations during mental calculation. An eye-tracker with high spatio-temporal resolution was used to measure eye movements during the auditory presentation of addition (43+4) and subtraction problems (53-6). Eye movements were observed as soon as the operator was heard, and their direction was predictive of the expected side of the answer on a mental continuum where numbers are represented from left to right relative to the first operand. When the arithmetic operation could be guessed from the magnitude of the first operand, the eyes started to move even before the operator was heard, confirming their predictive role. For instance, numbers on the leftmost end of the continuum elicited rightward movements as soon as they were heard because these were more often selected in addition than in subtraction problems. Further analyses linked the fast deployment of spatial attention to the carrying and borrowing procedures triggered by the problem presentation, suggesting a role in alleviating the working memory load. These new findings show that the cognitive system optimally integrates the terms of the problem to direct spatial attention toward the probable location of the answer on the mental numerical continuum. It is clear from the predictive nature of these attention shifts, which typically occur before the presentation of the second operand, that their primary role is not to identify the exact answer but to reduce uncertainty about its probable location.

Presentation 3: Studying arithmetic word problem solving using eye tracking: A peek into mathematical representations

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Hippolyte Gros, Hippolyte Gros (CY Cergy Paris University); Sander, Emmanuel (University of Geneva, Jean-Pierre Thibaut, Université Bourgogne Franche-Comté); Thibaut, Jean-Pierre (Université Bourgogne Franche-Comté)*

How do adults think about situations involving numbers, and how can we investigate the nature of the mental representations they construct? To tackle this question, we created arithmetic word problems devised to promote contrasting representations and solving strategies. Following recent work on the perception of cardinality and ordinality (Gros, Thibaut, & Sander, 2021), we hypothesized that the use of specific quantities (weights, prices, collections) would foster a cardinal representation of the problems, whereas other quantities (durations, heights, number of floors) would favor an ordinal representation instead. The problems we created were thought to be easily solvable from an ordinal point of view but should require an extra step when solved from a cardinal perspective. We recorded the eye movements of pre-service teachers (N = 50) engaged in a solution validity assessment task on 18 such problems. We compared participants' gaze patterns on the problems to gather insights into their encoded representations. On problems featuring cardinal quantities, we found that specific sentences describing elements relevant in a cardinal understanding of the problems but irrelevant otherwise were looked at longer and were the focus of a higher number of backward eye movements. Additionally, increase in pupil dilation on correctly solved cardinal problems supported the idea that participants needed to engage in an additional step of semantic recoding only on cardinal problems. Overall, the results support the growing line of evidence that daily-life knowledge about the quantities featured in a problem may interfere with its solving by promoting one of two competing representations.

Presentation 4: Number Processing in Arithmetic Word Problems

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Daroczy, Gabriella (University of Tuebingen); Roth, Lilly (University of Tuebingen); Nuerk, Hans-Christoph (University of Tuebingen)*

Word problems require text processing, including reading and building up a mental representation, and number processing, including the choice and execution of the solution-relevant mathematical operation. However, the role of number processing within word problem solving is still unclear: When are the numbers in a word problem processed, and do numbers play a role in constructing the mental model of the word problem? To address this issue, word problem solving was investigated in both adults and children (fifth and sixth graders). The word problems consisted of solvable and non-solvable problems with two two-digit numbers, while manipulating the mathematical difficulty (carry/borrow) of addition and subtraction. The non-solvable word problems were designed to not require number processing at all. In case number processing would play a role in constructing the mental model or at a very early stage of the problem-solving process, an increase attention to the numbers would be expected when word problems require a carry or borrow operation – even in non-solvable problems. We recorded eye-movements and measured the attention to numbers (number and duration of fixations) during word problem solving. The preliminary results for children suggest that numbers indeed played a role in the mental representation of non-solvable word problems. Nevertheless, the involvement of the numerical processing might depend on the mathematical difficulty. The first results from adults will be presented as well.

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