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MATHEMATICAL COGNITION AND LEARNING SOCIETY

Book of Abstracts

The 1st Mathematical Cognition and Learning Society Conference

8th and 9th of April 2018
Examination schools, Oxford (UK)

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Symposia/Parallel sessions: South school, East school, Room 6 and Room 7.
Poster session/Refreshments: North school.
Speakers' room: Room 10.
Luggage deposit: Room 8.
Registration desk: Great hall.

UNIVERSITY OF OXFORD

Sunday 8th of April 2018

Time: 8:00 – 8:30
Room: Great hall

Registration

Time: 8:30 – 10:00
Room: South School

Symposium: **Math and Spatial Anxiety: Correlates and Consequences across Development**

Organiser: Coleen Ganley

Overview: Even after many years studying math anxiety, there are still a number of critical questions to be answered in regard to the development, correlates, and consequences of math anxiety (Dowker, Sarkar, & Looi, 2016). There is also a growing area of work studying spatial anxiety as an important correlate of math anxiety and as an important construct in its own right. Current evidence suggests that both of these anxieties may have important implications for mathematical learning. The talks in this symposium aim to address several key questions about math and spatial anxiety across development. We will cover four main themes across the six talks in this symposium.

Talk 1: **Affective Correlates of Math and Spatial Performance During Elementary School: Gender Differences and Predictive Specificity**
Jillian E. Lauer; Alena G. Esposito; Patricia J. Bauer

Superior mathematical and spatial reasoning abilities in childhood predict greater success in male-dominated science, technology, engineering, and math (STEM) disciplines later in development, yet relatively little is known about the affective correlates of children's math and spatial performance or gender differences therein. In the present research, we assessed math and spatial anxiety in 400 elementary-school children (ages 6 to 11 years) and examined the relations between these anxiety types and children's performance on math and spatial tasks. To determine whether within- and between-gender variability in math and spatial anxiety is specific to those cognitive domains, we also evaluated children's verbal anxiety and verbal ability. Math, spatial, and verbal anxiety were moderately correlated with one another and with children's performance across cognitive tasks, implicating a role for domain-general factors (e.g., general anxiety) in the observed correlations. Importantly, however, when controlling for the other two types of anxiety assessed, each anxiety type only accounted for unique variability in children's performance within the corresponding cognitive domain, suggesting some domain-specificity in the relation between anxiety and cognitive performance during elementary school. Gender differences in anxiety also displayed specificity to male-stereotyped domains: girls reported significantly greater math and spatial anxiety across the age range tested, but there was no gender difference in verbal anxiety. Together, these results demonstrate that math, spatial, and verbal anxiety represent unique constructs early in development, exhibiting specificity in their relations to both gender and cognitive performance within the first years of elementary school.

Talk 2: **Age Differences in Children's Attitudes to Mathematics and Mathematics Anxiety**
Ann Dowker; Olivia Cheriton; Rachel Horton

There is much recent research into attitudes to mathematics, most of which suggests a significant relationship between attitudes and performance. In particular, mathematics anxiety is often associated with worse mathematics performance. This makes it particularly important to study the development of attitudes to mathematics. The present study investigated children's and adolescents' attitudes to mathematics, with a particular focus on whether and how these are affected by age and gender. 216 pupils from Years 2 (6-to 7-year-olds), 6 (10-to 11-year-olds), 9 (13-to 14-year-olds) and 12 (16-to 17-year-olds) participated in the study. They were equally divided as to year group, and each year group was approximately equally divided by gender. They were given (1) the Mathematics Attitude and Anxiety' questionnaire (Thomas & Dowker, 2000), which assesses levels of maths anxiety; unhappiness at failure in maths; liking for maths, and self-rating in maths; and (2) the British Abilities Scales Basic Number Skills Test to establish actual mathematics performance. Age had a significant effect on both liking for maths and self-rating in maths: older children were lower than younger children in both. The decline in attitudes to maths with higher age was steeper in girls. Gender had a significant effect on self-rating: boys rated themselves higher than girls, though there was no significant gender difference in mathematical performance. Self-rating, but not anxiety, was a significant predictor of maths ability for both genders. Some implications for our understanding of mathematics anxiety and attitudes to mathematics are discussed.

Talk 3: **Examining Potential Bidirectional Relations between Math Anxiety and Performance in Elementary School**
Colleen M. Ganley; Amanda L. McGraw; Connie Barroso; Elyssa A. Geer

Past research with young children has found small to moderate concurrent relations between math anxiety and performance. In addition, research on the link between math anxiety and achievement suggests these may relate to each other over time in a bidirectional way. In the present study, we examined whether there were bidirectional relations between math anxiety and performance in young children when measured at three time points over the course of two years. Participants were 313 children who progressed from grades 1-3 in Year 1 to grades 3-5 in Year 3 of the study. With attrition, there were 170 children in Year 3. Math anxiety and math performance were tested near the end of each of three consecutive school years. We conducted a path analysis that modeled both the autoregressive paths and cross-lag paths between each time point. Math anxiety and performance were concurrently related in Year 1, but the model residuals for math anxiety and performance were not related in later years. Math anxiety and performance had significant and strong autoregressive paths, though these were stronger for math performance than anxiety. The cross-lag paths from math performance to math anxiety from Year 1 to Year 2 and Year 2 to Year 3 were statistically significant. However, the paths from math anxiety to performance were not significant at either time. Overall, our results suggest that math anxiety and performance are initially concurrently related and relatively stable over the course of two years. Additionally, there is some evidence that students with lower levels of performance are more likely to develop math anxiety over the course of the next year. These results suggest that early interventions designed to increase math performance and decrease math anxiety may help prevent math anxiety.

Talk 4: **Reciprocal Relations Among Motivational Frameworks, Math Anxiety, and Math Achievement in Early Elementary School**

Elizabeth A. Gunderson; Daeun Park; Erin A. Maloney; Sian L. Beilock; Susan C. Levine

Recent work has established that math anxiety is already present and correlated with lower contemporaneous math achievement as early as 1st and 2nd grades. Here, we asked whether there are longitudinal relations among math anxiety, math achievement, and motivational frameworks (a combination of performance goals and entity theories of intelligence), and whether these relations were reciprocal or directional. We assessed 1st- and 2nd graders' ($N = 634$) math anxiety, math achievement, and motivational frameworks at the beginning and end of the school year, 6 months apart. Cross-lagged path analyses revealed reciprocal effects such that higher math anxiety in the fall predicted lower math achievement in the spring, and higher math achievement in the fall predicted lower math anxiety in the spring. Interestingly, the effect of initial math achievement on later math anxiety ($\beta = -0.20$) was substantially larger than the effect of initial math anxiety on later math achievement ($\beta = -0.06$). We also found a directional effect of motivational frameworks on math anxiety, such that more entity-oriented motivational frameworks in the fall predicted higher math anxiety in the spring, but not the reverse. Finally, entity motivational frameworks were related to lower math achievement in a reciprocal manner. Our results suggest that math anxiety may be both a cause and consequence of low math achievement, and that children's entity motivational frameworks – focusing on performance rather than learning, and believing that intelligence is fixed – may contribute to the development of math anxiety. We conclude that reciprocal relations between children's math skills, beliefs, and emotions reinforce one another over time, leading to either a vicious or virtuous cycle. These results underline the importance of promoting early math learning and math attitudes for setting children onto a positive trajectory in math.

Talk 5: **Math Anxiety in U.S. Adults: Prevalence and Correlates**

Sara A. Hart; Colleen M. Ganley

Math anxiety is under intensive study right now, but we are not aware of any recent work simply describing the nature of math anxiety in the general U.S. adult population. Hembree (1990) used meta-analysis to characterize the nature of math anxiety, however, the eldest participants in the samples were undergraduate students, and this work is almost thirty years old. We sought to use a well-powered, preregistered study of a sample of adults in the U.S. to update Hembree's work and set a contemporary baseline for research describing the nature math anxiety in adults, focusing on correlates and subgroup analyses. The combined final sample of 1000 participants recruited through Mechanical Turk and social media was 56.51% female, with a mean age of 36.84yrs old (SD = 12.01yrs, range = 18-74yrs). The sample was 80.67% White, 10.22% Black or African American, 6.03% Asian, 1.84% Multiracial, 1.02% American Indian or Alaska Native, and .20% Native Hawaiian or Other Pacific Islander. The sample was 5.50% Hispanic/Latino, with a mean household income of $56,255.03. We found that our sample's average math anxiety was normally distributed, with average scores between "some" and "moderate" math anxiety, with 5.4% of the sample reporting "quite a bit of anxiety". Math anxiety was significantly negatively correlated with probability knowledge and math fluency, and significantly positively correlated with general anxiety and test anxiety. No correlation was found between math anxiety and income or age. Differences were found between men and women, with women showing significantly higher math anxiety. No differences by race or ethnicity were found. Participants who had completed graduate school, or had a STEM career, had significantly lower levels of math anxiety than those who had less education, or non-STEM careers. In sum, our results are remarkably similar to Hembree, and broader implications of this will be discussed.

Talk 6: **Spatial Anxiety Scale – A Novel Tool with Applications for STEM Education**
Ian M. Lyons; Richard J. Daker; Moriah Sokolowski; Zachary Hawes; Gerardo Ramirez; Erin A. Maloney; Danielle N. Rendina; Susan C. Levine; Sian L. Beilock

Spatial skills are a strong predictor of achievement and pursuit of employment in STEM fields. However, some individuals experience anxiety arising from situations that require performing spatial tasks, and may thus avoid spatial mental activities, including mathematics. We present a new instrument that assesses anxiety about three different common spatial abilities: navigation, mental-manipulation and imagery. The three subscales are high in internal reliability, selectivity, and external validity. Next, we show how the new scale can help understand a critical issue in education: why women tend to be under-represented in STEM fields. A large body of research has documented that females experience more math anxiety than males. We show that women tend to be higher in spatial anxiety as well. In addition, we show that processes within the spatial domain but not in the mathematical domain mediated the relation between sex and math anxiety. Moreover, within the spatial domain, spatial anxiety was the strongest mediator between sex and math anxiety, even after controlling for general anxiety. This raises the possibility that sex-differences in math anxiety may be rooted in sex-differences in anxiety about or avoidance of spatial strategies in solving mathematical tasks. In sum, we present an empirically validated spatial anxiety scale that respects the multifaceted nature of spatial processing, and has the potential to provide a more comprehensive screening tool for identifying potential barriers to STEM education.

Time: 8:30 – 10:00
Room: East School

Parallel session: **Numerical processing 1**

Chair: Christine Schiltz

Talk 1: **Role of domain-general processes in numerosity estimation : A life-span study of congruency effects and their sequential modulations in dot comparison tasks.**
Patrick Lemaire; Angélique Roquet; Celine Poletti

Numerosity estimation has been found to crucially involve domain-general cognitive processes (e.g., inhibition) and domain-specific (e.g., numerical) processes. The present study brings evidence of a new type of domain-general processes, namely sequential modulations of executive control processes. Children (second, fourth, and seventh graders) as well as (young and older) adults were asked to accomplish a dot comparison task (i.e., they were presented two dot arrays and had to select the largest array). First, participants' performance revealed congruency effects, as they were slower on incongruent items (i.e., visual cue mismatched numerosity) than on congruent items (i.e., visual cue matched numerosity). Also, congruency effects were smaller on current items after processing incongruent items than after congruent items. Finally, age-related differences in sequential modulations of congruency effects were found both in children and in adults. These age-related differences depended on participants' executive control processes. For example, older adults with highly efficient executive control processes sequentially modulated congruency effects with comparable magnitudes than young adults. In contrast, older adults with less efficient executive control processes showed no sequential modulations of congruency effects. Such individual differences were also found in children. These findings have important implications to further our understanding of how general cognitive mechanisms contribute to numerosity estimation performance and how such contribution changes during children and adults' cognitive development.

Talk 2: **The Evolutionary Role of Continuous Magnitudes in Magnitude-Related Decisions**
Tali Leibovich-Raveh; Shai Gabay

Magnitude discrimination is crucial for humans and animals. E.g., swimming with a larger shoal of fish increase the fish's chances of survival. According to the 'number sense' theory, such a decision is made possible due to an innate ability to discriminate numerosities. An alternative suggestion would be that both humans and animals use not only number but also continuous magnitudes (like the total area of the fish in the shoal) in making such decisions. Accumulating evidence points to a strong involvement of continuous magnitude in numerosity comparison in humans. In the current study we examine the suggestion that like humans, animals, specifically archerfish, are highly affected by continuous magnitudes. Since fish and humans diverged 200 million years ago, studying this fish can shed light on the evolutionary origin of magnitude discrimination. Archerfish can be trained to respond to artificial targets shown on a computer monitor above a water tank in an experimental setting. Accordingly, archerfish can be used as the fish equivalent of a human subject reporting psychophysical decisions by pressing a key. To test the natural preference of archer fish (n=5), we presented the fish two dot arrays, and rewarded response to each array (240 trials per fish). We manipulated the number of the continuous magnitudes that were congruent (correlated with number) or incongruent (anticorrelated with number). We found that selecting the array with the larger number increased with the number of continuous magnitudes congruent with numerosity. Specifically, when most continuous magnitudes were concurrent with numerosity, fish were more likely to choose the numerically larger array. Yet when most continuous magnitudes were incongruent with numerosity, fish were more likely to choose the numerically smaller array. This pattern of results supports the suggestion that continuous magnitudes play an important role in magnitude-related decisions across evolution.

Talk 3: **Simulating the approximate number system with deep learning: Role of continuous visual cues and emergent encoding of numerosity**
Alberto Testolin; Marco Zorzi

Recent computational modelling work has shown that visual number sense can emerge as a high-order statistical feature of visual sets from unsupervised learning in deep neural networks, where the goal is to learn a hierarchical generative model of images (Stoianov & Zorzi, 2012, Nat. Neurosc.). Further research has revealed that numerosity discrimination can be supported even by untrained neural networks endowed with basic visuospatial processing, suggesting that a form of innatism based on architectural and learning biases is a viable approach to understanding the origin and development of number sense across species (Zorzi & Testolin, 2018, Philos. Trans. Royal Soc. B). At the same time, analysis of the emergent computation in the network has shown that, following learning, some neurons in the deepest layer become specifically tuned to number, that is, their activation profile is mostly modulated by changes in discrete numerosity rather than to other continuous variables, such as cumulative area. Here we more systematically investigate the effect of the manipulation of continuous visual properties in a numerosity discrimination task by adopting a recently proposed stimulus space (DeWind et al., 2015, Cognition), which allows to carefully measure the contribution of the various non-numerical cues (e.g., cumulative area, total perimeter, item size, convex hull, density, etc.) to numerosity judgment. We show that numerosity discrimination in the deep network is modulated by continuous visual cues in a way that closely mimics the performance of human observers, thereby further extending the range of empirical phenomena explained by the computational model. In particular, it turns out that numerosity is by far the most relevant dimension for carrying out numerosity discrimination tasks; however, as for human participants also non-numerical visual features affect discrimination performance. Finally, by analysing the activation profiles of the neurons when the network is probed using this carefully controlled stimulus space we are able to more precisely characterize the emergent encoding of numerosity in the model.

Talk 4: **Non-numerical cues are (roughly) irrelevant to determining the content of our numerical thoughts**
Justin Halberda

Infants, children, and adults of all cultures, as well as many non-human animals, share an Approximate Number System (ANS) that allows them to rapidly estimate the approximate number of items or events in a stimulus. What are the perceptual foundations for this ability – what cues do we rely on – and how do such cues relate to the content of our number representations? A seductive notion is that participants rely on continuous extent cues (e.g., total area, perimeter, density) in approximate number tasks, and that the resulting representations therefore lack numerical content. Here I suggest that such claims embrace a fallacy – that it is the input to our later representations that determines their content. In this presentation, I will begin by describing a challenge we face when characterizing the content of our mental representations – what role do input, computational transformation, and output each play in determining the content of our thoughts? I will then explore the specific case of the representations of the Approximate Number System (ANS). Lastly, I present an argument that the input to our representations never wholly determines the content of our representations – even though many have erroneously thought it so. In conclusion, I urge that we must look to both the input and the output of computations to determine the content of the requisite representations. My conclusion is that approximate number representations are in fact numerical, even if it turns out that we rely on input from continuous extent cues as evidence for them.

Talk 5: **Understanding prices: Electrophysiological evidence of fully compositional analysis**
Fernando Ojedo; Pedro Macizo

We evaluate if the processing of two-digit prices involves fully compositional analysis (separate processing of the numerical value and monetary category, and separate processing of decades and units comprising the numerical value of prices) or a mixture of compositional and holistic analysis (separate processing of the numerical value and monetary category but holistic processing of decades and units). Event-related potentials (ERPs) were recorded when participants chose the higher of two prices presented sequentially. Prices were number-monetary (NM) compatible when the digits and the monetary category of one price were higher than those of the other price (38 euros - 26 cents, 38 > 26 and euros > cents), and NM incompatible when the number of one price was larger but the monetary category smaller than those of the other price (49 euros - 57 cents, 49 < 57 but euros > cents). Furthermore, prices where unit-decade (UD) compatible when the decade and unit of one price were larger than those of the other (47 euros - 59 cents, 4 < 5 and 7 < 9), and UD incompatible when the decade of one price was larger but the unit smaller than those of the other (36 euros - 28 cents, 3 > 2 but 6 < 8). Regarding behavioural data, the NM compatibility effect was found (slower responses and more error rates on incompatible trials than on compatible trials) but not the UD compatibility effect. However, the ERP data in the 350-500 ms time window revealed NM compatibility effect (more negative amplitudes on incompatible trials relative to compatible trials), and DU compatibility effect in the NM incompatible trials. Together, behavioural and electrophysiological data suggest that the processing of two-digit prices is fully compositional.

Talk 6: **Finger dexterity of the pointing hand is linked to dot counting abilities.**
Catherine Thevenot; Nolwenn Guedin

Children with and without finger dexterity impairment were asked to count a set of 4 to 9 dots presented on a computer screen. Despite the fact that, during the task, none of the children used their fingers to point the dots, we show that their finger dexterity was linked to their performance. Interestingly, this correlation was significant only when the dominant hand, or in other words the hand they use to point objects, was considered. We interpret these results within the embodied cognition framework.

Time: 8:30 – 10:00
Room: Room 6

Parallel session: **Maths achievements 1**

Chair: Marie-Pascale Noël

Talk 1: **Identifying children with persistent low math achievement throughout elementary school years**
Terry Tin-Yau Wong; Winnie Wai-Lan Chan; Gary Kam-Chun Tam

While there has been an increasing number of research studies investigating the cognitive deficits related to difficulties in learning mathematics, little is known about whether these cognitive deficits longitudinally predicted low mathematics achievement in the long-run. The current six-year longitudinal study was conducted to address this issue. A sample of 101 kindergarteners was tested on various numerical and cognitive competencies when they were in the kindergarten and in Grade 1. They were then followed until they were in Grade 6, in which their mathematics achievement was assessed bi-annually. A group of persistent low mathematics achievers (PLA) who scored consistently below the 25th percentile was identified. This group of PLA showed difficulties in most of the numerical and cognitive tasks as early as in the kindergarten. More importantly, by employing three of the early predictors, 78% of the PLAs were correctly identified. The current findings provided valuable information concerning the core cognitive deficits underlying the difficulties in learning mathematics as well as an important tool for educators for identifying children who are at risk of persistent math learning difficulties in the elementary school years.

Talk 2: **Persistent mathematics learning difficulties from childhood to adolescence in very preterm children**
Sarah Clayton; Lucy Cragg; Camilla Gilmore; Neil Marlow; Victoria Simms; Rebecca Spong; Samantha Johnson

Previous research has found that primary school-aged children born very preterm (VP; <32 weeks) have significantly lower mathematics achievement than their term-born peers. The move from primary to secondary education imposes greater cognitive demands and the mathematical ideas and procedures to be learned become increasingly complex. It is not yet known whether VP children's mathematical difficulties remain consistent in the transition to secondary school, or whether they either catch-up or fall further behind. The present longitudinal study assessed the mathematical skills of 83 VP children and 49 term-born controls, who were matched for age and sex, and attending mainstream school. Each participant completed standardised tests of mathematics achievement and nonverbal IQ at primary school (Mean age=9.6 years) and again at secondary school (Mean age=13.6 years). Mathematics achievement was assessed using the Wechsler Individual Achievement Test-II (WIAT-II) Numerical Operations and Mathematical Reasoning subtests and non-verbal IQ with the Raven's Coloured Progressive Matrices (CPM, primary) and Raven's Standard Progressive Matrices Plus (SPM+, secondary). Results showed that VP children had significantly lower IQ scores (M=100.5) in comparison to their term-born peers (M=109.9) at primary school ($t(130)=3.24$, $p=.002$) and secondary school (VP M=93.8, control M=100.4; $t(130)=2.08$, $p=.039$). Likewise, VP children demonstrated significantly poorer mathematics achievement than term-born controls at both time points (primary: VP M=93.1, control M=107.9; $t(130)=4.25$, $p<.001$; secondary: VP M=95.5, control M=110.5; $t(130)=4.10$, $p<.001$). Group differences were stable over time and persisted after controlling for IQ. There were no significant differences in socioeconomic status between groups. The present results indicate that VP children in mainstream school are at an increased risk for persistent mathematics difficulties and do not catch up with their term-born peers despite greater levels of additional learning support. Research is needed to elucidate the cognitive mechanisms underpinning these difficulties to develop interventions to support VP children's attainment at school.

Talk 3: **Complexity and plasticity of number processing in a case of developmental dyscalculia**
Vitor Haase; Maria Raquel S. Carvalho; Borges Júlia; Isabella Starling-Alves; Giulia Moreira-Paiva

Group comparison studies implicate basic number processing deficits in developmental dyscalculia (DD). It is not known if DD is related to an approximate number representational deficit or to impairments in accessing nonsymbolic numerical representations from symbolic ones. If number processing is consistently implicated in DD, case studies could contribute to characterize profiles of impairment. At the time of assessment, JP was a 10 years old boy attending to the 4th grade. JP was clinically referred because of DD. His FSIQ was 102 and he did not present difficulties with other academic subjects or emotional/behavioral problems. He was aware of his difficulties but not anxious or demotivated. The Rey figure copy and executive functions (selection, inhibition, and shifting) were impaired. Standardized math achievement was below the 25th percentile. Difficulties were accentuated in counting speed and single-digit multiplication. Transcoding abilities were typical. Initial assessment suggested impairments in both non-symbolic ($w = 0.42$, w[controls] = 0.25 [sd = 0.13]) and symbolic numerical comparison tasks ($P = 2635.38$, P[controls] = 1625.60 [sd =236.68]). Comparing the neutral with the congruent condition, no facilitation was observed in the numerical Stroop task for JP (RT reductions of -16.80 [sd = 455.8] ms for JP and of -97.07 [sd = 106.17] ms for controls). JP received 8 weeks of cognitive-behavioral training in arithmetic facts. Repeated measures of number processing indicated a reduction of w to 0.24 and to 0.21 and higher RTs and higher accuracy in the symbolic comparison and Stroop tasks. Non-symbolic and symbolic number processing abilities interacted in a complex and time variable way in a child with DD. Characterizing number processing impairments in single cases of DD is limited by uncertainties related to validity, stability and effects of motivation and interventions on measures of basic number processing.

Talk 4: **Relative left handedness more frequent in spelling but not in math learning difficulties: A pilot study**
Maria Raquel Carvalho; Mariuche Rodrigues de Almeida Gomides; Filipe Santos; Giulia Moreira Paiva; Vitor G. Haase

Earlier studies, using categorical measures, investigated handedness in learning disabilities with contradictory results. Recently, relative left-handedness (RLH), a dimensional measure, was introduced and higher levels of RLH have been described in dyslexia (DL). Indeed, genes regulating hemispheric lateralization such as PCSK6 have been associated with DL. The association of RLH with math learning difficulties has never been investigated. We tested the hypothesis of higher levels of RLH in individuals with math (MLD) and spelling (SLD) learning difficulties defined as standardized achievement below the PR=25. Participants were children with normal intelligence attending from 2nd to 7th grades: 181 children assessed at their schools and 97 children clinically referred due to persistent learning difficulties. The sample was subdivided according to achievement into Typical Achievers (TA, n=137), MLD (n=47), MLD+SLD (n=71) and SLD (n=23) groups. Hand dexterity was assessed with the 9-Hole Peg Test. Relative handedness was defined by the formula 2[(TimeL - TimeR)/(TimeL + TimeR)]; degree of negativity indicates RLH. RLH distribution was bell-shaped with left dislocated mean. Mean RLH were TA:0.076 (sd=0.107), MLD:0.077 (sd=0.116), MLD+SLD:0.080 (sd=0.133), and SLD:0.037 (sd=0.091). ROC analyses indicated a tendency of RLH discriminating only between the SLD and TA groups (AUC=0.624, p=0.058, CI95%=0.511 to 0.736). Results of ROC analyses are in accordance with the hypothesis that RLH levels are higher in written language learning difficulties, extending it from dyslexia to SLD, but not to MLD and MLD+SLD. These results are supported by neuroimaging and neuropsychological data which indicate that number magnitude representations underlying arithmetic learning are bilaterally organized early in life. This is in accordance with the hypothesis that left hemispheric specialization for symbolic number processing develops under the influence of experience.

Talk 5: **Impaired neural processing of transitive relations in children with Math Learning Disability**

Flora Schwartz, Justine Epinat-Duclos; Jessica Léone; Jérôme Prado

Math Learning Disability (MLD) affects up to 10% of children and has far-reaching consequences for affected individuals. Converging evidence suggests that MLD is associated with impairments in the intraparietal sulcus (IPS). However, the role that these deficits play in MLD remains unclear. On the one hand, IPS deficits may specifically affect core numerical skills. On the other hand, the IPS is involved in several domain-general processes whose disruptions may also contribute to MLD. Critically, this domain-general view raises the possibility that at least some math difficulties in children with MLD may stem from factors that are not necessarily related to basic numerical processing. For instance, neuroimaging research indicates that the IPS supports transitive reasoning (i.e., the ability to integrate relations such as A > B and B > C to infer that A > C), a skill that is central to many aspects of math learning in children. Here we tested the hypothesis that the processing of transitive relations in the IPS might be impaired in children with MLD, even when these relations do not involve numerical information. We measured fMRI activity of 9- to 12-year-olds with MLD and typically developing (TD) peers (matched for age and verbal IQ) while they listened to stories that included transitive relations. After each scenario, children also answered questions evaluating whether transitive inferences were made during story-listening. Compared to relations that could not be integrated (e.g., A>B and C >D), the on-line processing of integrable transitive relations was associated with enhanced activity in the left IPS in TD children, but not in children with MLD. Children with MLD were also less accurate when making transitive inferences than TD peers. Given the importance of transitive reasoning for math learning, our study suggests that a deficit in the processing of transitive relations in the IPS might contribute to MLD.

Talk 6: **How Do We Compare Stimulus Magnitudes? Evidence from an Artificial Algebra**

Randolph Grace; Anna Wilson; Simon Kemp

How do we compare stimuli that vary in magnitude? According to a well-known conjecture of Torgerson (1961), observers perceive only a single relation between stimuli, that is either a ratio or difference, but which one cannot be determined empirically. Previous research has used direct scaling procedures in which observers have judged ratios and differences numerically, but with mixed results. We used a novel ‘artificial algebra’ in which observers learned to produce non-symbolic ratios and differences by feedback and without explicit instruction. In two sets of experiments, observers viewed pairs of stimuli that varied in brightness, numerosity, or circle areas, and responded by clicking along a bar. Feedback was provided based on either the stimulus ratios or differences and the response location. Observers produced ratios and differences accurately, with average individual correlations of r = .94 and .95 across experiments, respectively. Analyses revealed that responding was controlled jointly by ratios and differences, with the untrained relation predicting significant variance in about half of individual cases. Results show that observers computed both differences and ratios when comparing stimuli in our task, so that Torgerson’s conjecture is false. Evidence for two comparison operations suggests that the perceptual system represents elements of an algebraic field, allowing a richer representation of the environment than if a single relation were available, which may have evolved to support locomotion in time and space.

Time: 10:00 – 10:30
Room: North school

Coffee/Tea break

Time: 10:30 – 12:00
Room: South school

Featured Symposium: **Is there (really) an evolved capacity for number?**

Organiser: Rafael Núñez

Overview: A widely accepted view in cognitive neuroscience, child psychology, and animal cognition posits that there is a biologically evolved capacity specific for number and arithmetic that humans share with other species. In line with this view, many scholars have unproblematically endorsed claims that there is, for instance, a specific ‘evolved capacity for number’, ‘evolutionary foundations for number’, ‘numerical abilities and arithmetic in infancy’, ‘monkey mathematical abilities’, and ‘numerical and arithmetic abilities in non-primate species’. Elaborations on this view have been presented recently in influential meetings and venues (e.g., “The origins of numerical abilities”, The Royal Society, February 2017; Philosophical Transactions Royal Society B, Vol. 373, Issue 1740). Although findings with human and non-human animals unambiguously point to the fact that many species (including humans) do have biologically endowed abilities for discriminating ‘quantities’ (i.e., non-symbolically, and largely in an inexact manner), a crucial question is whether these abilities are truly ‘numerical’ (i.e., exact, relational, symbolic). On the one hand, taking these abilities as being de facto ‘numerical’ may blur important distinctions necessary for the understanding of the biology of what is genetically endowed in phylogeny and of what is learned in ontogeny mediated by human intervention, and cultural pressures. On the other hand, not taking these abilities as ‘numerical’ proper, opens up new questions such as, what exactly does it take to move from quantity-related (‘quantical’) cognition to actual ‘numerical’ cognition? And how do the two forms—non-symbolic and symbolic— relate to each other? These issues have been recently discussed in a featured theme in Trends in Cognitive Sciences (“Is there an evolved capacity for number?”, June

2017, Vol. 21, No. 6). In this multidisciplinary symposium, six renowned specialists with diverse academic viewpoints, research backgrounds, and distinct theoretical positions vis-à-vis the title question will discuss their views and analyze their arguments. First, each of them will give a brief 10' statement-talk, which will be followed by a 20' panel-like discussion. Finally, the symposium will close with a 10' discussion with the audience.

Talk 1: **The number sense and its evolutionary and developmental foundations**
Elizabeth Brannon

Talk 2: **Do infants really have a sense of number? - a meta-analytic approach**
Daniel Ansari

Talk 3: **Selective developmental deficits and its implications for the evolution of numerical abilities**
Brian Butterworth

Talk 4: **Counting systems as cultural tools**
Andrea Bender

Talk 5: **Origin and refinement of number sense in deep neural networks**
Marco Zorzi

Talk 6: **Quantical or numerical? Disentangling biological enculturation from biological evolution**
Rafael Núñez

Time: 12:00 – 14:00
Room: North school

Lunch

Time: 12:30 – 13:15
Room: South school

A lunch with the President:

a discussion about MCLS with Prof. Mark Ashcraft, the MCLS president.

Take your lunch and join the meeting.

Time: 12:00 – 14:00
Room: North school

Poster session 1

1. The processing of prices across symbolic formats

Fernando Ojedo; María Mercedes Sánchez-Fortis; Pedro Macizo

In the current study, we evaluate whether the format in which euro prices are presented determine the processing of their magnitude. Furthermore, we compared the componential vs. holistic analysis of prices across numerical formats. A price comparison task was used in which two-digit prices were presented sequentially in the euro currency and participants selected the one with higher monetary value. The numerical value of prices was presented with Arabic digits, written numbers or auditory numbers words. Prices were number-monetary category (NM) compatible (49 euros, 36 cents) where the numbers and monetary category of one price were larger than those of the other (49 > 36, euros > cents); or NM incompatible (49 cents, 36 euros) where the number of one price was larger but the monetary category smaller than those of the other (49 > 36, cents < euros). In addition, there were unit-decade (UD) compatible prices where the decade and unit of one price were larger than those of the other (49 euros, 36 cents, 4 > 3, 9 > 6) and UD incompatible prices where the decade of one price was larger but the unit smaller than those of the other (46 euros, 39 cents, 4 > 3, 6 < 9). The results showed NM compatibility effects in all numerical formats. However, the DU compatibility effect was not found in any numerical format. This pattern of results is consistent with the compositional processing of prices suggesting a separate processing of the number and monetary category. However, the absence of DU compatibility effect suggests that decades and units are processed holistically when they are embedded within prices.

2. Overcoming language barriers in early mathematics instruction with “MaGrid” - a language-neutral training tool for multilingual school settings

Véronique Cornu; Tahereh Pazouki; Christine Schiltz; Antoine Fischbach; Romain Martin

Mathematical knowledge at the onset of formal schooling paves the way for children’s achievement in formal mathematics (e.g. Duncan et al., 2007; Watts et al., 2014). Hence, it is crucial to equip children with sound basic mathematical competencies by deploying effective teaching interventions during preschool years. However, multilingual school settings, such as Luxembourg (65% of the pupils are second language learners) pose a special challenge for instruction. Non-native pre-schoolers perform lower on early mathematics tests than their age-matched peers (Bonifacci et al., 2016; Kleemans et al., 2011). This gap is most likely due to missing out on learning opportunities, as a result of lower proficiency in the language of instruction. To provide equal access to early mathematics education for all children, we developed a language-neutral early mathematics training tool, the “MaGrid”-app. This innovative training tool has been evaluated, so far, in two studies in multilingual Luxembourg. In a first study, children from five classrooms (N = 68) used the tool to train visuo-spatial abilities, an important predictor of mathematical abilities (see e.g. Mix et al., 2016), over ten weeks (2x20min/week). At post-test, significant gains in the visuo-spatial domain were observed, compared to children from “teaching-as-usual” classrooms (N = 57). In a second study, we elaborated a comprehensive language-neutral early mathematics intervention, with “MaGrid” at its core. In a randomized controlled trial (RCT) design, Portuguese language minority pre-schoolers were randomly allocated to the early mathematics intervention (N=93) (IG), or a language intervention (N=93) (CG). The intervention period span two pre-school years. At post-test, children from the IG outperformed children from the CG on measures of visuo-spatial abilities, counting, number naming and number sequence knowledge. Findings from both training studies will be presented in detail and the importance of domain-specific versus domain-general precursors, as well as practical implications, will be discussed.

3. The contribution of long term memory and working memory to the mental representation of magnitudes and letters

Yafit Oscar

Representation of numbers and other ordered dimensions along a “mental” line is frequently measured by the SNARC effect, presumed to be LTM-based (reflecting representation in long term memory). Recently, it was shown that when participants are required to remember the order of numbers in sequences of stimuli presented’ sequence, a WM-based SNARC effect (reflecting order in working memory) is obtained. We tested the WM-based and the LTM-based SNARC effects in numbers and letters on Hebrew speakers. We conducted two experiments in which participants were required to remember the sequence of the numbers (in one experiment) or of the letters (in the other) in the order presented. Note that for both stimulus types LTM-based and WM-based SNARC effect can be estimated. For numbers, we found left-to-right LTM-based and WM-based SNARC effects respectively to numerical magnitude and to the location in the sequence. For Hebrew letters a right to left SNARC effect was found both as a function of their alphabetic order and as their order in working memory. Apparently, both 'prothetic' dimensions (numerical magnitude\letters order in LTM and ordinal position in WM) may be mapped on the same infrastructure space. Apperantly, both effects (LTM based and ordinal position in WM) of numbers and letters are influnced by cultural habits (the direction of reading and writing) which are mixed in Hebrew speakers (Hebrew speakers read and write numbers from left to right and letters in the opposite direction.

4. A longitudinal study on finger counting strategies in 6-years old children

Justine Dupont; Catherine Theveno

In this study, we followed 82 six-year-old children over two consecutive years and we observed their finger counting strategies during a simple addition task involving one-digit numbers. In the first year, 52 children used their fingers to solve the problems and we obtained a correlation between working memory and finger use. This correlation was significant for small problems with a sum up to 10 and larger problems with a sum larger than 10. In the second year, 66 children used their fingers to solve the problems but the correlation between working memory and finger use was only significant for large problems. Overall, the use of fingers also correlated with the rates of success. Therefore, it seems that the most efficient children use their fingers to solve addition problems but that, across development, their use of the finger counting strategy is favoured for larger problems.

5. The relation between the understanding of different arithmetic principles and math achievement

Kam Tai Kwan; Terry Tin-Yau Wong

This study aimed to investigate the relation between the understanding of different arithmetic principles and math achievement. A sample of 64 university students was tested on their arithmetic principle understanding using an explicit recognition task, as well as magnitude processing by fraction comparison task. Objective numeracy task and Grade of the subject Mathematics in the Kong Diploma of Secondary Education Examination (HKDSE) were used as math achievement measures. The finding suggested that the understanding of arithmetic principles in general accounted for unique variance on math achievement, controlling for magnitude processing, gender and language ability. In particular, the understanding of principles Associativity, Relation to operands and Direction of effect were most strongly correlated with students' math achievement. This study provides a clearer picture of how different arithmetic principles are linked to math achievement among young adults.

6. Finger numeral representations contribute to acquiring number semantic
Rosario Sánchez; Laura Matilla; Josetxu Orrantia; David Muñez

The role of fingers in children's developing quantitative skills has received increasing attention from researchers in recent years. Since the fingers can be an external aid to represent numbers, it has been suggested that they could play a functional role in the development of basic numerical abilities (Di Luca & Pesenti, 2011; Moeller et al., 2011), and they have been considered as a mediator between a number sense and a symbolically represented number concept (Andres et al., 2008; Fayol & Seron, 2005). Surprisingly, no firm empirical evidence has been provided to support the view that canonical finger configurations facilitate the learning of number semantics and symbols in children. This was the aim of our study. For this purpose, 148 typically developing kindergartners were assessed, 50 4-years-old children and 98 5-years-old children. Two hierarchical regression analyses were conducted to investigate to which extent the efficiency of processing finger configurations explained a unique part of the variance in a task that assess number semantic access such as symbolic magnitude comparison task. Intellectual ability, mathematic achievement, digit identification, dot counting, dot patterns and finger configurations were included in the analyses. The model explained 66.7 % of the variance in symbolic magnitude comparison in 4-years-old children and 46 % of the variance in 5-years-old children. The best predictor of symbolic magnitude comparison in 4-years-old children was dot patterns ($ß = .58$, $p < .001$), a task like dot counting, but in this case the dots appeared ordered in patterns (like those on dices). On the contrary, in 5-years-old children the best predictor was finger configurations ($ß = .53$, $p < .001$). These data would suggest that finger configurations may only be a relevant factor in 5-years-old children, but not in 4-years-old children, where counting is a better predictor of symbolic magnitude comparison task. These findings would support the use of finger configurations as a bridge between numerical quantities and their symbolic representation, but only in children from the age of five upwards.

7. The role of spatial numerical associations in a short-term memory task involving digits
Jeanne Bagnoud; Pamela Banta Lavenex; Jasinta Dewi; Catherine Thevenot

In this research, we studied spatial numerical associations via a memory game. We investigated whether the representations of numbers on a hypothetical mental number line (MNL) stored in long-term memory can influence the short-term encoding of numbers positioned on an external display. Our results showed that memorization of number positions was better when small numbers were placed to the left side of the game and large numbers to the right side rather than in the inverse (i.e., incongruent) or in a random configuration. This could support the view of the existence of a left-to-right orientated MNL, which was activated during the memory task and constituted a framework that helped individuals to encode and recall number positions. Nevertheless, we showed that memory performance was not worse in the incongruent than in the random configuration. This indicates that, in the incongruent condition, there was no conflict between the spatial configuration of the game and the organization of number magnitudes along a MNL. We therefore conclude that the MNL is not automatically activated when a number is encountered and, more generally, that there is no automatic association between magnitude and space. Our results seem to favor the view that the relationships between numbers and space are not due to number magnitudes that would be intrinsically associated with spatial positions but rather due to mere left-to-right ordinal representations of numbers, as for letters of the alphabet or months of the year.

8. Statistical learning of number pairs: an ERP study

Ferenc Kemény; Sabrina Finke; Anna Steiner; Corinna Perchtold; Karin Landerl

Purpose: Learning the association between different numbers plays a crucial role in arithmetic performance. Children need to learn the result of basic arithmetic operations in order to solve more complex ones. The current study tests how repeated sequential presentation of number pairs alters the neural correlates (EEG) of predictor (first number) and predicted (second number) stimuli. Method: The study tests adult participants in a passive statistical learning task. Participants were aimed at observing visually or auditorily presented stimuli, and were asked to report any immediate stimulus repetitions (same number appearing twice in a row). Unknown to the participants, the numbers were ordered to four pairs, a unimodal visual pair, a unimodal auditory pair, an auditory-visual pair, and a visual-auditory pair. Items within pairs always followed each other, whereas the order of the pairs were randomized. Thus the first element of the pairs was not predictable, but the second element was. Results: The unimodal visual condition showed increased negative amplitudes to predicted (compared to unpredicted) numbers on the frontocentral electrodes, peaking at 300 and 480 msec. In the unimodal auditory conditions, predicted stimuli elicited lower frontocentral positivity than unpredicted stimuli, peaking around 400 msec. No prediction based differences were observed in the crossmodal conditions. Conclusion: Results argue that associations between numbers are primarily formed within the modality boundaries. Association across modalities are not as salient as unimodal associations. These results are in line with previous theoretical account suggesting similar but separate statistical learning mechanisms for each modality as well as for crossmodal stimulus binding.

9. The relationship between Mathematics Anxiety and Working Memory measures in mathematical and non-mathematical situations.

Ruggero De Agostini; Silke M. Göbel

Mathematics Anxiety, the amount of negative apprehension that arises in people when dealing with mathematics, negatively affects mathematical performance. One possible reason for this relationship is that mathematics anxiety might lead to interference in working memory, and that this interference in turn affects mathematical learning leading to lower performance in mathematical tasks. The aim of the current study was to investigate the situational effect of mathematics anxiety on three working memory systems (Phonological loop, Visuospatial sketchpad, and Central executive). We tested 36 university students twice on separate days. In both sessions we tested participants' performance in a verbal working memory, a visuospatial working memory, and a listening span task (which measures verbal working memory capacity and efficiency of inhibition processes). In the non-mathematical session participants were also tested on general anxiety and were instructed that they will be tested on general anxiety and working memory, in the mathematical session we assessed their mathematics anxiety and mathematical performance and they were told beforehand that they will be tested on mathematical anxiety and mathematical performance. The order of sessions was counterbalanced. Correlational analysis for both sessions showed significant relationship between mathematics anxiety and listening span and no significant relationship between mathematics anxiety and verbal and visual working memory. However, only for the mathematical session we found a significant negative correlation between mathematics anxiety and inhibition efficiency. Moreover, regression models show mathematics anxiety as a main factor in mathematical performance, even when controlling for general anxiety, and mathematics anxiety as a main factor in the efficiency of inhibition processes, even when controlling for baseline performance and general anxiety. In conclusion, results suggest that mathematics anxiety has a significant unique relationship with mathematics performance, and that arousal in mathematical situations is associated with lower efficiency of the inhibition processes.

10. Preschool Math Skills Impact Future Achievement

Pamela Davis-Kean; Thurston Domina; Megan Kuhfeld; Alexa Ellis; Elizabeth Gershoff

Many studies indicate that preschoolers' knowledge of numbers, counting, and arithmetic is closely related with students' math achievement throughout their school careers (Duncan et al., 2007; Geary, 2013; Watts et al., 2017). However, many existing studies tracing the links between mathematics skills in early childhood and later outcomes use continuously scaled standardized test scores. In doing so, existing research implicitly assumes that children develop a single underlying math ability that develops in a continuous fashion and is linearly associated with later outcomes (Resnick, 1989). The current study attempts to identify whether there are distinct mathematical skills that serve as building blocks to later math achievement and other academic outcomes. Method: 1,364 children from the NICHD longitudinal dataset were examined. Time points of interest were the assessments at 54 months, the end of high school, and college age. Based upon questions from the Woodcock-Johnson Revised Applied Problems, factor analyses revealed three numeric competencies at 54 months—counting, arithmetic operations using visual object representations, and abstract arithmetic operations. Diagnostic classification models then identified four skills groups based upon these numeric competencies: (a) mastery of no skills, (b) mastery of counting only, (c) mastery of counting and arithmetic operations with visual representation, and (d) mastery of all three skills. Results: Child groupings based on early math skills at 54 months impact an individual's chances of taking an advanced math course in high school, or attending a four-year college. For example, of the children who enter school with no early math skills, only 26% of them attended a four-year college. 76% of children who entered school with all three skills attended a four-year college. Conclusion: Our findings demonstrate that mastery of these early skills is highly predictive of later mathematical skill development and achievement in high school mathematics and higher education. Our future directions include examining how these early skills interact with classroom math instruction.

11. Investigating White Matter Pathways in Children's Arithmetic through Spherical Deconvolution

Brecht Polspoel; Maaike Vandermosten; Bert De Smedt

Structural brain connectivity is integral to efficient cognitive processing; understanding its role may thus further clarify the neural mechanisms of arithmetic abilities. Previously, white matter pathways have been examined through Diffusion Tensor Imaging (DTI) and the fractional anisotropy (FA) index (Matejko & Ansari, 2015 for a review). Despite the availability of the technique, (developmental) DTI research in arithmetic is scarce. Furthermore, the available DTI studies in children have major shortcomings such as collecting data from wide age ranges, correlating a broad variety of arithmetic problems and using classical DTI to analyze data. DTI only estimates the direction of one fiber per voxel, which is especially problematic in arithmetic as many crossing fibers are situated around the parietal cortex. Also, the interpretation of the FA index is not clear-cut, as it is determined by micro- and macrostructural properties. These limitations can be resolved by more complex non-tensor models, such as spherical deconvolution, which has the asset of characterizing the orientation of multiple fibers per voxel. Furthermore, the hindrance modulated orientational anisotropy (HMOA) index provides information about diffusion properties along each fiber orientation, even in regions with fiber-crossings. The current study is the first to investigate how white matter tracts relate to arithmetic, using spherical deconvolution, and small arithmetic problems across all four operations. Our data from 48 children (ages 9 to 10; $M = 9.68$, $SD = 0.33$) mainly indicate an association between (fast automated processes in) simple arithmetic and white matter integrity of the right inferior longitudinal fasciculus. The importance of this pathway was previously observed when comparing children with dyscalculia to controls, and might reflect verbal/memory representations of numbers, as it connects the fusiform gyrus with temporo-parietal white matter. Other previously observed relations of white matter tracts and mathematical abilities (e.g., corona radiata or superior longitudinal fasciculus) were not found.

12. Do General Ordinal Relationships Account for Symbolic Number Representation in the Brain?

Celia Goffin; Stephan Vogel; Daniel Ansari

How are symbolic numbers (i.e., Arabic digits) represented in the brain? fMRI research consistently implicates the intraparietal sulcus (IPS) as critical for symbolic number representation. In functional Magnetic Resonance Adaptation (fMR-A) the repeated presentation of a stimulus attribute reduces activation in neural regions involved with processing that attribute. A rebound effect is observed when another stimulus differing from the adaptation-phase stimulus (the deviant) is presented. Upon presentation of the deviant, activation in the adapted brain region rebounds. The rebound effect is modulated by the numerical ratio or difference between presented numbers within the IPS. A prevalent hypothesis is that symbolic number is mapped onto a magnitude system called the Approximate Number System (ANS). This neural ratio/distance-dependent effect in the IPS appears consistent with the ANS account of number representation. An alternative hypothesis is that IPS activation reflects ordinal associations between numbers. This hypothesis can be explored by examining adaptation to non-numerical sequences that have ordinal associations but no numerical magnitude. We used fMR-A to present 24 adults with symbolic stimuli that have strong ordinal associations: digits and letters. The repeated presentation of a single-digit number or corresponding letter was interspersed with the presentation of deviant numbers or letters. A parametric regressor was calculated for each participant, whereby numerical distance between the repeated symbol and the deviant symbol was modelled. At the whole-brain level, a significant parametric rebound effect was observed in the right IPS for the number condition, whereas no significant parametric rebound effect was found for the letter condition. When the number parametric effect was contrasted with the letter parametric effect, the left IPS remained. The current results do not refute the ANS theory of number representation and seem to suggest that the activation of the IPS during symbolic number processing cannot be accounted for by general ordinal relationships.

13. Can we count on order when performing arithmetic and when performing mathematics?

Helene Vos; Bert Reynvoet; Wim Gevers; Iro Xenidou-Dervou

The ability to process ordered sequences has been shown to be highly related to arithmetic skills in adults. However, two questions regarding order processing remain unanswered. Firstly, it is still under debate which cognitive mechanisms underlie order processing exactly. Secondly, despite the well-established relationship between order processing and arithmetic, it is not clear whether order processing is also related to other mathematical skills. The current study aimed at addressing these questions by inferring the underlying processes of order processing from behavioral effects. In addition, it was investigated which aspect of the order task was most predictive for the performance on the order task. Furthermore, the current study examined whether performance on order processing is related to arithmetic and mathematical reasoning. An ordinal judgement task was administered in which participants had to indicate whether a sequence was presented in an order or not. Furthermore, an arithmetic test and mathematical reasoning task were administered. Both order (e.g. order and non-order) and distance (e.g. small distance, medium distance and large distance) were manipulated. Within the ordered sequences, direction (i.e. ascending and descending) and regularity (i.e. regular sequences like 345 and irregular sequences like 346) were manipulated. Results demonstrated - in contrast, with previous research - standard distance effects for all ordered and non-ordered sequences, probably due the presentation of sequences with less strong associations which trigger digit comparison strategies (e.g. comparing the magnitude of digits in a sequence with each other). All manipulations were significant predictors of the reaction time on the order task. Finally, order processing was highly related to arithmetic ability but not to mathematical reasoning.

14. A reliability generalization study on Test of Early Mathematics Ability across studies
Peera Wongupparaj

The Test of Early Mathematics Ability (TEMA) is a standardized and one of the most widely used instrument for measuring formal and informal mathematical abilities among children aged 8-12 years. The present meta-analysis aimed to assess 'reliability generalization' or the amount of variability in reliability coefficients and to identify the sources of its variability across studies. Out of the 767 studies from published and unpublished literature located, 48 reliability coefficients from 30 studies met the inclusion criteria, covering 29 years and 28,630 participants. For the sources of variability in reliability scores, 'Sample size', 'Male%', 'Type of reliability', 'Test edition', 'Mean age', and 'Type of source' were included in the multiple regression model as moderators. The results indicated that the mean reliability of TEMA was 0.91 (SD = 0.05). Only type of reliability and test edition were significant moderators or predictors of variability in reliability coefficients. In addition, the analyses showed that reliability scores were invariant across sample size, gender (male%), age group (mean age), and type of source.

15. Larger SNARC amplitude in high math-anxiety individuals: an evidence of worse spatial skills?
Àngels Colomé; M. Isabel Núñez-Peña

It has been recently claimed that math anxiety might be negatively related with spatial skills. Georges et al. (2016) suggested this might lead high math-anxiety (HMA) individuals to have a stronger number-space association than their low math-anxiety (LMA) peers: they found a larger SNARC effect in a parity task for the former, but no correlation between their SNARC amplitude and rotation skills. In contrast, Viarouge et al. (2014) had reported less SNARC amplitude with faster and more skilled performance in rotation. The aim of our study was to assess the relationship between math anxiety and the SNARC effect, and how rotation skills might influence it. SNARC was measured in a comparison task and the rotation task included latencies' measurement and a more fine-graded angle manipulation. Forty university students with extreme scores in a math anxiety scale (SMARS) took part in this study. Experiment 1 required participants to decide whether a digit was smaller or larger than 5, by pressing one of two buttons with their left or right index fingers. Distance between the digits and the standard was manipulated. Experiment 2 consisted in judging whether the stimulus displayed was a number or the mirror image of a number. Seven angles were used. Experiment 1 showed a distance effect but no effect of math anxiety or interaction between math anxiety and distance. There was a SNARC effect across the 40 participants. However, the SNARC effect amplitude was larger for HMA participants. Experiment 2 showed faster latencies for normal than for mirror numbers, and smaller angles leading to faster reaction times. None of the main effects interacted with math anxiety but HMA individuals were slower than their LMA counterparts. Further analyses showed no correlation between the SNARC and the distance or rotation effect sizes. Results are discussed according to the existing literature.

16. The role of the serial order short-term memory neural network in calculation abilities in children.
Lucie Attout; Steve Majerus

Behavioral studies have highlighted the importance of distinguishing item and serial order short-term memory (STM) components for studying the role of verbal STM in numerical development. This study explored the developmental neural correlates of serial order and item STM abilities and their link with calculation abilities. Children (N=37) aged between 7 to 12 years performed item and serial order STM tasks while their brain activity was measured using fMRI. The children also completed a speeded arithmetic test outside the scanner. We observed that item and serial order STM elicited similar fronto-parietal networks in our developmental sample as previously observed in adults, with a specific involvement of the right intraparietal sulcus in the serial order STM task. Second, fronto-parietal activity associated with the serial order STM task specifically predicted calculation abilities, in contrast to the item STM task. This study shows that a specialized network supports serial order STM already in school-age children and is closely related to the developmental increase in calculation abilities.

17. Eye Fixations and Number Line Estimation: The effect of an external benchmark on whole number estimation using eye-tracking

Kelsey Mackay; Lieven Verschaffel; Filip Germeys; Koen Luwel

The present study investigated whether the provision of an additional benchmark at the midpoint of the number line would: (a) improve adults' number line estimation (NLE) performance and (b) elicit a different solution behavior compared to a condition in which such a midpoint was not present. Twenty-five students were instructed to position all target numbers between 0 and 100 on a 0-100 number line in two conditions: a control condition where only the origin and endpoint of the number line were specified and a midpoint condition with the same number line with an additional benchmark at 50. Participants' eye-movements were recorded with an EyeLink® II binocular eye tracker with a 500 Hz sampling rate and they had to estimate the position of the target number by fixating its position for 30 ms. A contour analysis (Ashcraft & Moore, 2012) that analyzed the percentage absolute error around the quartiles of the number line (i.e., the origin, 25%, 50%, 75% ,and the endpoint) revealed in both conditions a typical M-shaped pattern with more accurate estimates at the origin, midpoint and endpoint than at 25% and 75%. In addition, estimates were more accurate around the midpoint in the midpoint compared to the control condition. Interestingly, we did not find any differences in participants' eye movement behavior between both conditions. The finding that responding with eye fixations yields a similar pattern of results as a traditional paper and pencil NLE task seems to validates this alternative way of responding. The provision of an additional benchmark at the midpoint leads to an improved NLE performance but this improvement does not extend to other regions, such as the quartiles. Presumably, the 0-100 number range was too familiar to adult participants, which might have prevented larger beneficial effects of providing a benchmark at the midpoint.

18. The Influence of Different Size Dimensions on Mental Rotation

Lisa Beckmann; Naama Katzin; Ronit Goldman; Avishai Henik

The mental rotation task manipulates and tests our visuo-spatial abilities – in particular, our ability to mentally rotate different objects. The effect typically found shows a linear coherence between rotation angle, reaction time (RT) and accuracy – respectively, the bigger the angular difference to the upright position, the longer the RT and the lower the accuracy. In previous research, the effect of the physical size of the stimuli on mental rotation was investigated and the results showed RT decreased as the stimuli became bigger. The common explanation for these findings is size normalization; specifically, that we dilate the smaller objects before rotating them. We investigated whether the conceptual size of stimuli had any influence on the reaction time of participants. In two mental rotation experiments, we presented either numerals (3, 4, 7, or 9) or objects that fit into the category small (e.g., lamp) or huge (e.g., construction crane). One of the stimuli was rotated and participants were asked whether they were the same or different. While we found that RTs were significantly longer for the small numerals, we also found that RTs were significantly shorter for the small-category objects. The results provide new evidence that other size dimensions influence rotation speed differently. These results call for reexamination of the normalization hypothesis.

19. Dyscalculic present distance effect in the mental clock task

Yarden Gliksman; Avishai Henik

The distance effect occurs during number comparison. It is indicated by a decrease in response time (RT) as the distance between the digits increases. This effect serves as a marker for the mental representation of numbers. Students who suffer from Developmental Dyscalculia (DD) show a larger distance effect than typically developed (TD) controls. Their larger distance effect suggest a less distinct representation of magnitudes. Paivio (1978) reported that a distance effect could be found if the numbers-to-be-compared required to mentally imagine the digits. Specifically, he employed the mental clock task. Participants were presented with pairs of times (e.g., 2:30 and 5:30) and are asked to indicate, using key presses, which time involved a larger angle. Participants were instructed to carry out the task while imagining clock faces and mentally comparing the imagined angular sizes created by the clock hands. The aim of the current study was to describe how students with DD process a mentally constructed distance effect. The study results presented similar distance effect in the mental clock taskforTD and DD. DD participants, however, presented much slower RT compared to controls. Our finding are not in line with previous findings of weaker magnitude representation in DD; and raised questions of the process of mental comparison in Dyscalculia.

20. State- and Trait-Model of Math Anxiety

Lars Orbach; Moritz Herzog; Annemarie Fritz

This study investigated math anxiety (MA) during the transition from primary to secondary school. Currently, very disparate findings exist for these school years, which can be explained amongst others by inconsistent definitions and different operationalizations of math anxiety. The study aims at contributing to the definition of terms. For this purpose, questionnaires on the basis of the psychological state-trait-anxiety model were used. State-math anxiety (s-MA) is a temporarily and situation-related anxiety reaction, which is associated with an increased arousal of the autonomic nervous system. Trait-math anxiety (t-MA) as a personality trait includes an acquired and relatively enduring disposition of an individual. Due to this disposition the individual perceives a variety of math situations as ‘potentially dangerous’. In the present research t-MA (MAQ 4-5), s-MA (KAT-III), test anxiety (PHOKI), attitudes towards mathematics, self-rating of math skills (all MAQ 4-5) and math achievement (curriculum oriented and basic number skill test) of 1179 students (48.1% girls) from grades 4 and 5 were assessed in total. In both grades exists a negative correlation between s-MA and math achievement, also when controlling for test anxiety. Like in previous surveys to t-MA, no significant negative correlation was found. Actually, when examining different t-MA expressions, a performance-enhancing effect could be observed. T-MA and s-MA were closely related, whereby more children experience s-MA. Children with s-MA and children with both MA-types showed much poorer performances than children with only t-MA or no MA. Additionally, children with both MA-types had much lower self-ratings and attitudes than children with only s-MA, t-MA or no MA. As key factors for the development of math difficulties s-MA and self-rating were identified. These findings underline the complexity of the relationship between MA and math performance. Besides, they highlight the benefit of the state-trait-anxiety model for research on MA, because inconsistencies can be explained.

21. Numerical magnitude extraction process improved in children using mental abacus: evidence from ERP study
Yuan Yao; Feiyan Chen

When the semantic distance between two numbers becomes larger, the easier it is to discriminate between them. This phenomenon is called the Distance effect, which has been regarded as the best established marker of basic numerical magnitude processes. This study explored whether long-term abacus-based mental calculation (AMC) training improved the extraction process of numerical magnitude. Thirty-eight children participated in the study and were randomly assigned to two groups at primary school entry: 24 from the abacus group and 14 from the control group. They were matched for age, gender and IQ. After a five-year training, they were tested with a number comparison paradigm: comparing the symbols (digital or the number of dots) with "5". Meanwhile, Electroencephalographic (EEG) recording techniques were used to monitor the temporal dynamic. In terms of behavioral results, the distance effect was obvious: the response time was shorter and the accuracy was higher in the abacus group. We further defined the size of distance effect (DE) as the result of difference between the two distance conditions derived by the Close distance. A 2 (symbol) x 2 (group) ANOVA showed that the DE in abacus group was significantly smaller than the control group. As for the ERP analysis, PO7 and PO8 were selected as two representative electrodes. The distance effect of the abacus group appeared both in N1 and P2p while the control group only showed in P2p. Besides, DE appeared on both sides of parietal lobe in the abacus group, while the control group only on the left side. This may reflect that in the process of numerical processing, the children with long experience of AMC training entered the quantitative extraction phase earlier and adopted different processing strategies with the control group.

22. The Open Calculation Based on Numbers (ABN) method for learning mathematics as an alternative to the Closed Calculation Based on Ciphers (CBC)
Carmen M. Canto; Manuel Aguilar; José I. Navarro; Carlos Mera Cantillo

The open calculation based on numbers (ABN) is an innovative mathematics teaching-learning methodology used with a huge number of school children in several countries. Last years the cognitive processing involved on this new methodology is being explored. The main goal of this study was to compare results obtained by primary school students in several mathematic tasks after teaching through ABN or a more traditional procedure, such us the calculation based on ciphers (CBC). Written and mental calculation, numeracy, problem solving, and numerical line estimation task were assessed. 49 second grade primary school children have being learning mathematic during the last two academic years, by using one of the two methods: CBC or ABN, were evaluated. Participants were distributed in two groups: experimental group (ABN method; N = 24) and control group (CBC method; N = 25). Aquasi-experimental ex-post-facto design was used. The results confirmed that students who used ABN method achieved higher scores on arithmetic and estimation tasks, than those who followed the CBC methodology. Experimental group scores in number’s decomposition and composition tasks and solving problems were statistically significant in contrast to the control group. Ananalogous to others studieslineal math function was found for the experimental group. These findings suggest that the ABN method could improve mental and written calculation, numeracy and estimation tasks.

23. Training early numerical skills: Preliminary evidence on preschoolers
Cristina Semeraro; Rosalinda Cassibba; Daniela Lucangeli

An extensive body of research has focused on highlighting the contribution that cognitive processes and other early numerical skills can have on the acquisition of mathematical competences. The aim of this study was to verify the efficacy of a training early numerical skills in fourty-nine Italian 4-year-old kindergarteners. The participants were randomly assigned to the training group or control group: children in the training group worked about semantic trials, whereas children in the control group followed the ministerial teaching mathematical programs focused on lexical skills. The training group and control group were matched for IQ and number of sessions. Specifically, the training regarded numerical skills that mainly required the comparison of non-symbolic numerical quantities (e.g., choosing the larger or the smaller between two sets of objects, creating two sets with equal number of elements). The training and the control activity lasted for 8 weeks, there were usually 2 sessions for week, and each session lasted approximately 45 min. The training and control groups completed a similar number of sessions. Outside the experimental sessions, children attended their regular scholastic program. Specifically, the training was respectively carried out by the curricular teacher. The teacher received a specific training in order to use the cognitive programmers with her pupils. The pre-training and post-training measures were assess with a standardized battery (The Numerical Intelligence Battery-BIN) to evaluate several aspects of numerical competence: Semantic, Pre-syntactic, Counting and Lexical. The training group showed improvements in semantic, pre-syntactic and lexical subscales whereas the control group showed improvements, albeit small, simply in lexical subscales of the numerical assessment battery. Trainings efficacy suggests that the effect size of the trainings enhancing numerical skills since the early childhood highlights the outcomes in terms of improvements of specific aspects of mathematics achievements (e.g., number sense, counting sequences, quantity comparisons).

24. Bidirectional estimation on the number line in kindergarteners in Chile: effect of familiarity with numbers

Christian Peake; Cristina Rodríguez; Felipe Sepúlveda

Human beings, as other animals, are born with an innate capacity to deal with numbers: the approximate number system. We have developed a cultural tool to represent numbers exactly and to calculate with quantities, but how do young children stablish the mapping between numerical symbols and quantities? Bidirectional mapping hypothesis (Castronovo & Seron, 2007; Crollen, Castronovo & Seron, 2011; Crollen & Seron, 2012) proposes that mapping among magnitudes and number symbols is stablished in parallel and uses estimation tasks to demonstrate that transcoding from non-symbolic and symbolic is bidirectional in adults. Conversely, some researchers have pointed that transcoding from symbols to non-symbolic cuantities is acquired later than non-symbolic to symbolic mappings (Ebersbach & Erz, 2014; Mejias & Schiltz, 2013; Odic, Le Corre & Halberda, 2015). In fact, It has been proposed (Ebersbach, et al., 2008; Moeller, Pixner, Kaufmann & Nuerk, 2009) that familiarity with numbers plays a role in transcoding acquisition. Spatial estimations have been consistently used to access number representations and it has been claimed as a predictor of mathematical development, but number line tasks have not been used to test the bidirectional mapping hypothesis. Here, 746 chilean kindergarteners were assessed with a number-to-position task and a position-to-number task (Siegler & Opfer, 2003) to study bidirectional transcoding acquisition. Number lines were bound from 1 to 20. Participants were administered with a counting task to register their familiarity with numbers. Results showed linear representations in both tasks except for those participants with lower familiarity with numbers. These participants showed a developmental acquisition pattern in both tasks, as logarithmic and exponential functions fitted with data as well as linear functions.

25. The different developmental tendencies of gender differences in number semantic and spatial processing
Wei Wei; Tingyan Zhang; Chen Chen

Number magnitude processing ability is a core ability in mathematics, especially for children. Basic number magnitude processing includes semantic processing and spatial processing. Two different mechanisms underlie the semantic and spatial number magnitude processing. In Experiment 1, we used two-digit Arabic number comparison and 0-100 number line estimation tasks and recruited 6 and 7 years old children to investigate the gender differences and developmental tendency of the two number magnitude processing. Results of Bayesian statistics showed that, (1) 7 years old children performed better than 6 years old in both of the number magnitude processing; (2) There were no gender differences in number semantic processing for both age groups; (3) 6 years old children had a logarithmic representation of 0-100 numbers. Boys performed better than girls; that is, boys already had a linear representation, while girls had a logarithmic representation; (4) 7 years old children had a linear representation of 0-100 numbers and no gender differences existed. In order to investigate the impact of difficulty on gender differences, we conducted Experiment 2. We used three-digit Arabic number comparison and 0-1000 number line estimations tasks and recruited 7 years old children. We found that there was no gender difference in number semantic processing; there was gender difference in number spatial processing. In general, 7 years old children had a linear representation of 0-1000 numbers. Boys had a linear representation, while girls had a logarithmic representation of 0-1000 numbers. All the results suggested that number semantic and spatial processing had difference development tendencies of gender differences. The difficulty only influenced number spatial processing. Boys developed earlier than girls on number spatial processing.

26. A Longitudinal Investigation of the Relations Between Spatial Skills and Math Performance in Elementary School Children
Elyssa Geer; Jamie Quinn; Colleen Ganley

Previous research has demonstrated a link between spatial skills and math performance. However, little research has examined this relation longitudinally. The current study examines the longitudinal relation between spatial skills and math performance in elementary school students over the course of two years. We administered two spatial tasks and a math task to 313 first- through third-grade students at three time points over two years. The first spatial task was a spatial visualization/rotation task, the puzzle task, in which students saw numbered puzzle pieces and a grid and were asked to write the number of the puzzle piece that went in each spot on the grid so that if you put them together they made a particular image. The second task was a spatial perception task, the water level task, which required students to indicate the correct angle of water in tilted glasses. The math test included 15 items assessing number, algebra, and measurement. A latent variable, cross-lagged structural equation model indicated that controlling for task-specific (i.e., autoregressive) growth, the puzzle task at time 1 was a significant predictor of water level at time 2 ($b = -0.40$), which means that better puzzle scores are related to closer accuracy on the water level task. Time 1 puzzle scores also positively predicted time 2 math scores ($b = 0.37$), which subsequently predicted puzzle scores at time 3, such that students with higher math scores at time 2 had higher puzzle scores at time 3 ($b = 0.26$). Further, there were significant gender-, age-, and grade-related relations. These results suggest that spatial visualization/rotation skills predict spatial perception and math skills in young children, and that math skills predict later spatial visualization/rotation skills. Thus, we find some evidence for bidirectional relations between spatial skills and math skills over the course of development.

27. The Effects of Online Math Fact Training

Marshal Rodrigues; Darcy Hallett

This study investigated the effect on an online multiplication math fact training program on working memory load during a dual task. This study paralleled that of Tronsky (2005) except that it used a large number of simple math calculations normally considered to be math facts, while Tronsky trained on a small set of harder calculations. It also examined whether math anxiety, understanding of magnitude, or general math ability would be affected by math fact training. A total of 61 Canadian university students completed a dual-task measure involving recalling letters and answering a math fact at two time points. In between these two time points, students were randomly assigned one of two conditions, online multiplication training and online math literacy training. The multiplication training involved repetitive learning of multiplication facts between 2 x 2 and 12 x 12. The math literacy training (i.e., the control group) involved reading short stories about the history and application of math. Both sets of training were completed on the participant's own time at home using a web-based program, and they completed thirty sessions (about 5 minutes per session) before Time 2 testing. Participants in the math training group improved significantly more on the multiplication questions during the dual task and trended towards improving more on the letter recall task during the dual task. This suggests that math fact training can lead to a reduction of working memory load that can free up resources to use for other tasks. At the same time, the experimental group did not show a greater improvement, compared to the control group, in math anxiety, number line performance or a general math test.

28. Relations between Numerical, Spatial, and Executive Function Skills and Mathematics Achievement: A Latent-Variable Approach

Zack Hawes; Joan Moss; Beverly Caswell; Jisoo Seo; Daniel Ansari

Mathematics skills are integral to STEM, predict educational attainment, and share strong links with important life outcomes, such as SES and health. As such, there is a need to better understand factors that contribute to individual differences in learning and achievement in mathematics. The purpose of the current study was to examine the cognitive foundations of early mathematics achievement in a sample of 4-to 10-year-old children (N=316, Mage =6.68 years). Latent-variable analyses were used to examine relations between numerical, spatial, and executive function (EF) skills and mathematics achievement. Results of a CFA demonstrated that numerical, spatial, EF, and mathematics skills are highly related, yet separable, constructs. Follow-up structural analyses revealed that numerical, spatial, and EF latent variables explained 84% of children's mathematics achievement scores, even after controlling for age. However, only numerical and spatial performance were unique predictors of mathematics achievement. The observed patterns of relations and developmental trajectories remained stable across development (preschool – 4th grade). Mediation analyses revealed that numerical skills, but not EF skills, partially mediated the relation between spatial skills and mathematics achievement. That EF skills, including measures of visual-spatial working memory, did not mediate the space-math link provides evidence against the possibility that this relation exists due to the high cognitive demands of both spatial and EF tasks. Instead, our results point to spatial visualization as an independent and important predictor of children's mathematics achievement.

29. Generating non-symbolic stimuli: An extent to Piazza's (2004) method to control for non-numerical visual cues

Mathieu Guillaume; Christine Schiltz; Amandine Van Rinsveld

Since nearly two decades, researchers have expressed their interest in evaluating the Approximate Number System (ANS) and its potential influence on cognitive abilities that involve number processing, such as mathematic skills. On the other hand, studies showed that the method by which the stimuli are created – and by which inherently confounded visual dimensions are handled – has a substantial impact on participant performance. This methodological concern challenges the validity of the ANS assessment. Some authors tackled this issue by providing various procedures to generate non-symbolic stimuli while manipulating non-numerical visual cues. Most of recent procedures are sophisticated but tend to be difficult to implement. In this poster, we propose an easy generation algorithm based on the procedure popularized by Piazza and colleagues (2004). Originally, their procedure only controlled for two visual cues that are mediated by the Number, the Total Area and the Dot Size (i.e., N = A/S). In our extended paradigm, we control for two additional dimensions related to the overall extent of the array, which are also mediated by the Number, the Convex Hull Area and the Density (i.e., N = CH/D). These "two-dimensional" constructs are independent from each other; so that our paradigm can easily generate non-symbolic stimulus sets that are controlled for the most influential visual cues reported in the literature. We illustrate how stimuli are created and we briefly present the MATLAB script that generates them. We finally discuss the nature of adult data that were acquired with this new algorithm and their correlations with mathematical skills and executive functions.

30. More than number sense: Associations between cognitive control, metacognition and arithmetic in primary school

Elien Bellon; Wim Fias; Bert De Smedt

This longitudinal study jointly investigated two important domain-general predictors (i.e., cognitive control and metacognition) and one domain-specific predictor (i.e., numerical magnitude processing) of individual differences in arithmetic. To date, there is a lot of ambiguity about the specific and unique roles of these factors in addition to each other, as well as about their predictive roles. We investigated this issue in 127 typically developing 2nd graders and followed them up one year later (3rd grade). We used experimental task to investigate cognitive control (n-back task, WCST, Flanker task and animal Stroop task), metacognition (trial-by-trial confidence rating after the arithmetic items) and numerical magnitude processing (single digit comparison task). Both frequentist and Bayesian statistics were used to investigate how cognitive control, metacognition and numerical magnitude processing were (jointly) related to arithmetic. Our findings revealed that calibration of confidence and numerical magnitude processing were significantly related to arithmetic in both grades. Regression analyses revealed that calibration of confidence and numerical magnitude processing remained unique predictors of arithmetic in addition to each other in both grades. Inhibition was a unique predictor of addition in second, but not in third grade. Growth in response time in arithmetic was predicted by calibration of confidence in second grade. These data stress the importance of children's calibration of confidence, which should be considered as an important variable in studies on children's arithmetic performance and at the level of (mathematics) education, where children can be learned to identify their own errors and consequently learn from their mistakes.

31. Directional magnitude ordering as a marker of understanding counting principles in preschoolers

Maciej Haman; Katarzyna Lipowska

One-hundred twenty-two preschoolers aged 3-5 year participated in the multi-session, multi-task study of numerical representations and processing, designed to assess developmental change ongoing along with acquisition of the symbolic (number-words and Arabic numerals) numerical representations. Three factors has been determined as controlling the largest part of variance in most of the numerical tasks: counting principles knowledge, assessed with Give-a-number task, counting list knowledge, and left-to-right ordering of numerical magnitudes assessed in a task of ordering cards with four sets of elements (ranging from 1 to 16). Only about fifty per-cent of children with G-a-N<4 ordered the sets from left to right, while in children with G-a-N>4 this proportion raised to almost 90%. Using multiple regression models we have found that left-to-right magnitude ordering controls unique part of variance of several numerical tasks performance, including both non-symbolic and symbolic variants of magnitude comparison and number-line tasks. Interestingly, however, left-to-right ordering does not correlate with SNARC-like effect in magnitude comparison nor with operational momentum effect. In line with our previous analyses (Patro et al, 2014), magnitude ordering is a special case of SNA and its emergence corresponds with the acquisition of symbolic numerical representations and counting principles. At this moment it could not be determined however if directional magnitude ordering ability is a prerequisite or a consequence of developmental change in the numerical processes in preschool age.

32. Patterns, Mathematics, Art and Human Relaonships: Assessments and Interventions to Facilitate Progress in a Young Person on the Autism Spectrum

Christine Lawson

Background: Schiralli (2007) considered mathematics as the creative exploration and formal representation of possible patterns, with art as the creative exploration and sensory representation of them. Byers (2007) discussed how pattern production or recognition seemed fundamental to intelligence, with mathematics being 'intelligence in action' and mathematical comprehension concerning individuals understanding themselves and their environment. Some find abstract patterns very meaningful and associated with positive emotions. A young person with Asperger syndrome is presented who had shown an early facility with geometrical patterns. Aims: This contribution aims to highlight the use of patterns in mathematical contexts and in association with other approaches to facilitate development. Methods: He received family support and individual sessions early in primary and in weekly batches at secondary school in his first to fourth years. Initially, activities included human formations from Object Assembly items, drawing people and a subitizing task with the fast apprehension of small numerosities concerning dots and schematic facial features. At secondary level, his early facility concerning geometrical pattern formation was investigated with Wechsler blocks. His ability with different patterns was developed with a multisensory technique for learning the multiplication tables. Results: Using Wechsler blocks, he formed complex patterns with considerable alacrity. Also, he noticed patterns in the multiplication tables and used them to facilitate access to particular answers. Conclusion: The approaches involving patterns, mathematics and interpersonal aspects appeared to facilitate cognitive and social changes.

33. When 7 is closer to 9 than to 8: an expanded measure of implicit number conception

Rachel Jansen; Ruthe Foushee; Tom Griffiths

How are numbers related? Initially, number words are learned in rote sequences, and only later mapped onto meaningful magnitudes. Our conceptions of individual numbers are enriched as we discover more and more of their properties: evenness and oddness become more important attributes than just magnitude, and shared factors become more salient than shared digits. Earlier work showed that adults' conceptions of numbers include properties beyond mere proximity on the number line (Shepard et al., 1975; Miller & Gelman, 1983). This was demonstrated by having participants rate the similarity between all pairs of numbers 0-9 and applying multidimensional scaling (MDS) to the average rating. We first replicated this work with 21 adults, and found similar patterns in our MDS analysis: numbers were ordered from smallest to largest, but clustered into groups based on evenness, oddness, and shared factors. Here, we explore two new uses for this measure: as snapshots of individuals' number conceptions, and for pre- and post-test use. To this end, we developed two 10-item sets that each contained three numbers under 10, four between 10 and 19, three between 20 and 29, five evens, five odds, three primes, three multiples of 3 and of 4, two multiples of 5 and 7, and two perfect squares. In a pilot study, 10 participants performed all pairwise similarity judgments on the 20 items from both sets. They then completed an explicit math task where they categorized all 20 numbers by mathematical property (e.g., "Which numbers are multiples of 3?"). Most participants responded correctly to the explicit math categorizations, but did not necessarily attend to these properties in their similarity judgments. We thus see this as a promising way to measure implicit number conceptions, and track the salience of rich numerical properties in individuals' number representations. Ongoing studies capitalize on this new approach.

34. The Impact of Stereotype Threat on Mathematical Performance: The case of aging.
Poshita Nicolas; Patrick Lemaire; Isabelle Régner

Mathematics often arouses affective reactions that can seriously disrupt mathematical performance at all stages in our life, from childhood to late adulthood. Simple task-descriptive statements like 'you are to perform a simple problem-solving task' rather than 'you are evaluated on solving arithmetic multiplication problems' calls for a significant difference. Several studies on different affective states like mathematical anxiety (Ashcraft & Faust, 1992, Ashcraft & Fleck, 1996), choking under pressure (Beilock et.al., 2004, 2005, Bielock & DeCaro, 2007), and stereotype threat (Aronson et al., 1999, Block, Rydell & McConnell, 2007) have provided sufficient evidence of decrement in mathematical performance following changes in task presentation. Unknown are the underlying mechanisms, although different proposals have been made. The present study aimed at testing the strategy hypothesis that such socio-emotional effects on mathematical performance occur via changes in strategy use and strategy execution. To achieve this end, we tested the case of age-based stereotype threat during arithmetic problem solving tasks. Our results showed that stereotype threat effects occur via impairing older adults' ability to select the best strategy and/or to execute strategies efficiently on each problem. In computational estimation tasks where young and older adults were asked to find approximate products to two-digit multiplication problems, we found that older adults use different sets of mechanisms under stereotype threat and control groups to solve the same problems and execute these mechanisms with different levels of efficiency. Our findings have important implications to further our understanding on the sources of changes in mathematical performance as a function of different socio-emotional factors (like math anxiety, choking under pressure, stereotype threat, and others).

Time: 14:00 – 15:30
Room: South school

Symposium: **Preschool Foundations of Emerging Mathematics: Building interdisciplinary bridges across children's cognition, the preschool and the home educational environment.**

Organiser: Gaia Scerif

Overview: Early numerical abilities measured prior to school entry are strong predictors of children's later academic achievement. Accordingly, starting school with strong foundational numerical skills helps set children up for future academic and career success. At the cognitive level, preschoolers' acquisition of numerical symbols has been identified as a key predictor of later mathematics achievement. At the educational level, while much is known about what educational activities introduce young children to the building blocks of emerging literacy, foundational maths skills are less well understood. Recent investigations have explored structured and unstructured opportunities offered by the home and preschool environment that facilitate children's readiness for primary school mathematics. Here, we propose to discuss interactions between cognitive, educational, and affective factors that are important for early mathematics development. This proposed symposium aims to facilitate interactions between and across these complementary areas of study and levels of analysis. We propose to begin with a treatment of key individual differences in some mathematical skills over the transition from preschool into primary school (Dowker and Scerif). This talk highlights both the wide math-related differences across children entering formal schooling and the opportunities to intervene. We then turn to specific investigations of how children's understanding of number changes over the preschool period (Sokolowski and colleagues; Gilmore and Batchelor). The following talk then assesses the impact of educational opportunities in the home environment on early number understanding and maths skills (Simmons and colleagues), such as the availability of formal and informal math games, as well as individual differences in parents' math anxiety and attitudes to maths. We close with a discussion of maths learning opportunities offered by educators' in preschool, as well as the influence of math anxiety on math talk (Dove and colleagues). We tackle these topics in the context of both cross-sectional experimental manipulations as well as longitudinal correlational data. We aim to bring cognitive scientists and education experts together to solicit input on these developing lines of work and discuss cross-disciplinary interactions.

Talk 1: **How should we study individual differences in preschoolers' numerical abilities?**
Ann Dowker; Gaia Scerif

Research indicates that even before starting school, children show marked individual differences in numerical abilities. Like later mathematical abilities, early counting and number representation are not unitary processes, but are made up of many conceptual and procedural components. Individual differences can occur in any or all of these components, and children can show marked discrepancies between the different components. We do not yet have a strong understanding of the underlying internal and environmental bases for these individual differences. There are several questions that require further study: (1) Are there foundational numerical abilities that predict individual differences in counting-related abilities? In particular, do early subitizing and magnitude approximation predict them, and might they differentially predict different abilities: (2) Do different aspects of early counting procedures and concepts predict later performance in different aspects of arithmetic? (3) To what extent are preschool numerical abilities predicted by domain-general factors such as language, working memory, and executive functions such as inhibition? (4) To what extent do environmental factors, such as home numeracy and nursery school experience, contribute to the development of early numerical abilities? Answering these questions will require not only correlational studies, but also longitudinal and intervention studies. It is important to consider and plan appropriate approaches to develop such studies. We here discuss some current work in progress, set up to answer some of these questions.

Talk 2: **Learning verbal number words relates to how children attend to numerical quantity**
Moriah Sokolowski; Rebecca Merkley; Sarah Samantha Kingissepp Bray; Praja Vaikuntharajan; Daniel Ansari.

Learning the meaning of verbal number words is a major milestone for young children's numerical thinking. Although a large body of research has examined how number words are mapped onto quantity, no study to date has examined how the acquisition of verbal number words affects the degree to which children attend to quantity in the world. In the present study, "The Train Task," was developed and used to examine the degree to which preschool aged children attended to discrete, numerical quantity. Specifically, this task measured whether children spontaneously used a number strategy or physical size strategy on a matching task for trains with anywhere from one to five cars. One hundred and eight children between the ages of 2.5 and 6 years old, (M = 3.92, SD = 0.87; Females=57, Males = 83) completed The Train Task, as well as the Give-a-Number task, to assess their knowledge of the meaning of verbal number words. Results revealed that all children were more likely to use a number strategy than a size strategy on the train task. Critically, preschool aged children only used a number strategy if they knew the verbal number word that corresponded to how many cars the train was that they were asked to match. This relation between verbal number word knowledge and attending to quantity was significant even when controlling for age. Therefore, this study revealed that verbal number word knowledge relates to the degree to which preschool aged children attend to discrete, numerical quantities. Together, this suggests that when children learn number words, it influences the way that they attend to quantity in the world.

Talk 3: **Preschool children's understanding of number**

Camilla Gilmore; Sophie Batchelor

Children who develop good numeracy skills during the preschool period are more likely to succeed in mathematics by the end of primary school. Yet many children are already behind their peers in numeracy when starting school. To best support children's early mathematics learning we need to know how children attach meaning to number words and symbols. Some theories of number learning propose that number words and symbols gain meaning from being mapped onto information about magnitude, while other theories propose that numbers gain meaning from their relationship to other numbers. These theories make different predictions about the types of activities and resources that would be most beneficial for young children. Here we report two experiments that investigate the role played by specific number skills in explaining individual difference in early mathematics. In Experiment 1 (n = 84, aged 3 – 5 years) we show that understanding of cardinality and the ability to map between number symbols and magnitudes are both important for early mathematics. In Experiment 2 (n = 63, aged 3 – 4 years) we show that knowledge of the number system (ordinality) is also an independent predictor of mathematics outcomes, alongside cardinality. Finally, we consider the types of activities that parents can engage in to help their child's emerging mathematics skills and whether parents are typically provided with appropriate advice in how to do this.

Talk 4: **The preschool home learning environment and early number skills**

Fiona Simmons; Elena Soto-Calvo; Anne-Marie Adams; Hannah Francis; Catherine Willis

Parental questionnaires and child assessments were used to examine the relationships between different aspects of the home learning environment and early number skills (sequential counting, cardinal counting, number transcoding and early calculation) in 274 pre-schoolers (mean age 4:0, SD 4 months). Frequency of number experiences and code-focussed literacy experiences were consistently and positively associated with all early number skills. These relationships were independent of children's age and indices of socio-economic status. Interestingly, the code-focussed literacy experiences explained variance in all number skills over and above variance explained by number experiences. In contrast, number-focussed experiences only explained variance over and above code-focussed literacy experiences in a number recognition task. Meaning-focussed literacy experiences were unrelated to number skills, as were parental attitudes towards mathematics. Potential explanations for the robust relationships between early number skills and code-focussed home literacy experiences are discussed.

Talk 5: **Having the confidence to count: reported practitioner maths confidence and the use of "maths-talk" with pre-schoolers**

Emma Dove; Anne Mills; Megan von Spreckelsen; Daniel Ansari; Ann Dowker; Rebecca Merkley; Victoria Murphy; Gaia Scerif; the Preschool Maths Foundation team

Current research has highlighted considering the importance of different aspects of young children's mathematical interactions with the adults from whom they learn. For example, maths anxiety in adults can alter the mathematical understanding of the children they interact with in both the home and the preschool environment. Furthermore, researchers have begun to investigate the use of mathematical language ('maths talk') by adults when they interact with young children. Currently the use of maths talk with preschool children focuses mainly on the home environment. However, given that young children spend an increasingly extended amount of time with carers outside the home environment, it is important to consider the type and impact of practitioners' 'maths talk' for the children in their care. In this talk, we will consider how data collected from preschool and nursery settings in Oxfordshire (N = 13 thus far), as part of a wider cross-sectional and longitudinal study into the cognitive foundations of mathematics in preschool children (N~250 thus far), fit into this broader body of work. Here we focus on observations from practitioners involved in this study. First, we describe the preschool practitioners' reported levels of maths anxiety across different areas of maths. We detail practitioners' use of maths language across different areas of maths. Finally, we assess whether there is a relationship between the reported levels of maths anxiety amongst practitioners and the proportion of maths language they use for different skill areas in maths. Preliminary observations point to the need to integrate information on individual differences in young children's early numerical skills with that on the home and preschool environment.

Time: 14:00 – 15:30
Room: East school

Symposium: **Number words and Arabic digits: development and cross-linguistic differences**

Organiser: Silke M. Göbel

Overview: Recent research has highlighted the importance of both Arabic digit knowledge and the early use of exact number words for mathematical development. Once the mapping between number words and Arabic digits is mastered, humans can easily switch between these two symbolic codes. However, there is evidence that specific number word characteristics continue to influence Arabic number processing well into adulthood. In this symposium, a selection of current research on the importance of mappings between number words and Arabic digits and its relationship to arithmetic performance will be presented. First, Landerl et al. will present data from primary school children showing that in their study the longitudinal relationship between approximate number processing skills and later arithmetic performance was mediated by symbolic number comparison highlighting the importance of Arabic number knowledge. Next, Reynvoet et al. will present developmental and adult data comparing symbolic- symbolic (Arabic digits-number words) and symbolic-non-symbolic (Arabic digits-numerosities) mappings. First, they will present data of a study with 3-5 year old children showing that digit-number word mappings are acquired before symbolic-non-symbolic mappings. In a second study with adult participants, they observed that digit-number word mappings are processed faster than symbolic-non-symbolic mappings highlighting the special status of digit-number word mappings in early and later development. Clayton et al. will then explore mistakes children made in transcoding from spoken number words to Arabic digit strings in two large samples of primary school children from Austria (German-speaking) and the UK (English-speaking). In particular, the effect of differences in number word structure between English and German on transcoding errors and the concurrent relationship between number transcoding and arithmetic performance in both samples will be discussed. The findings presented by Bahnmueller et al. indicate that inverted number word structure for teen numbers affects performance on a symbolic arithmetic task even in adults speaking an otherwise non-inverted language (i.e., English). This clearly indicates that number word structure influences place-value processing of multi-digit numbers even in a non-inverted language. Together this series of talks highlights the importance of efficient mapping between number words and Arabic digits for mathematical development and arithmetical performance in adults.

Talk 1: **Symbolic Processing Mediates the Relationship between Nonsymbolic Processing and Later Arithmetic Performance**
Karin Landerl; Sabrina Finke; Harald Freudenthaler

The nature of the relation between nonsymbolic and symbolic magnitude processing in the prediction of arithmetic remains a hotly debated subject. This longitudinal study examined whether the influence of nonsymbolic magnitude processing on future arithmetic is mediated by symbolic processing skills. A sample of 130 children was followed from the end of Grade 1 (mean age 7;3 years) through the beginning of Grade 4. Symbolic comparison of one- and two-digit numbers serially mediated the influence of nonsymbolic comparison on later arithmetic. These results support a developmental model in which nonsymbolic processing provides a scaffold for processing single digit numbers, which in turn provides a scaffold for multi-digit processing. We conclude that both nonsymbolic and symbolic processing play an important role in the development of arithmetic during primary school and might be valuable long-term indicators when aiming to identify children at risk for low achievement in arithmetic.

Talk 2: **Semantic digit-number word mappings, independent from the ANS**
Bert Reynvoet; Mila Marinova; Delphine Sasanguie

As humans, we acquire symbols (i.e., number words and Arabic digits) to help us represent numbers exactly. An ongoing debate considers the question on how these symbols relate to the proposed ontogenetic and phylogenetic system for representing non-symbolic numerosities, i.e., the Approximate Number System (ANS). On one side, the most prominent approach so far claims that symbolic numbers are mapped onto pre-existing non-symbolic number representations. Consequently, number words, digits and numerosities share the same abstract representation. Alternatively, others have argued in favor of a less intrinsic relation between non-symbolic and symbolic number, sometimes even suggesting two different systems, i.e., an approximate representation for numerosities and an exact representation for symbols. Here, we present data of two studies unravelling the relation between symbolic and non-symbolic number. In the first study with 3 to 5 year old children who are in the process of acquiring symbolic numbers, we observed that the mapping from number words to dot-arrays occurs first, followed by digit-number word and finally digit-numerosity mappings. This suggests the importance of number words as a facilitator for digit comprehension. In the second study with adults, we demonstrate that one of the claims in favor of an abstract representation, i.e., similar behavioral effects for non-symbolic and symbolic processing, is no longer tenable. Using audiovisual presentation to overcome the pitfalls of the purely visual presentation, we contrasted symbolic, non-symbolic and mixed conditions with numbers ranging from 10-40. We obtained a ratio effect in the non-symbolic and the mixed conditions. Crucially, however, no ratio effect was present in the symbolic condition, i.e., in which a visually presented digit and an auditory presented number word had to be compared. Together, these observations shed new light on the relation between non-symbolic and symbolic number and suggest that the dominant theory might have to be revised.

Talk 3: **Number writing and its concurrent relationship with arithmetic in year 1 children: does number word inversion matter?**
Francina Clayton; Anna Steiner; Karin Landerl; Silke M. Göbel

The development of formal mathematical knowledge relies upon the ability to translate between Arabic digits and spoken number words. However, few studies have investigated whether linguistic differences in number word structure might influence transcoding ability and further, how it relates to mathematics performance. This talk will describe findings from a large study with two samples of primary school children aged between 5-7 years old, from Austria (German-speaking) and the UK (English- speaking). These languages provide a useful comparison as in English number words the order of tens and units (e.g., forty-two) follows the order of the digits in the Arabic notation (e.g., 42), whereas in German number words are inverted (e.g., zweiundvierzig – literally 'two-and-forty'). As part of a larger battery of assessments, children were required to write single and multi-digit numbers from dictation. Results revealed a clear concurrent relationship between arithmetic and transcoding ability in both language groups. In addition, while there were some similar patterns of transcoding errors across language groups, there were some notable differences. For example, as predicted Austrian children made significantly more errors transcoding double-digit numbers from spoken number words to Arabic digits compared to the English children. However, English children made more errors writing teen numbers, which are exceptional in English because of their inverted number word structure. This study provides clear evidence that language-specific number word structure plays an important role in transcoding ability, and suggests that the concurrent relationship between transcoding and mathematics ability is similar across languages.

Talk 4: **Number word inversion influences mental arithmetic in English-speaking adults**
Julia Bahnmueller; Maier, C. A.; Silke M. Göbel; Korbinian Moeller

For languages with an inconsistent mapping of Arabic digits and number words, detrimental effects on basic numerical tasks (e.g., magnitude comparison), but also on mental arithmetic (e.g., addition), have been observed in children but also in adults. One specific intransparency is the inversion of number words with respect to Arabic digits. In German, for example, the order of tens and units in two-digit numbers larger than twelve is consistently inverted [e.g., 23 □ "dreiundzwanzig" (literally: "three-and-twenty")], whereas in English only teen numbers from 13 to 19 are inverted [e.g., 16 □ "sixteen" (meaning six-and-ten)]. While previous studies focused on between group comparisons of inverted and non-inverted languages, in the current study we investigated whether number word inversion affects arithmetic performance within an otherwise non-inverted language (i.e., English). We used a symbolic addition verification task, including carry and no-carry problems, with sums ranging from 13 to 29. In particular, we focused on the influence of inverted (I; teen numbers ≥ 13) and non-inverted summands (N). Based on this differentiation, three categories of addition problems were created: N+N (e.g., 6+21), N+I (e.g., 12+15), and I+I (e.g., 13+14) with problem size matched across categories. We observed that problems within the twenty and thirty number range were responded to faster when no inverted summands were part of the problems as opposed to problems with one or two inverted summands. Paralleling results of general processing speed, for twens and thirties the carry effect was larger when no-carry problems involved only non-inverted summands compared to problems with one or two inverted summands. This clearly indicates that inverted number word formation influences place-value processing of Arabic digits even in an otherwise non-inverted language.

Time: 14:00 – 15:30
Room: Room 6

Parallel session: **Arithmetic and beyond 1**

Chair: Jo-Anne LeFevre

Talk 1: **Sampling Incidental Mental Arithmetic in Everyday Life with the Aid of Mobile Phones**
Oliver Lindemann; Martin H. Fischer

Psychological research typically investigates human number cognition under controlled experimental conditions in which participants are required to focus for a longer period on the processing of a large amount of arithmetic problems. However, mental arithmetic under natural circumstances is characterized by an incidental processing of single isolated problems. It is therefore unclear to what extent findings obtained in the lab, such as the problem size effect, can be generalized. The present study aims to demonstrate how mobile phone applications can be used to get an insight into human numerical cognition in everyday life situations. We describe an Android app that replaces the default lock screen by a program depicting simple arithmetic problems together with multiple answer alternatives. Users have to select the correct solution to unlock and use their device. This app generated a large corpus of responses to arithmetic problems outside the lab. We report analyses of performances of about 14,000 subjects in about two million simple addition problems and discuss the results in the context of recent theories on mental arithmetic.

Talk 2: **Simple fractions may not be represented componentially: A rejoinder to Bonato et al (2007)**
Darcy Hallett; Jillian D. Adams; Kyle R. Morrissey

In their study, Bonato and colleagues (2007) asked adults to compare a set of fractions (1/1 thru to 1/9) to 1/5, and, by examining the distance effect data, suggested participants were processing fractions componentially (i.e., focusing on the value of the denominator) to judge distance rather processing them holistically (i.e., considering its actual magnitude). Other researchers have since found that adults can be induced to process fractions holistically if more complicated fractions are used (e.g., Schnieder & Siegler, 2010). However, the general conclusions from these studies is that certain kinds of fractions will elicit componential processing while others will elicit holistic processing. The present study tests whether the same fractions used by Bonato and colleagues (2007) can elicit magnitude processing if they are presented non-symbolically. We tested 52 participants with a modified version of this task where the same set of fractions were sometime represented as numerals (i.e., symbolically) and were sometimes represented as partially shaded circles (i.e., non-symbolically). They were asked to judge whether both symbolic and non-symbolic fractions, in mixed and unmixed experimental blocks, were more than or less than 1/5. Results from analyses assessing the distance effect suggested that participants were treating both symbolic and non-symbolic fraction stimuli in a componential manner, which seemed unlikely to be true. Results from analyses assessing the SNARC effect, on the other hand, suggested the symbolic and non-symbolic fraction stimuli are treated differently. Further consideration of these results suggest participants in the current study may indeed be accessing a fraction’s real magnitude (even when presented symbolically), but that magnitude is represented logarithmically. The implications of these results is that the current theories cannot explain these data, and a new way forward may include rethinking some classic effects in numerical cognition.

Talk 3: **Division as rational numbers: Is there an easier way to introduce fractions?**
Arava Kallai
Children and adults struggle with fractions. However, there are several ways to represent rational numbers, some are easier than others. The current study compared the performance of college students in two tasks: numerical comparison and physical comparison, with rational numbers being presented as fractions vs. as division. Division is one of the four basic arithmetic operations and is familiar to children when they first encounter rational numbers. To assure that participants refer to the stimuli as fractions or as division, the stimuli were number-words (forcing participants to read "two fifths" or "two divided by five"). In addition, the stimuli set included both proper and improper fractions, given that division is more familiar when the larger number is divided by smaller number. In the numerical comparison task, participants were more accurate when the rational numbers were presented as division. However, they were also slower in the division condition, and although there are more words to read in the division stimuli (in Hebrew, three words, compared to two, in the fraction-words), speed-accuracy tradeoff cannot be dismissed. In the physical comparison task, which tested the automatic processing of the numerical values of the stimuli in a Stroop-like design, size-congruity effects were shown in most conditions. The size-congruity effects were somewhat larger for improper than for proper fractions. In conclusion, I suggest that division might be used to introduce rational numbers before fractions.

Talk 4: **The semantic networks are involved in mathematical processing**
Xinlin Zhou

Numerous studies have shown that the brain regions around bilateral intraparietal cortex are critical for number processing and arithmetical computation. However, the neural circuits for more advanced mathematics such as mathematical concepts, mathematical principles and mathematical problem solving (with little routine arithmetical computation) remain unclear. Using functional magnetic resonance imaging (fMRI), we have investigated the brain systems for mathematical terms, arithmetic principles and mathematical problem solving. Direct subject- and item-wise comparisons revealed that the advanced mathematics had greater activation than arithmetical computation in typical general language-based semantic system (which was based on a meta-analysis of 120 functional neuroimaging studies on semantic processing). Arithmetical computation typically had greater activation in the supplementary motor area and left precentral gyrus. The results suggest that the semantic system in the brain supports advanced mathematical processing.

Talk 5: **Interactions of Space and Arithmetic: Operational Momentum in Preschool Children**
Koleen McCrink; Viola Macchi Cassia; Hermann Bulf; Maria Dolores de Hevia

When adults add or subtract sets of objects, they tend to over- or under-estimate outcomes, and shift their spatial attention rightward or leftward (respectively). These phenomenon form operational momentum, wherein we move attention along a number line when solving arithmetic problems. In the current study, we tested whether operational momentum is present when performing the operation of ordering amounts from least to most. 3-4-year-old children and college-aged adults saw two blocks of trials. In the Order block, participants viewed sets that increased in magnitude across three slides (4, 8, 16 dots), and were instructed to choose the next set in that order (e.g., 32 dots). In the No Order block, participants viewed a single magnitude, presented three times (32 dots, thrice), and were instructed to choose the same magnitude. Participants were subsequently presented with test choices on the left and right side of the screen. The correct answer was presented alongside an over- or under-estimated amount. In other trials, an overestimate was presented alongside an underestimate. We predicted more overestimate choice in the Order block. Additionally, we presented two identical values alongside each other. Here, we predicted increased right-side responding in the Order block. Spatial and estimation biases appeared only in trials with no correct answer present (e.g., conditions of uncertainty). When choosing between an overestimate and underestimate, adults were more likely to choose the overestimate in the Order block than the No Order block. In tie trials, adults chose the right-side response more in the Order block than the No Order block. Preschoolers solely exhibited spatial biases; in the tie trials, they chose the right side more often in the Order block than the No Order block. These results suggest that spatial biases during arithmetic operations are present before formal schooling with the mental number line or symbolic math.

Time: 15:30 – 16:00
Room: North school

Coffee/Tea break

Time: 16:00 – 17:30
Room: South school

Symposium: **Spontaneous focusing on numerical aspects and the development of mathematical skills**

Organiser: Cristina Nanu

Overview: There is growing interest in the investigation of spontaneous focusing tendencies on mathematical aspects in relation to mathematical development. Children´s tendency of Spontaneous Focusing On Numerosity (SFON) has been demonstrated to be positively and domain specifically related to mathematical skills before school age and from kindergarten to much later in primary school. This symposium is focused on SFON, spontaneous focusing on number symbols and numerical and quantitative aspects in preschool and primary school children. The symposium consists of six studies. Notwithstanding their common focus, the different contributions vary in theoretical and methodological details, significantly broadening and deepening our understanding of young children´s early mathematical development. Furthermore, this set of cross-sectional and longitudinal studies covering age range from four to seven years, data from seven countries involve advance analysis techniques such as path analysis and latent profile regression models. Viarouge and colleagues investigates children´s spontaneous orientation toward dimensions of magnitude as a factor of numerical development in early school years. Mazzocco explores the extent to which attention to number may be promoted by manipulating the relative salience of numerical information in materials that children may encounter. Poltz and colleagues examine the longitudinal relation between SFON in preschool and arithmetic achievement from first to third grade in a large German sample as well as predictors of mathematical learning difficulties. Next, Batchelor and colleagues focus on the effect of school starting age on SFON and mathematical skills in a four cross-country comparison study, while Nanu and colleagues unpack the data from the same sample by using a person-centered approach for investigating SFON and basic arithmetical skill profiles in relation to school starting age and amount of schooling. Rathe and colleagues demonstrate how children's spontaneous focusing on number symbols develops in relation to their SFON, numerical abilities during kindergarten. This collection of studies suggest that uncovering this kind of mathematically meaningful perceiving of the surroundings is fruitful avenue of research, which could lead to further discoveries of efficient ways of promoting children´s mathematical development and thus prevention of later failure in learning mathematics.

Talk 1: **Development of numerical estimation: the role of spontaneous orientation towards different dimensions of magnitude.**
Arnaud Viarouge; Olivier Houdé; Grégoire Borst

When estimating the number of objects in a set, children's responses can be influenced by a variety of dimensions of magnitude, such as the size of the objects, or the surface area occupied by the set. Several recent models of the development of children's representations of number have posited that at least part of this development relied on the capacity to inhibit the non-numerical dimensions of magnitude when they are incongruent with numerical quantity (e.g., when a set of large objects is less numerous than a set of small items). At the individual level, this raises the question of the role of the possible differences in children's spontaneous orientation towards these numerical and non-numerical dimensions of magnitude. Using a card-sorting game whereby the participants were asked to sort arrays of dots on the basis of the criterion of their choice, we were able to assess Kindergarteners' and First graders' relative spontaneous orientation towards numerosity, item size, or spacing. We observed that children's spontaneous orientation towards numerosity was predictive of their ability to overcome the interference between numerosity and non-numerical magnitudes in several numerical estimation tasks. Altogether, our results suggest that individual differences in spontaneous orientation towards dimensions of magnitude could be an important factor to consider when investigating the development of numerical representations.

Talk 2: **Attention to Number: Specificity and Malleability**
Michèle Mazzocco; Jenny Chan; Taylor Praus-Singh; Sarah Lukowski

Children's focus on number has been shown to predict their early and later mathematics performance (e.g., Hannula, 2005). Moreover, the frequency with which children focus on number appears to correlate with their caregivers' attention to number. These findings suggest that it is important to consider ways to naturally increase children's focus on number, such as by intentionally creating play materials that enhance the salience of numerical features. Accordingly, our lab has conducted experimental studies designed to vary and manipulate numerical salience. In earlier work (Chan & Mazzocco, 2017), we showed that attention to number was relatively infrequent among preschoolers and adults during a simple matching task, but we also showed that we could increase this frequency by reducing the presence of highly salient competing features (such as color) in experimental stimuli. Subsequently, we have replicated and expanded this work by a) varying the combinations of competing features to measure the effect on attention to number, with similar findings; b) manipulating different aspects of numerical features, such as whether these features vary within items or within sets; and c) measuring attention to number among children ages 4 to 7 years. Our findings that experimental materials can be manipulated to affect the frequency of attention to number in children and adults suggest that intentional design of materials may be an effective way to promote greater spontaneous attention to number in naturally occurring materials. Observational lab and field studies are an important next step to address this possibility.

Talk 3: **The effect of school starting age on children's spontaneous focusing on numerosity and mathematical skills**

Sophie Batchelor; Joke Torbeyns; Victoria Simms; Cristina Nanu; Eero Laakkonen; Bert De Smedt; Minna Hannula-Sormunen

Research has shown that preschool numerical skills are a remarkably strong predictor of later mathematical achievement. As such, there has been an increase in attention to early numeracy experiences, with studies demonstrating that children's informal use and recognition of number (spontaneous focusing on numerosity, or SFON) is related to more formal mathematical skills. This study investigated whether the age at which children start formal mathematics instruction affects the development of (and interrelations between) SFON and mathematical skills. Children (N=685) aged 4 to 7 years participated from four countries; Northern Ireland, England, Belgium and Finland, where children start school at 4, 5, 6, and 7 years respectively. They completed measures of SFON, digit naming, verbal arithmetic and written arithmetic. The results revealed strong age effects for all measures. There were country effects for SFON and mathematical skills, but the differences did not show a consistent pattern that was predicted by the onset of formal mathematics instruction. These findings suggest that the starting age of formal mathematics instruction does not have a significant effect on the development of SFON, mathematical skills and the relationship between SFON and arithmetic skills. While the predicted country effects were not observed, this does not imply that education does not impact on learning. The countries involved in this study differ in what they describe as "formal schooling", but the activities children engage with at different ages may be similar.

Talk 4: **A person-centered approach on the effects of formal mathematics education on spontaneous focusing on numerosity and basic arithmetical skill profiles**

Cristina Nanu; Eero Laakkonen; Sophie Batchelor; Joke Torbeyns; Victoria Simms; Bert De Smedt; Minna Hannula-Sormunen

A previous study using variable-centred approach on the ICCAL (International Comparison of Children´s Attention and Learning) project did not detect any systematic effects of school starting age on the development of formal mathematical skills and spontaneous focusing on numerosity (Batchelor et al, submitted). However, variable-centered approach may lack the ability to detect effects between some potential skill profiles of participants. Person-centered approaches are promising in showing that there are different profiles of children with different strengths and weaknesses in early mathematical skills. These profiles can be useful for evaluating the benefits of learning environments for different learners. Here we investigate mathematical skill profiles based on basic arithmetical skills and Spontaneous Focusing On Numerosity (SFON) in relation to formal education in the ICCAL project. A total of 652 four to seven-year-old children from four European countries with different school starting ages were tested. We used a person-centered approach with hierarchical latent profile regression analyses based on four factor score variables (basic arithmetical skills, SFON imitation, SFON memory and SFON picture description) while investigating the effects of school starting age and amount of schooling on the identified six mathematical skill profiles. Both starting age of school and amount of schooling were uniquely related to mathematical skill profiles when age and SES were controlled for. In addition, they had positive direct effects on basic arithmetical skills and on SFON imitation factor score variables. Results show that formal education has an effect on mathematical skill profiles but the effect is not similar across all skill profiles. Educational implications of the findings emphasize the heterogeneity in children´s mathematical skill profiles and potentially different effects of formal schooling across the mathematical skill profiles.

Talk 5: **Spontaneous focusing on Arabic number symbols and its association with numerical abilities and math performance**

Sanne Rathé; Joke Torbeyns; Bert De Smedt; Lieven Verschaffel

Children's tendency to spontaneously attend to and use exact numerosities in their everyday surroundings (i.e., SFON) has been identified as an important contributor to their early mathematical development. In this new line of research, SFON has been operationalized exclusively as spontaneous focusing on numerosities (e.g., ***). As such, children's tendency to spontaneously attend to Arabic numerals (e.g., 3) has not yet been addressed in this research. The present study aimed to address this gap by exploring whether there might exist a separate tendency to spontaneously focus on Arabic number symbols (SFONS). More specifically, we studied children's SFONS, in relation to their SFON, their early numerical abilities, and teacher ratings of their math competence. Participants were 111 kindergartners (59 boys; Mage = 4 years 8 months) coming from the three different years of Flemish kindergarten. All children completed a battery of five tasks, namely a SFON Picture task, a SFONS Picture task, a Arabic numeral identification task, a verbal counting task, and a counting objects task. Children's math competence was rated on a 4-point Likert scale by their kindergarten teachers. Findings revealed that children largely differ in their tendency to spontaneously attend to Arabic number symbols in the pictures they had to describe. We also found significant associations between children's SFONS, their early numerical abilities, and teacher ratings of their math competence, but no association with SFON after taking into account their verbal skill. These results suggest that SFONS might be a relevant component of children's early mathematical development.

Time: 16:00 – 17:30
Room: East school

Symposium: **Mathematics anxiety: Going a few steps further**

Organiser: Kinga Morsanyi

Overview: The construct of mathematics anxiety (MA) was first described over 60 years ago, but there are still many gaps in our knowledge and understanding. The aim of this symposium is to address some of the outstanding issues in this research field by presenting studies that introduce new approaches and ask novel questions. Talk 1 investigates the process of learning new maths content (as opposed to the typical approach of looking at the link between MA and the recall and application of previously learnt content) in young children. Across two experiments (Study 1: N = 120, conducted in Northern Ireland; Study 2: N = 120, conducted in Italy), 6-year-olds were presented with two novel maths contents that were not part of their school curriculum, and their knowledge was tested before and after the learning phase. The results revealed that MA was negatively related to initial level of knowledge for 3 out of the 4 maths contents, as well as to changes in performance as a result of the training for 2 out of 4 tasks. This study provides the first demonstration that MA interferes with the acquisition of new maths knowledge, possibly leading to cumulative gaps in maths proficiency for children with high levels of MA. Talk 2 presents a new instrument to measure MA in young children. The 9-item MAS-EES scale offers a multi-informant assessment of children's MA that takes into account parent and teacher ratings. The talk presents the psychometric properties of the new scale, taking into account dimensionality, reliability, and validity. The invariance of the scale was also measured for gender and language (i.e., Italian and English). Using self-report, teacher- and parent ratings together could offer better insight into young children's maths-related feelings. Talk 3 discusses the need to go further with the measurement of MA. Apart from the development of valid and reliable assessment tools which can be applied in different linguistic and cultural contexts, norms allowing for the interpretation of single results also need to be established. Cut-off criteria for high and low MA should be proposed as well. The feasibility of online measurement of MA also needs to be thoroughly investigated, as it makes it easier to conduct large-scale studies. The talk presents an overview of recent studies using the AMAS, and makes recommendations for resolving the issues related to the measurement of MA. Talk 4 presents a study that investigated MA, arithmetic performance and maths reasoning skills in 68 adult participants. Trait MA and cortisol levels (i.e., a measure of physiological arousal/stress level) independently predicted maths performance and the two measures were unrelated. Additionally, participants' self-reported state anxiety also predicted their maths performance, but it was only moderately related to self-reported trait anxiety, and it was unrelated to cortisol levels. The results suggest that self-reported trait MA is only one aspect of negative feelings towards maths, and using multiple ways of measuring MA can lead to a better understanding of how anxiety and stress might affect maths performance.

Talk 1: **Math anxiety interferes with math learning in 6-year-old children**
Carlo Tomasetto; Patrick O'Connor; Veronica Guardabassi; Kinga Morsanyi

Most of the research conducted thus far has tested the interference of math anxiety with the recall and application of previously learned math contents within the context of school-based or standardized math assessment procedures. Whereas some initial evidence exists that math anxiety may interfere with math performance in very young children as well, no study to date has attempted to investigate whether math anxiety may also interfere with math learning (i.e., with the encoding of new math knowledge) in young children, and not only with recalling already mastered contents. Across two experiments (Study 1: N = 120, conducted in Northern Ireland; Study 2: N = 120, conducted in Italy), we addressed this goal by presenting 6-year-old children with two math contents that had not been part of their school curriculum up to the time of the study. Children were tested immediately before (time 1) and immediately after (time 2) the learning phase, and after a one-week delay (time 3). Results of longitudinal structural equation models revealed that math anxiety was negatively related to the initial level of knowledge for 3 out of the 4 math contents. Moreover, and consistent with our hypothesis, math anxiety was also negatively related to children's performance at the immediate and delayed post-test in two out of four tasks (one task in Study 1 and one in Study 2), thus confirming a selective interference of math anxiety with the encoding of new math contents in memory. This is the first evidence that math anxiety may interfere with the acquisition of new math knowledge in very young children, thus possibly leading to cumulative gaps in math proficiency for children with high levels of math anxiety at the very beginning of their school experience.

Talk 2: **Math anxiety assessment in early elementary school students**
Caterina Primi; Maria Anna Donati; Viola Izzo; Kinga Morsanyi

Given the prevalence of mathematics anxiety (MA) and its detrimental long-term impact on academic performance and career opportunities, it is essential to develop instruments that can be used to identify MA as early as possible. Some previous studies with young children (Harari, Vukovic, & Bailey, 2013; Krinzinger, Kaufmann, & Willmes, 2009; Ramirez, Gunderson, Levine, & Beilock, 2013) have highlighted that initial signs of MA may emerge as early as 6 years of age (Aarnos & Perkkilä, 2012). The current study aimed at presenting a new instrument, the Mathematics Anxiety Scale for Early Elementary School Students (MAS-EESS), a 9-item scale to assess mathematics anxiety in young children. The psychometric properties of the scale have been analyzed, taking into account its dimensionality, reliability, and validity. Additionally, the invariance of the scale was measured for gender and language (i.e., Italian and English). Finally, the MAS-EESS is a multi-informant assessment of children's math anxiety that takes into account parent's and teacher's ratings. The consistency of the scale and items across the self-report, teacher and parent versions facilitate the comparison of information between sources and offers a more precise evaluation of mathematics anxiety in young children.

Talk 3: **Questionnaire math anxiety measurement one step further - norms and online testing; insights from Poland and Germany**

Krzysztof Cipora; Christina Artemenko; Klaus Willmes; Hans-Christoph Nuerk

Math anxiety is one of the most thoroughly investigated factors related to numerical processing, and several efforts were made to measure it accurately. Here we would like to discuss the need to go further with math anxiety measurement by (i) developing accurate norms and cut-off criteria, (ii) establishing psychometric validity of instruments for online as well as lab measurement, and (iii) considering math anxiety in the context of other related constructs. Apart from the development of freely available, valid and reliable assessment tools, which can be applied in different linguistic and cultural contexts, norms allowing interpretation of a single person's results need to be prepared. Cut-off criteria for high and low math anxiety should be proposed as well. Establishing these will help transferring insights from basic research to clinical and educational practice by providing practitioners with tools to screen students and accurately identify those who need additional support. A thorough investigation of the feasibility of online measurement of math anxiety is also needed. Online testing allows conducting large-scale studies easily. Such a strategy can be a valuable way to corroborate and extend results from studies conducted in the lab, based on larger and more comprehensive samples. Some attempts were made regarding these two points with the AMAS (Abbreviated Math Anxiety Scale, Hopko et al., 2003) questionnaire. This 9-item measure appeared to be valid and reliable in numerous linguistic and cultural contexts. Moreover, online and paper-and-pencil administration are largely equivalent, which we show in Polish and German speaking individuals. Very recently, norms for AMAS were proposed in two language versions (Italian and Polish), similar German norms are currently underway. Recent developments - including our own studies conducted in Poland and Germany - show that the relationship between math anxiety and math performance is not consistent across all individuals, e.g., the correlation between math anxiety and math performance is lower in individuals who study math-related subjects. Considering specific constellations of related variables such as math anxiety, math self-concept, and general trait anxiety will possibly improve usefulness of individual diagnosis in planning support or interventions. Considering the three points mentioned above will refine basic research on math anxiety by making separate studies more comparable, unifying instruments, introducing norms and cut-offs. Furthermore, it will have an influence on everyday educational practice regarding accurate diagnosis and intervention planning.

Talk 4: **Trait and state maths anxiety, cortisol level and maths performance: Exploring the links**

Kinga Morsanyi; Judith Wylie; Zoltan Molnar; Caterina Primi

This talk presents a study that investigated maths anxiety, arithmetic performance and maths reasoning skills in 68 adult participants. Self-reported trait and state maths anxiety was measured together with participants' cortisol levels (a measure of physiological arousal/stress). A time pressure manipulation was used with the aim of inducing higher levels of anxiety. Trait maths anxiety and cortisol levels independently predicted maths performance and the two measures were unrelated. Additionally, participants' self-reported state anxiety also predicted their maths performance, but it was only moderately related to self-reported trait anxiety, and it was unrelated to cortisol levels. These results were similar whether a time pressure manipulation was used or not, although participants reported higher stress levels and lower confidence in their performance under time pressure. The results suggest that self-reported trait maths anxiety is robustly related to mathematics performance, even when state anxiety is manipulated. At the same time, trait maths anxiety is only one aspect of negative feelings towards maths, which is partially independent of state maths anxiety, and might be unrelated to physiological measures of stress. Using multiple ways of measuring maths anxiety can lead to a better understanding of how anxiety and stress might affect maths performance.

Time: 16:00 – 17:30
Room: Room 6

Parallel session: **Maths achievements 2**

Chair: Javier Garcia-Orza

Talk 1: **Multiple Skills Underlie Arithmetic Performance: A Large-Scale Structural Equation Modeling Analysis**
Sarit Ashkenazi; Sarit Silverman

Current theoretical approaches point to the importance of several cognitive skills not specific to mathematics for the etiology of mathematics disorders (MD). In the current study, we examined the role of many of these skills, specifically: rapid automatized naming, attention, reading, and visual perception, on mathematics performance among a large group of college students (N = 1,322) with a wide range of arithmetic proficiency. Using factor analysis, we discovered that our data clustered to four latent variables 1) mathematics, 2) perception speed, 3) attention and 4) reading. In subsequent structural equation modeling, we found that the latent variable perception speed had a strong and meaningful effect on mathematics performance. Moreover, sustained attention, independent from the effect of the latent variable perception speed, had a meaningful, direct effect on arithmetic fact retrieval and procedural knowledge. The latent variable reading had a modest effect on mathematics performance. Specifically, reading comprehension, independent from the effect of the latent variable reading, had a meaningful direct effect on mathematics, and particularly on number line knowledge. Attention, tested by the attention network test, had no effect on mathematics, reading or perception speed. These results indicate that multiple factors can affect mathematics performance supporting a heterogeneous approach to mathematics. These results have meaningful implications for the diagnosis and intervention of pure and comorbid learning disorders.

Talk 2: **Children's contextual sensitivity predicts concurrent mathematics skill**
Sarah Lukowski; Michele Mazzocco

Children are often faced with lexical ambiguity, and homonyms provide a particular word learning challenge. Children's interpretation of homonyms show far more protracted development throughout elementary school compared to rapid growth in vocabulary and other language skills. Here we argue that number words provide challenges similar to homonyms as the numeric nature of their referents varies across contexts (e.g. 3 eggs, 3 dozen eggs, Apartment 3, 3-year-old). Thus, in the present study we evaluated whether contextual sensitivity (i.e. a skill in which children rely on using contextual clues to draw correct interpretations), measured with a pseudo-homonym interpretation task, uniquely predicted mathematics skill. A total of 178 2nd graders completed a battery of cognitive assessments. A critical question was the extent to which their contextual sensitivity for homonyms was related to mathematics skill beyond the contribution of other cognitive skills, including letter/word identification, vocabulary, matrix reasoning, and executive function. Factor analysis was used to extract Basic Concepts (Numeracy, Rational Numbers, Geometry subscales) and Applied Problems (Measurement, Time & Money, Estimation, Interpreting Data subscales) factor scores from KeyMath subscale raw scores of each participant. Across mathematics skills, contextual sensitivity was modestly correlated with mathematics (r ranged 0.28 – 0.36 between contextual sensitivity and Test of Mathematics Ability score/KeyMath factor scores). Math skills were highly correlated with each other (r ranged 0.81 – 0.82). Hierarchical linear regression showed that contextual sensitivity remained a significant and independent predictor of mathematics beyond variance accounted for by age, gender, reading, vocabulary, matrix reasoning, and executive function. Contextual sensitivity was a significant predictor of Test of Early Mathematics Ability raw scores, and KeyMath Basic Concepts and Applied Problems factor scores. Thus, the present study provides support for the claim that contextual sensitivity represents a potential independent pathway that contributes to individual differences in early number knowledge and mathematics skills.

Talk 3: **Are we barking up the wrong tree? The relation between inhibitory abilities and mathematical achievement**

Kerry Lee

An important aspect of executive functioning (EF) is inhibition. Itrefers to the efficiency with which we maintain focus on a task without being distracted by irrelevant information or prepotent patterns of behaviour. Although a large number of studies have found mathematical performance to be associated with aspects of EF, fewer studies have examined their relation when different domains of EF are considered together. This is important because the various domain (inhibition, updating, and switching) are known to be interrelated, both conceptually and at the measurement level. In a recent review, Bull and Lee (2014)found relations between inhibitory abilities and mathematics performance to be weak and inconsistent. This is surprising as inability to resist external distraction or intruding thoughts should more likely result in task failure. A potential explanation for the weaker than expected relation is the use of subtraction scores in gauging inhibitory abilities. As Lord (1956) pointed out, internal reliability is typically low with subtraction measures. To examine whether findings from alternative measurement or analytic strategies methods differ, I will present findings from correlational analyses using residual scores, path analyses, and measures segmented by reaction time. With few exceptions, they produced non-significant relations even when different criterion measures of mathematical performance were used. I will present arguments that the poorer than expected association is due to (a) age-related differences in the structure of executive functioning, (b) a mismatch in the way in which inhibition and mathematical performance are measured, (c) the sensitivity of inhibitory tasks commonly used in the literature, and (d) variation in the amount of inhibitory demands imposed by different mathematical tasks.

Talk 4: **Kindergarten Predictors of Mathematics: Quantitative, Working Memory and Linguistic Skills**

Marcie Penner-Wilger; Rylan Waring

Children enter kindergarten with considerable differences in numeracy. These differences, prior to formal schooling, may not initially seem important. However, kindergarten numeracy skills predict later mathematics achievement and general academic achievement (Duncan et al., 2007; Romano et al, 2010). Children who enter school with poor numeracy skills do not catch up (Aunola, et al., 2004), likely due to the lack of early identification and intervention tools. In LeFevre and colleagues (LeFevre et al., 2010; Sowinski et al., 2015) Pathways to Mathematics model, three types of cognitive skills that predict mathematics performance, both concurrently and longitudinally, were identified:

quantitative, working memory, and linguistic skills. In the current research, we evaluate the Pathways to Mathematics model concurrently, in Kindergarten (N = 159 children; 87 girls; mean age = 5 years, 10 months), as the first testing point in a larger longitudinal study. Quantitative skills were assessed using subitizing and both non-symbolic and symbolic number comparison. Working memory skills were assessed using phonological and visuo-spatial span tasks. Linguistic skills were assessed using receptive vocabulary and phonological awareness tasks. Controlling for age in months, all three factors (quantitative, working memory, and linguistic skills) accounted for significant unique variance in mathematics performance, measured using the KeyMath Numeration subtest (Connolly, 2000) – a standardized mathematics outcome measure (betas of .21, .28 & .31, respectively). Jointly the three factors accounted for 41% of variance in mathematics performance. Our findings add to evidence that early quantitative, working memory, and linguistic skills are robust predictors of mathematical performance, across a range of studies, labs, and tasks used for each skill (Cirino, 2011; Hornung et al., 2014). Thus, performance on measures of quantitative, working memory, and linguistic skills can be combined to identify which children are likely to struggle to gain numeracy skills, in Kindergarten, allowing them to receive early intervention.

Talk 5: **The development of number line estimation strategies**
Koen Luwel; Dominique Peeters; Lieven Verschaffel

The current study investigated if, and to what extent, children make use of benchmark-based strategies when making number line estimations and whether there are developmental changes this strategy use (NLE). In addition, we examined whether the provision of additional benchmarks on the number line would have a beneficial effect on children's NLE performance as well as their strategy use. Third and fifth graders solved a 0-1000 NLE task and were assigned to one of three conditions. In the control condition only the origin and endpoint were specified, the midpoint condition included an additional benchmark at 500, and the quartile condition contained three additional benchmarks at 250, 500, and 750. Trial-by-trial verbal strategy reports revealed that children from both age groups made use of benchmark-based strategies on the large majority of trials. Fifth graders relied on a larger variety of benchmarks and applied quartile-based strategies more frequently than third graders. In addition, the provision of additional benchmarks led to a stronger increase in the frequency of benchmark-based strategy use as well as in NLE performance in fifth than in third graders. Furthermore, a larger variety and frequency of benchmark-based strategies was positively related to children's mathematics achievement. We conclude that developmental changes in NLE performance can at least partially be explained by a refinement in children's benchmark-based strategy use.

Time: 16:00 – 17:30
Room: Room 7

Parallel session: **Arithmetic and beyond 2**

Chair: Torkel Klingberg

Talk 1: **Sequence Patterning Explains Individual Differences in Children's Calculation**
Kelsey Mackay; Bert De Smedt

Many studies have examined the cognitive determinants of children's calculation, yet the specific contribution of children's patterning abilities to calculation remains relatively unexplored. This study investigated if children's ability to complete sequence patterns (i.e. add the missing element into: 2 –

4 – ? – 8) uniquely predicted individual differences in calculation and whether these associations differed depending on the type of stimuli in these sequence patterns, i.e. number, letter, time or rotation. Participants were 65 children first and second graders (Mage = 7.40, SDage = 0.44). All completed four tasks of sequence patterning, which required them complete patterns of numbers, letters, time and rotation. Calculation was measured via addition and subtraction tasks. We also measured other cognitive determinants of individual differences in calculation, namely symbolic number comparison, motor processing speed, visuospatial working memory, and non-verbal IQ, to verify if patterning remained to predict calculation when these additional measures were controlled for. We observed significant relationships between the patterning dimensions and calculation except for the rotation dimension. Follow-up regressions, controlling for the aforementioned cognitive determinants of calculation, revealed that the number and time dimensions uniquely predicted calculation while the letter and rotation dimensions did not, suggesting some specificity of different types of sequence patterning in predicting calculation. Symbolic magnitude processing remained a powerful unique correlate of calculation performance. These findings add to our understanding of individual differences in calculation ability, such that sequence patterning could begin to be considered as one of the cognitive skills underlying calculation ability in young children.

Talk 2: **Development of proportional reasoning: The role of congruity and salience**
Reuven Babai; Ruth Stavy

Proportional reasoning involves the use of ratios in the comparison of quantities and is widely used in science, mathematics, and everyday life. Comparison of ratios is difficult for children and adults. Recently, we showed through fMRI that both congruity and salience affect adult performance and brain activity. Here we explore the role of congruity and salience in proportional reasoning during development, using a reaction time test, with 244 participants (Grades 1, 3, 5, 9 and adults). Students were asked to compare the intensity of color of mixtures of red and white paint drops. To explore the role of congruity, we compared congruent (the mixture with the larger number of red drops is darker) and incongruent (the mixture with the larger number of red drops is equally as dark as the other) conditions. To explore the role of salience we compared emphasized (the difference in the number of red drops is larger than the difference in the number of white drops) and nonemphasized (the difference in the number of red drops is equal to the difference in the number of white drops) congruent conditions. The findings indicated that most children in Grades 1 to 3 attend only to the number of red drops. They do not succeed in incongruent trials and succeed in congruent trials. With age, participants attend to the number of white drops as well; they start correctly answering the incongruent trials. Participants' accuracy in nonemphasized congruent trials drops from Grade 1 to 5 and then increases from Grade 9 on. In-depth analysis of participants' accuracy of responses, error types, and reaction times allowed understanding the role of congruity and salience and their interactions and impact on proportional reasoning during development. Such information is indispensable for promoting research as well as for teaching science and mathematics.

Talk 3: **"Knowing how" versus "knowing that": the relative contribution of conceptual and procedural knowledge to overall fraction and algebra performance.**
Felix Ayesu; Darcy Hallett; Cherryll Fitzpatrick

Typical mathematical competence rests on the ability to excel in individual mathematical domains. Two skills that are considered critical to math performance are the ability to understanding basic domain-specific principles, how those principles relate to each other ("knowing that", or conceptual knowledge), and, as well, the ability to execute the procedures to solve domain-specific problems ("knowing how", or procedural knowledge). While in practice these two knowledge types are usually applied simultaneously, recent studies have shown that these skills can be theoretically and statically separated, often for trying the tell whether one is learned first or they both are learned in tandem. In a few instances, however, researchers have asked which type of knowledge best predicts mathematical performance. In a large-scale longitudinal study, Nunes, Bryant, Barros, & Silva (2012) found that both conceptual and procedural knowledge independently predict mathematical performance, although conceptual knowledge explained about twice as much variance as procedural knowledge. However, their measures of conceptual and procedural knowledge were administered when children were 8 years olds and their procedural measure assessed simple speeded arithmetic ability. It is not clear if this same finding would hold for more advanced skills such as fractions or algebra. This study presents data from several studies assessing the relative contribution of conceptual and procedural knowledge in fractions and algebra. All of these studies found that both conceptual knowledge and procedural knowledge were independent predictors of mathematical performance. Unlike Nunes and colleagues (2012), procedural knowledge often predicted just as much variance as conceptual knowledge. These data suggest that we should be considering both conceptual knowledge and procedural knowledge when trying to maximize mathematical performance.

Talk 4: **Testing a game-based learning intervention to improve arithmetic via number knowledge**

Tim Jay; Jake Habgood; Martyn Mees

We will report the first trial of a game-based learning intervention, created for the RAIDING project (Researching Adaptivity to Individual Differences n Number Games), funded by the Leverhulme Trust. This is an interdisciplinary project, bringing together expertise in mathematical cognition, neuroscience and computing. At the heart of the game, played on touch-screen tablet computers, is a demand for the player to identify members of sets. In some scenarios within the game players must identify members of a times-table (e.g. recognise that 30, 40 and 70 all belong to the 'ten times-table' set) and in others they must identify pairs of numbers that add together to make a target number (e.g. recognise that 6 and 4 add together to make 10; these pairs are often referred to in primary schools as 'number bonds'). Around these scenarios, we have designed the game so that children are motivated to carry out substantial numbers of these 'membership identification' tasks. The aim of this trial was to test whether playing the game resulted in: 1. Improved knowledge of times-tables and number bonds 2. Improved arithmetic ability. Twenty-eight children (approx 8 years old) played the game for 20 minutes a day for 10 days, while twenty -seven children acted as controls. Pre- and post-tests measured times-tables and number bonds knowledge using a tablet app, and arithmetic ability using pencil and paper tests. Results show that the game-playing children improved in their knowledge of both times-tables and number bonds. In addition, there was an improvement in arithmetic ability due to the game. We will discuss further analyses linking these outcomes with data collected during game-play, and consider potential implications for our understanding of arithmetic development and learning.

Talk 5: **The effects of teaching mental calculation in the development of mathematical abilities**

Carola Ruiz

Many countries include mental calculation within their teaching curriculum, as past research points out numerous benefits related to this teaching goal. However, available evidence mainly focuses on the effects of teaching mental calculation on computational fluency and not on other mathematical abilities. Therefore, the present study aimed to assess the effects of teaching mental calculation on double-digit computation, number line estimation and computational fluency. Fifty grade 2 primary school students were randomly assigned to a control or treatment condition (n = 25 in each group).

The treatment group participated in 15 sessions of mental calculation intervention, while the control group received 'teaching as usual'. The intervention combined number facts, number composition and decomposition, as well as calculation strategies for addition and subtraction. Students were assessed before and after the intervention on computational fluency, double-digit computation and number line estimation. We found no significant impact of the treatment on any of the mathematical outcome variables. We believe that our results can be explained in the light of available literature considering content –specific as well as methodological decisions made. Future decisions for research and educational practice are also discussed.

Time: 18:00 – 19:30
Location: Museum of Natural History

Drinks reception

Monday 9th of April 2018

Time: 8:30 – 10:00
Room: South school

Symposium: **Arithmetic and Reading: Related Building Blocks**

Organisers: Lien Peters; Kiran Vanbinst

Talk 1: **Individual differences in (cognitive) precursors of arithmetic and reading in 5-year olds**
Kiran Vanbinst; Elsje van Bergen; Pol Ghesquière; Bert De Smedt

The first goal of this study is to explore associations between arithmetic and reading before formal instruction. Secondly, we aim to investigate how precursors of arithmetic and reading relate to cognitive skills that are known to be important for future fluency in arithmetic and/or reading. Participants were 5-year old preschoolers (n = 86, 45 girls) who have not yet received formal education, and who were asked to calculate with concrete materials (i.e., marbles) as well as on a more abstract level with symbols (e.g., 2 + 3 = ?). Cognitive skills that have been related to future fluency in arithmetic were also tested: Symbolic comparison, nonsymbolic comparison and numeral recognition. In analogy, letter knowledge was assessed as a precursor of reading, and phonological processing was measured as cognitive determinant of future reading ability. By applying classic correlational and regression analyses as well as Bayesian hypothesis testing on the current data, we revealed strong connections between precursors of arithmetic and reading, even after controlling for intellectual ability. Further, we found that nonsymbolic comparison was an important cognitive determinant of concrete (marbles) arithmetic, and that symbolic comparison contributed to abstract (symbols) arithmetic. Phonological processing was correlated with letter knowledge. Most interestingly, numeral recognition appeared the most important cognitive determinant of both arithmetic and letter knowledge. This finding suggests that an individual’s ability to identify (complex) abstract symbols such as Arabic numerals is an important skill to learn to calculate and to read.

Talk 2: **Pattern understanding as a predictor of early growth in reading and arithmetic skills**
Kelly Burgoyne; Stephanie Malone; Charles Hulme

Pattern understanding (patterning) is related to reading and arithmetic but evidence for a causal relationship is limited. We report a large-scale longitudinal study examining the role of patterning, alongside a wide range of other cognitive abilities, as a predictor of the early growth of reading and arithmetic skills in children between the ages of 5 and 6 years (N = 569). Reading growth was predicted by initial word reading ability, phoneme awareness and RAN, whereas growth in arithmetic was predicted by early calculation skills and by number knowledge. Alphanumeric patterning (in contrast to non-alphanumeric patterning) explained significant additional variance in both reading and arithmetic. Patterning was in turn predicted by executive function, which indirectly predicted both reading and arithmetic. The role of patterning in the development of reading and arithmetic therefore appears to be largely explained by alphanumeric knowledge and executive function skills.

Talk 3: **Early childhood general knowledge: A domain-general mechanism for long-term achievement in arithmetic and reading**

Tanya M. Evans; David W. Grissmer

Compelling evidence at both the behavioral and brain level exists for an association between arithmetic and reading skills. However, children with co-morbid deficits present with both domain-specific (i.e., math; reading) as well as domain-general (e.g., memory, visuo-spatial skills) cognitive difficulties, leaving it unclear how to best remediate. Domain-specific interventions have proven effective in the short-term, but partially or fully fade out in the long-term for both math and reading. Plasticity of brain regions supporting each skill have also been observed following some interventions. However, longitudinal survey data suggests that domain-general cognitive skills at school entry, including attention, fine motor skills, and general knowledge, are stronger predictors of long-term math and reading achievement than early domain-specific skills. Importantly, no study has rigorously tested this hypothesis experimentally. A lottery of 2253 children were randomly assigned to a school-based intervention at kindergarten entry that left math and reading instruction unchanged. The intervention consisted of a high-dose (4 years) integrated curriculum across remaining academic subjects that focused on strengthening domain-general comprehension skills hypothesized to improve long-term math and reading skills. The intent-to-treat results show significant effects in math, reading, writing and English for female and low-income students. Results are discussed in the context of educational neuroimaging studies and brain-based models of co-morbid arithmetic and reading difficulties. We suggest that early instantiation of domain-general brain circuitry subserving declarative memory and semantic processing provide the scaffolding for the refinement of complex networks required for long-term proficiency in reading and math.

Talk 4: **Differences in cognitive profiles of children with MD, RD or MDRD**

Jonna Salminen; Tuire Koponen; Kenneth Eklund; Riikka Heikkilä; Mikko Aro

The aim of this paper was to study the potential between-group differences in children with dysfuency in reading (RD), in math (MD), or in both academic skills (MDRD). Approximately 200 Finnish children were classified to these three groups based on their word list reading and addition skills assessed at the beginning and end of Grade 2. Below the 25th percentile performance in both assessment points was required for each individual to be classified as dysfluent either in reading only (RD group, N=14), in addition only (MD group, N=12), or in both reading and addition (MDRD group, N=20). Domain-specific cognitive skills for reading (phonological awareness, PA, and rapid naming, RAN) and for math (number comparison, NC, verbal counting ,VC), as well as domain-general cognitive skills (processing speed, PS, short-term memory, STM, and verbal working memory, VWM) were assessed at the beginning of Grade 2. Interestingly, the results showed no statistically significant differences in math related (NC, VC), reading related (PA, RAN), or in domain-general cognitive skills (PS, STM, WM) between MD and RD groups. The effect sizes (rank correlations) were small and varied between .05 − .33. Instead, MDRD group seemed to be weaker than RD group in VC, PA, PS, STM, and WM with highest effect size for PA (r = .54). In addition, MDRD group seemed to be weaker than MD group in VC, RAN and STM with highest effect size for RAN (r = .44). There were no clear trends in cognitive profiles within or between the three sub-groups. To conclude, this data does not support the hypothesis of MD and RD, defined as performance within the lowest quartile, having unique cognitive profiles. Instead, this data supported the hypothesis of individual differences within children with dysfluency in different academic skills.

Talk 5: **Dyscalculia and dyslexia: Different behavioral, yet similar neural profiles**
Lien Peters; Jessica Bulthé; Nicky Daniels; Hans Op de Beeck; Bert De Smedt

Children with specific learning disorders, such as dyslexia or dyscalculia, have difficulties in acquiring basic academic skills despite otherwise normal intelligence. Research has thus far mainly focused on revealing the cognitive deficits associated with these specific learning disorders: deficits in phonological processing for dyslexia (Gabrieli, 2009), and deficits in number processing for dyscalculia (Butterworth, Varma, & Laurillard, 2011). However, it appears that difficulties in arithmetic, which are obviously the hallmark of dyscalculia, are also remarkably common in dyslexia, particularly when it comes to retrieving arithmetic facts from memory (Göbel, 2015). These calculation deficits are assumed to originate from brain abnormalities, yet those remain unclear to date. Furthermore, dyscalculia and dyslexia also often co-occur, but this comorbidity has thus far not been studied at the level of the brain. Against this background, we investigated the neural correlates of dyslexia, dyscalculia, and comorbid dyslexia/dyscalculia. Participants were 62 children aged 9 to 12. All children with specific learning disorders included in the study received a formal diagnosis by a trained clinician. These children were further classified into children with dyslexia (DL, n = 19), children with dyscalculia (DC, n = 11), and children with comorbid dyslexia/dyscalculia (DLDC, n = 9). These groups of children with specific learning disorders were matched to a sample of typically developing children (TD, n = 23) without any history of learning difficulties. All children underwent fMRI scanning during which they performed an arithmetic task in different formats (dot arrays, Arabic digits and number words). At the behavioral level, children performed as expected: children with DC and with DLDC performed more poorly compared to typically developing children on all formats of the arithmetic task. Children with DL scored lower than TD children on the symbolic formats (Arabic digits and number words) but not on the non-symbolic format (dots). At the neural level, TD children showed higher levels of brain activity during the arithmetic task compared to children with learning disorders. Contrary to our expectations however, there were very few differences between the three learning disorders under study. To statistically test the (dis)similarities between children with learning disorders, we performed multivariate subject generalization analyses. These analyses further confirmed that the neural activation patterns of children with DL, DC and DLDC were not distinguishable by a trained classifier. These data suggest that, despite obvious differences at the behavioral level, the neural profiles of children with different learning disorders may be more similar than initially thought.

Talk 6: **Neural bases of comorbidity of dyscalculia and dyslexia in adults**
Anna Wilson; David Moreau; Reece Roberts; Karen Waldie

In the Auckland comorbidity study, we recruited n=85 adults with either dyscalculia only, dyslexia only, both or neither (controls). Behavioural results based on a battery of cognitive tasks showed that dyscalculia and dyslexia exhibited independent domain specific cognitive deficits, but that comorbidity was also associated with domain general deficits (Wilson et al., 2015). A subset of the sample (n = 47) underwent fMRI scanning whilst performing reading and mathematical tasks, as well as a localizer paradigm (from Pinel et al, 2007). Preliminary published analyses using DTI and PLS have focused on dyslexia (Waldie et al., 2017; Moreau et al., under review). Here I will report on recent fMRI analyses of the full 2x2 (dyscalculia x dyslexia) design, with a focus on dyscalculia. Preliminary univariate analyses using SPM replicated previous findings of temporo-parietal impairment in dyslexia, but not IPS impairment in dyscalculia. Comorbidity was associated with increased frontal activitiy in both math and reading tasks. The updated analysis uses a multivariate approach (PLS), as well as ROIs identified using localizer data, to give increased power.

Time: 8:30 – 10:00
Room: East school

Parallel session: **Numerical processing 2**

Chair: Maria Dolores de Hevia

Talk 1: **When a million is more than infinity: The influence of the decimal structure on perceiving numbers as "large"**

Michal Pinhas; Rut Zaks-Ohayon

In the Arabic numeral system, a string of digits is treated as a single number, and a digit's position in the string represents its value. This syntactic structure associates number length with magnitude so that the more digits there are, the larger the number. In contrast, the infinity symbol (∞), which represents something that is larger than any given concrete magnitude, is constituted from one shape, resembling more closely to the external representational structure of small quantities (i.e., single-digits). The present study examined the influence of the associations between number length and magnitude by manipulating the notation of infinity and large numbers. In a series of experiments, participants performed numerical comparisons to the upper-end value in the set, as well as non-end comparisons. In Experiment 1, the stimuli set was comprised of single-digits and 1,000,000 for one group of participants, and of single-digits and the infinity symbol for the other. In Experiment 2, the stimuli set was comprised of single-digits and "X". The meaning of "X" varied between five groups of participants to denote "infinity"/"tends to infinity"/"a million"/"a trillion"/"the largest number in the set", respectively. In Experiment 3, the stimulus set contained the hundreds scale numbers (e.g., 100, 700) and a string of X's, varying in length between three groups of participants (i.e., XX/XXX/XXXX, respectively), denoted infinity. Overall, numerical comparisons to the upper end-value differed from non-end comparisons only when the upper end-value in the set was denoted by a larger number of constituents compared to the other numbers in the set. Furthermore, both types of end and non-end comparisons produced distance effects. Our findings suggest that perceiving numbers as "large" is highly affected by the place-value structure by demonstrating the internalization of the external representational syntax of the Arabic numeral system.

Talk 2: **The role of the left intraparietal sulcus (IPS) in tactile enumeration – Behavioral and neuroanatomical findings**

Zahira Ziva Cohen; Isabel Arend; Kenneth Yuen; Sharon Naparstek; Yarden Gliksman; Ronel Veksler; Avishai Henik

The ability to enumerate is one of the building blocks of arithmetic and fingers are used in the early steps of this process. We explored tactile enumeration with fingers as the input surface, and voxel-based morphometry (VBM) to study gray matter (GM) changes in an acalculic participant—JD, a 22-year-old female with acalculia following a stroke to the left intraparietal sulcus (IPS). JD and a group of neurologically healthy controls reported how many fingers were stimulated. JD was tested at four time points: one month after the infarct (acute phase), two months, six months and eighteen months later. For the sensory intact hand, the RT slope of enumerating up to four stimuli was significantly steeper than that of controls only in the acute phase. Moreover, JD's enumeration was poorer than controls when stimuli were applied to neighboring fingers in the acute phase. VBM analysis of the acute phase and six months later showed a larger GM volume for JD relative to controls in the right middle occipital cortex. Importantly, for JD, the concentration of GM significantly increased from the acute phase to six months later. JD's tactile performance serves as a first glance of tactile enumeration during acalculia. Deficit in tactile enumeration and subsequent recovery of this deficit suggests that subitizing (and not counting) is the basic tactile enumeration process using one hand. Moreover, GM increase in the occipital cortex, which is a multisensory object recognition and visual magnitude area, suggests that JD's recovery is based on plasticity change that involves the primitive "sense of magnitude" system.

Talk 3: **Meta-analysis study of fMRI activation in the interference effects of Numerical Stroop Task**
Patricia Freitas; Guilherme Wood

The studies of functional magnetic resonance imaging (fMRI) activation in numerical Stroop interference had been accomplished to evidence neural correlates of number, automatic and controlled processes. Meta-analyses of numerical Stroop interference tasks are needed to summarize results from fMRI studies that may contribute to current theories. During the processing of numerical Stroop interference tasks (and distance effect, which activates a sub-network of the size congruity effect) certain areas in a network are activated. The goal of this work is to summarize the activations of those areas of a network by a quantitative, function-location meta-analysis. In the present work, the size-congruity-effect is investigated by Counting Stroop and the physical-numerical interference paradigm with meta-analyses and comparisons regarding similarities in activations. The goal of the present meta-analysis is to identify brain regions that are commonly activated by functional magnetic resonance imaging (fMRI) investigating number stroop processing in healthy adults. Meta-analysis using an activation likelihood estimation (ALE) logarithm, in which the convergence of individual points is determined from different published studies. The study includes 17 published fMRI papers from 2012 to 2017. The results showed that both paradigms reveal similar activations during processing, such as in the fronto-parietal network for attentional control, that includes regions in the dorsolateral prefrontal cortex, the anterior cingulate gyrus, and the intraparietal sulcus. Significant activation in the anterior cingulate gyrus (BA 24/32), which was expected concerning studies with existing evidence, was demonstrated around both paradigms, namely for the counting Stroop and both effects of the physical-numerical interference paradigm (the size congruity and distance effect). Consistent activation over both paradigms was found for exactly nine regions, five in frontal and four in parietal lobe. The results of these meta-analyses suggest that both paradigms are comparable regarding their neuronal correlations and cognitive mechanism.

Talk 4: **Symbolic estrangement or symbolic integration of numerals with quantities: Methodological pitfalls and a possible solution**
Mila Marinova; Delphine Sasanguie; Bert Reynvoet

Previous studies which examined whether symbolic and non-symbolic quantity representations are processed by two independent systems or by one common system, have reached contradicting findings, possibly due to methodological differences. Some researchers advocate the two-systems approach, based on: (1) the presence of notation-specific switch cost in conditions where adults have to compare pairs of symbolic and non-symbolic quantities, and (2) the absence of such a cost in conditions containing quantities of the same notation (Lyons et al., 2012).Other researchers, however, used matching instructions and reported a facilitation in the mixed notation conditions, suggesting that the two systems are automatically integrated (Liu et al., 2015). To unravel the previous inconsistent findings, in the present study, we conducted three experiments, in which we examined the existence of two separate quantity systems, by using various experimental manipulations (e.g., the task instructions or the presentation order). In Experiment 1, we investigated the role of task instructions by presenting participants with pure and mixed notation trials for both comparison and matching tasks. In Experiment 2, we tested the role of blocked and randomized presentation order for the pure and mixed trials. Our data showed that cost for switching between the symbolic and non-symbolic quantities is present, but is prone to a certain methodological drawback: the cost for switching between the two systems is masked by not taking into account the differences between the processing times for two sequentially presented stimuli of different notations. To overcome this problem, in Experiment 3 we used an audio-visual paradigm (Sasanguie et al., 2017). Overall, our results provide further evidence for the existence of distinct quantity representations, independently of task instructions or presentation order. Additionally, considering the methodological drawback found, we argue that the audio-visual paradigm is better suited for investigating the integration between symbolic and non-symbolic quantities.

Talk 5: **Spatial order relates to the exact numerical magnitude of digits in young children**
Francesco Sella; Daniela Lucangeli; Roi Cohen Kadosh; Marco Zorzi

Spatial representation of numbers has been repeatedly associated with the development of numerical and mathematical skills. However, few studies have explored the contribution of spatial mapping to exact number representation in young children. Here we designed a novel task that allows a detailed analysis of direction, ordinality and accuracy of spatial mapping. Preschool children, who were classified as competent counters (cardinal-principle knowers), placed triplets of sequentially presented digits on the visual line. The ability to correctly order triplets tended to decrease with the larger digits. When triplets were correctly ordered, the direction of spatial mapping was predominantly oriented from left to right and the positioning of the target digits was characterised by a pattern of underestimation with no evidence of logarithmic compression. Crucially, only ordinality was associated with performance in a digit comparison task. Our results suggest that the spatial (ordinal) arrangement of digits is a powerful source of information that young children can use to construct the representation of exact numbers. Digits may acquire numerical meaning based on their location on the number line and in relation to the location of other digits.

Talk 6: **Roman Numerical Cognition**
Sophie Batchelor; Matthew Inglis

Dehaene’s (1992) triple-code model suggests that cardinal numbers are mentally represented and manipulated using three different codes: the auditory-verbal, the visual-Arabic and the analogue-magnitude. Dedicated translation paths allow conversion between the three types of cardinal representation. In other words, the Arabic numeral 4 can be quickly converted into an auditory-verbal representation (“four”, “vier” or “quatres”), and mapped onto an appropriate analogue-magnitude representation. Here we investigated whether the visual-Arabic code is inherently Arabic: while Arabic numerals dominate in most modern cultures, they are not the only symbolic numeral system in use (e.g., Bender & Beller, 2014; Schlimm & Neth, 2008). Specifically, we asked whether Roman numerals can also be mapped onto appropriate analogue-magnitude representations. In Experiment 1 we conducted a Roman version of Moyer & Landeur’s (1967) symbolic comparison task. We asked 13 adults to rapidly select the larger of two Roman numerals (represented with the non-subtractive notation, e.g. XIIII v XXV; Schlimm & Neth, 2008). We found that participants could successfully complete the Roman task, that their performance could not be predicted by the length of the numerals involved, or by various other non-numeric strategies, and that they exhibited standard ratio effects. In Experiment 2 we conducted a Roman version of Gilmore, McCarthy & Spelke’s (2007) approximate symbolic addition task. Ten adults were asked to rapidly select whether the sum of two addends was larger than a third comparison number (e.g. VI + VII vs XIIII). As in Gilmore et al.'s study – where children were asked to approximately add Arabic numerals before they had been taught to add exactly – we found that participants performed at above-chance levels when the ratio between the to-be-compared quantities was large, and exhibited a standard ratio effect, but that they performed at chance level on 'exact trials' (when the two quantities were separated by 1). In sum, both experiments suggested that Roman numerals can be rapidly converted to analogue magnitude representations, and that therefore Dehaene's visual-Arabic code is not inherently Arabic.

Time: 8:30 – 10:00
Room: Room 6

Parallel session: **Education**

Chair: Nancy C. Jordan

Talk 1: **Worked-out solutions to unstructured problems: A tool to support social metacognitive regulation?**
Sheila Evans

Students working productively together to solve challenging, unstructured mathematics problems, engage in social metacognitive regulation (SMR). This involves regulating their own cognitive processes, or scaffolding their partner's understandings by adopting the role of tutor. There may also be occasions when students equitably regulate their joint cognitive processes. Although such behaviour can improve learning and performance, it does not commonly occur in classrooms. Students lack the skills needed to effectively monitor their own or their partners emerging ideas. Worked-out solutions, in the form of designed student responses (DSRs) to problems, can cultivate less demanding situations for students to practise SMR. When jointly constructing a solution, students' approaches are evolving, may incorporate misconceptions, and exclude the most powerful methods. DSRs, in contrast, are coherent and accurate, and include powerful methods. Their anonymity means students do not need to overcome the emotional aspects of reviewing a peer's work. The expectation was that, freed of social tensions and performance demands, students would concentrate their efforts on gaining understanding of the mathematics. DSRs would provide explicit opportunities for students to practise SMR. These developed practises could then be transferred to the more challenging, though clearly analogous environment, of students constructing a joint solution. The study reported here establishes the veracity of this claim. Comparisons were made between the frequency and manner in which SMR manifested itself when a pair of students constructed a solution and worked with DSRs. Over four lesson periods, the pair were videoed. The transcripts were analysed using an SMR coding protocol and thick descriptions. The findings indicate that when working with DSRs, proportionally more SMR episodes arose and more of their talk included high quality reasoning. Although SMR research is growing, there is little in relation to DSRs to unstructured problems used in classrooms. This study contributes to this research agenda.

Talk 2: **Bridging intuitive and analytical thinking in mathematics education**
Uri Leron; Lisser Rye Ejersbo

As researchers in mathematics education we view ourselves as consumers, rather than producers, of psychological research: In the talk we demonstrate how research in different sub-disciplines of psychology (cognitive, social, evolutionary, developmental) helps illuminate important issues in the learning and teaching of mathematics. We are especially interested in the relationship between intuitive and analytical thinking. In this respect, the difference between psychologists and mathematics educators is analogous to that between scientists and engineers: While psychologists aim to understand how the mind works, thus for example documenting the gap between the two modes of thinking, we as educators are in the business of designing ways to help our students bridge this gap. Our design work branches in two different directions, both in the context of a specific intuition trap, namely, a task which elicit an intuitive non-normative response from a majority of people. The first branch, called bridging down, is designing a bridging task, namely, a task that is logically equivalent to the original task but is psychologically much easier. We demonstrate this kind of bridge via the famous medical diagnosis problem, where healthy and sick people are replaced by green and red pebbles, and the medical diagnostic test is replaced by a color-sensitive robot. This method does help students understand (and sometimes discover) the analytical solution, but it leaves untreated the pedagogically undesirable clash between that solution and their original intuition. For this we invoke the second branch, called bridging up: Following Seymour Papert, who compared students' learning to computer programming, we design interventions to help students debug (rather than discard) their original intuitive answer. We demonstrate this process via an interactive scenario involving a classical intuition trap: the 2-glass puzzle.

Talk 3: **Visuospatial working memory in mathematical performance using Open Calculation Based on Numbers Algorithm (ABN)**

Estibaliz Aragon; Manuel Aguilar; Carmen M. Canto; Carlos Mera; Candida Delgado; Gamal Cerda; Carlos Perez Wilson; José I. Navarro

The Open Calculation Based on Numbers (ABN) is a state-of-the-art mathematics teaching-learning procedure being used with a large number of school children in Spain and South American countries. Although first ABN experiences started in 2008 with few numbers of students, the amount of participants has been increasing in the last few years. Some recent research data suggests that general domain cognitive abilities, associated to short term memory, should be involved in improving early math performance. Considering this, we carried out a study describing the cognitive profile for students that were leaning early math using the ABN method. The main target of this study was to found cognitive profiles associated to ABN method. The cognitive and mathematical performances for a total of 128 first-year students were evaluated. A large series of cognitive tasks composed by the Automated Working Memory Assessment (AWMA) test was administered: Non-word recall, dot matrix, backward digit recall, Odd-One-Out. In addition, students' mathematic skills were evaluated by the Early Numeracy Test-Revised (ENT-R) Spanish version. Participants were distributed in an experimental group (n=74) and a control group (n=54). The experimental group learned mathematic using the ABN methodology; the control group used a CBC methodology. The linear stepwise regression analysis suggested the cognitive profile of the experimental group emphasized the significance of visuospatial working memory in mathematical performance. Students trained with ABN method seem to operate better with working memory, applying mentally visuospatial representations.

Talk 4: **Students' Mathematical Practices of Defining: A Piagetian Perspective**

Amelia Farid; Ellen Kulinsky

Mathematical definitions often evolve through a process of iterative refinement - a definition is proposed, a counterexample is encountered, the definition is refined, another counterexample is encountered, and so on. Considering mathematical definitions in light of counterexamples, or "monsters" (Lakatos, 1976), is a productive process both for definition formulation and concept development. In our research, we build on Piagetian conceptions of a search of equilibrium to understand this process. A definition, whether intrinsic or extrinsic, serves as a classificatory scheme. As the individual comes into contact with an instance of the mathematical object, he either assimilates it into the existing definitional scheme, or alters his definitional scheme to accommodate for the anomaly. Through an iterative process of assimilation and accommodation, the definition is reproduced and altered until it reaches a state of relative equilibrium, in which the set of what one would consider to be the object under consideration is exactly the set of objects that satisfy the proposed definition for the object. As this process occurs, the schemata are multiplied and differentiated by their progressive accommodation to the diversities of reality. In our research, we found that when definitions are challenged, individuals responded by either assimilating the examples to their definition or accommodating their provisional definition to fit new counterexamples. We found that these two processes coexist in defining practice, and mutually reinforce. Often, accommodation prompts assimilation, as a newly revised definition is spontaneously applied to and examined in light of previously encountered examples. On the other hand, as students attempt to assimilate new instances of an object to an existing definition, they are often naturally led to accommodate their definition to those instances. These processes of refinement, through which a definition is formulated, take place both at the level of moment-to-moment interactions among students, and at the level of sociogenetic processes in the community of mathematicians. In this paper, we build on and extend Piagetian theory to understand this process.

Talk 5: **Home numeracy and children's mathematical outcomes in Chilean preschoolers**
Maria Ines Susperreguy; Jo-Anne Lefevre; Heather Douglas; Chang Xu; Natalia Molina-Rojas
The early numeracy skills that children have before they start formal education are strongly related to the development of their mathematical knowledge in the first few years of schooling (e.g., Aunio & Niemivirta, 2010; Jordan et al., 2009; LeFevre, Fast, et al., 2010) and beyond (Duncan et al., 2007; Watts et al., 2014). The home numeracy environment (HNE) is a potential source of some of this early variability (Blevins-Knabe & Musun-Miller, 1996; LeFevre et al., 2009). The Home Numeracy Model (Skwarchuk et al., 2014) is a conceptual framework that links the HNE to children's numeracy skills. The aim of this study was to investigate whether the Home Numeracy Model would replicate in a sample of children coming from a different sociocultural background. Participants were 419 Chilean preschool-aged children (48% male, all Spanish monolingual, mean age 4 years and 7 months) and their parents (85% mothers). Parents completed a pencil-and-paper Spanish translation of a questionnaire (Skwarchuk et al., 2014), reporting on the home numeracy experiences they provided for their children, including formal (mapping and operational) and informal (number book exposure) practices; home literacy practices; numeracy and literacy attitudes; and numeracy and literacy expectations for children's performance prior to Grade 1. Children completed numeracy and literacy tasks at the beginning of preschool and 8 months later. Using path analysis, an enhanced Home Numeracy Model was tested. Parents with more positive numeracy attitudes and higher academic expectations reported a higher frequency of formal numeracy practices. Formal numeracy practices, specifically operational practices, predicted number line estimation and applied problem solving. In contrast, informal numeracy practices predicted non-symbolic arithmetic and magnitude comparison tasks. The links between home practices and numeracy and literacy outcomes were domain specific. The results support the enhanced home numeracy model and provide a complete framework connecting the HNE and children's outcomes.

Time: 10:00 – 10:30
Room: North school

Coffee/Tea break

Time: 10:30 – 12:00
Room: South school

Symposium**: Accessing rational numbers – Nature and nurture**

Organisers: Edward Hubbard; Jake McMullen; Percival Matthews

Overview: Recently, there has been an explosion of research in rational number processing from multiple disciplines and viewpoints. The goal of this symposium is to capture the extent and breadth of that emerging research. This symposium will present research motivated by one guiding question: How is it that humans gain access to rational number concepts? On the one hand, recent research has shown that there may be fundamental features of human cognition that support the understanding of fractions, such as non-symbolic ratio processing. On the other, other recent work has shown that reasoning about quantitative relations, both in guided (Möhring et al., 2015) and unguided (McMullen et al., 2016) contexts, supports the development of rational number knowledge. Moreover, certain external representations, such as number lines, have been shown to be effective at providing access to rational numbers (Kalchman, Moss & Case, 2001). Finally, constraints and contextual clues provided by fraction and decimal representations have been sown to support performance on rational number assessments (DeWolf et al., 2016). This symposium will explore these themes in four interrelated talks: First, Szkudlarek and Brannon will present findings from their exploration of the relations between children's ANS acuity, their ability to process nonsymbolic ratios made of dot arrays and their symbolic math ability. They will ultimately suggest that strengthening conceptual links between non-symbolic and symbolic ratio representations may be a promising avenue for improving children's symbolic math abilities. Second, Matthews and colleagues will present findings a) that adult participants demonstrate a SNARC effect with nonsymbolic ratios and b) that adults can make cross-format comparisons between symbolic fractions and nonsymbolic line ratios with no additional costs in terms of accuracy or RT when contrasted with comparing pairs of symbolic fractions. They will discuss some potential implications of the growing list of parallels between non-symbolic ratio processing and insights such parallels may offer into the links between numerical cognition and psychophysics more generally. Third, Gunderson will present results from an experiment that uses an experimental training design to isolate the effect of the number line's unidimensionality in promoting fraction magnitude concepts in 2nd and 3rd graders. Finally, Tian and colleagues will present evidence on how different representational constraints and contextual clues can affect performance on rational number assessments. Discussion will focus on the implications of these results for educational theory, particularly as it pertains to promoting understanding of multiplicative relations.

Talk 1: **Non-Symbolic Ratio Reasoning in Children and Adults**
Emily Szkudlarek; Elizabeth M. Brannon

Approximate Number System (ANS) representations are fuzzy and imprecise, however, a large literature links individual differences in non-symbolic numerical discrimination acuity with a variety of exact symbolic math skills (Chen & Li, 2014; Fazio, Bailey, Thompson, & Siegler, 2014; Schneider et al., 2016). Non-human primates, infants, children, and adults are all sensitive to the approximate ratio of a discrete set of items, but it is unclear if and how this ability is related to the ANS (Drucker, Rossa, & Brannon, 2015; Falk, Yudilevich-Assouline, & Elstein, 2012; Matthews, Lewis, & Hubbard, 2016; McCrink & Wynn, 2007). We explored whether children's ability to manipulate dot arrays in ratio operations is a mechanism of the relation between ANS acuity and symbolic math. Eighty-five 6-8 year old children and eighty-two undergraduates completed a non-symbolic (dot arrays) and symbolic (Arabic numerals) ratio comparison task, a dot comparison task, and measures of symbolic math skill. We found that non-symbolic ratio comparison skill fully mediated the relation between ANS acuity and symbolic ratio comparison skill for both children (bootstrapped indirect effect = -.17, $p <.001$) and adults (bootstrapped indirect effect = -.08, $p = .01$), as well as the fraction magnitude comparison skill of adults (bootstrapped indirect effect = .10, $p =.04$). Moreover, we found that non-symbolic ratio comparison skill partially mediated the relation between ANS acuity and the general math ability of children as measured in the Key-Math-3 Numeration section (bootstrapped indirect effect = -.10, $p = .04$). We argue that sharper ANS acuity provides the foundation for non-symbolic ratio reasoning, and that in turn, non-symbolic ratio reasoning highlights a relational magnitude based understanding of symbolic ratio. Both children and adults were less likely to use an incorrect strategy of one-dimensional comparison during non-symbolic compared to symbolic ratio comparison (children: chi squared = 8.50, $p = .004$; adults: chi squared = 13.71, $p = .0002$). We also found that for children who could identify all digits between 1-30, completing the non-symbolic ratio task first resulted in significantly higher accuracy on the symbolic ratio task ($t64 = 2.19$, $p = .03$). This suggests that strengthening the conceptual link between non-symbolic and symbolic ratio representations may be a promising avenue for future ratio reasoning intervention in children.

Talk 2: **Similar behavioral effects for nonsymbolic ratio processing and symbolic fractions suggests common mechanisms**

Percival Matthews; Rui Meng; John Binzak; Elizabeth Toomarian; Edward Hubbard

Recent research has begun to detail the ability of humans and non-human animals to perceive the magnitudes of nonsymbolic ratios. However, research into nonsymbolic ratio perception is relatively new, and many questions remain about its connections to symbolic number. Documenting similarities and associations between these ratio representations and symbolic number is integral for making the case that nonsymbolic ratios deserve equal attention alongside discrete representations like numerosities when theorizing about the roots of numerical cognition. In this talk, I will first present evidence that nonsymbolic ratios are characterized by the spatial-numerical association of response codes (SNARC) effect – the phenomenon whereby smaller numbers are associated with the left side of space and larger numbers with the right side of space. Next, I will present evidence that adults can make cross-format comparisons between symbolic fractions and nonsymbolic line ratios with no additional costs in terms of accuracy or RT when contrasted with comparing pairs of symbolic fractions. Finally, I will discuss some potential implications of the growing list of parallels between non-symbolic ratio processing and symbolic number processing. In particular, I will argue that dedicating more attention to ratio may offer insights into the links between numerical cognition and psychophysics more generally.

Talk 3: **Number line uni-dimensionality is key to promoting fraction representations**

Elizabeth A. Gunderson

Children's ability to estimate fractions on a number line (NL) is strongly related to algebra and overall high school math achievement. Further, experimental NL training leads to better fraction magnitude comparisons compared to circle area model (AM) training. Here, we asked whether uni-dimensionality is necessary for the NL to promote fraction magnitude concepts, or whether left-to-right orientation and labeled endpoints are sufficient. We randomly assigned 2nd- and 3rd-graders (N=162) to one of four 15-minute, on-on-one, experimenter-led training conditions. The three NL conditions had identical training scripts, and used NLs with the same horizontal extent (17.5cm) with endpoints of 0 and 1. In each condition, the experimenter taught children to segment and shade the NL along the horizontal dimension. The NL conditions varied only in the vertical dimension of the NL used during training: the pure NL was a 17.5cm horizontal line; the hybrid NL was a slightly 2-dimensional rectangle (17.5cm x 0.6cm, replicating Hamdan & Gunderson, 2017); and the square NL was a square (17.5cm x 17.5cm). In the AM condition, children were taught to segment and shade a square (17.5cm x 17.5cm) along the horizontal and vertical dimensions using a script matched to the NL conditions. The conditions significantly differed in posttest fraction magnitude comparison accuracy (a transfer task), controlling for pretest accuracy and age ($F(3, 107)=3.81$, $p=.012$). At posttest, both the pure NL ($M=.54$, $SE=.03$) and hybrid NL ($M=.55$, $SE=.03$) conditions significantly outperformed the square AM condition ($M=.43$, $SE=.03$); the hybrid NL also outperformed the square NL condition ($M=.47$, $SE=.03$). Uni-dimensionality of the number line (broadly construed to include the hybrid number line) aligns with a key concept – that rational numbers, including fractions, can be ordered along a single dimension. We argue that this makes uni-dimensionality a critical feature of the number line for promoting fraction magnitude concepts.

Talk 4: **Do Children Understand Fraction Addition?**

Jing Tian; David Braithwaite; Robert Siegler

The importance of fractions makes it very unfortunate that many children fail to master them (Siegler et al., 2012; Siegler, Thompson, & Schneider, 2011). To better understand children's difficulty with fraction arithmetic, a computational model was recently developed (Braithwaite, Pyke, & Siegler, 2017). The model, without any conceptual understanding of fraction arithmetic, successfully simulated various aspects of children's performance on fraction arithmetic problems. Such findings suggest that children, too, lack conceptual understanding of fraction arithmetic. On the other hand, children were very accurate when judging the direction of effects of fraction addition and subtraction (e.g., 31/56 + 17/42 > 31/56, True or False? Siegler & Lortie-Forgues, 2015), suggesting that children have good conceptual understanding with fraction addition and subtraction. To address this discrepancy, we conducted three experiments assessing children's conceptual knowledge of fraction addition via estimation. In Experiment 1, 4th and 5th graders estimated sums of two fractions by choosing among 1/2, 1, and 1 1/2 for the number that was closest to the sum. About half of the children performed no better than chance (i.e., 33%). Experiment 2 extended the findings of children's poor estimates of fraction sums to older students (6th and 7th graders) and to a different task (number line estimation). Experiment 2 also showed that children's poor performance could not be fully accounted by poor understanding of addition, as their estimates of sums were more accurate with whole numbers than with fractions. Experiment 3 showed that older students (7th and 8th graders) were also very inaccurate in estimating fraction sums when generating answers in a free-response format. In addition, difficulty with estimating fraction sums was at least partly specific to fractions rather than general to rational numbers, as estimates of decimal sums were more accurate than of fraction sums. Implications of these findings will be discussed.

Time: 10:30 – 12:00
Room: East school

Symposium: **Reliability and validity of the SNARC effect**

Organisers: Wim Fias; Jean-Philippe van Dijck

Overview: Mathematical processing and spatial processing are intimately related. The SNARC effect, indicating faster left than right hand responses to small numbers and faster right than left hand responses to large numbers, has implicitly been considered as important evidence expressing this relationship. However, the connection hasn't been firmly established, neither empirically nor theoretically. Important questions relating to reliability and validity will be addressed in the symposium. The stability of the SNARC effect, both within and between sessions, is an important prerequisite, as is the precision with which the SNARC effect is measured (Cipora) This will also be framed in the general question of using experimental paradigms in the context of individual differences (Hedge). But not only reliability is important. An equally important question is what the SNARC effect measures. An important issue that will be addressed is whether the SNARC effect reflects the operation of long term memory representation of numerical magnitude or, alternatively, expresses the organisation of working memory (van Dijck). Behavioral and neural modulations may provide an interesting approach to investigate construct validity of the SNARC effect. Apart from construct validity, also criterium validity is crucial: How do individual differences in the SNARC effect relate to mathematical proficiency? (Schiltz).

Talk 1: **The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences**
Craig Hedge; Georgina Powell; Petroc Sumner

What makes a task or effect reliable? For an experiment, a 'reliable' effect might be one that nearly always replicates; one that is shown by most participants in any study and produces consistent effect sizes. In the context of correlational research, reliability refers to the extent to which a measure consistently ranks individuals. Critically, these different definitions of reliability can be at odds with each other. For an experiment it is advantageous for individual differences in an effect to be low, whereas between-subject variability is fundamental for correlational research. This means that it may be suboptimal to try to correlate educational or neuropsychological outcomes with performance in cognitive tasks that are popular for their robust within-subject effects. Here, I will present three week test-retest reliability data for seven widely used tasks, including the SNARC effect in a magnitude comparison task, Eriksen Flanker, Stroop, stop-signal, go/no-go, Posner cueing, and the Navon task. The retest reliability of the SNARC effect was poor (.22), despite good reliability for the mean reaction times in each condition (.69-.74). A similar trend was seen for most of the tasks we examined, with reliabilities ranging from 0 to .82. I demonstrate how reliabilities in this region can affect the conclusions we draw from correlational studies, and the impact it has on statistical power. More broadly, these findings provide context for how we think about the reliability, reproducibility, and validity of experimental effects.

Talk 2: **Who has (a consistent) SNARC: investigating prevalence of the SNARC effect by means of estimating confidence intervals - psychometric and resampling approaches.**
Krzysztof Cipora

Addressing the measurement reliability issue plays a vital role in differential psychology. Only by using reliable measures one can effectively explore correlations between constructs. In that respect, the reliability of the SNARC effect (quantified by means of individual regression slopes) was also tested. Reliability estimates reported in the literature vary from moderate to satisfactory (ranging from about .6 to .8). The non-perfect reliability implies that observed estimates of the SNARC slopes are inaccurate as well. This raises important questions about the prevalence of the SNARC effect. Routinely the SNARC slopes are tested against zero by means of one-sample t-test, which evaluates presence of the effect at the sample level, not at a level of an individual. Nevertheless, the proportion of participants revealing negative slopes (usually between 70 and 80%) is treated as proportion of individuals revealing the SNARC. Such understanding does not consider the measurement inaccuracy. The presented study aimed at investigating prevalence of a consistent SNARC by checking proportion of participants whose SNARC slopes consistently deviate from zero. Two approaches, psychometric and bootstrapping were taken to estimate confidence intervals (CI) for individual slope estimates. Subsequently the proportion of individuals, whose CI do not contain 0 was examined. We managed to collect data from 18 independent experiments (total n > 1000). All datasets were analysed according to the same routine. Within the psychometric approach, we estimated CI based on the standard error of measurement (SEM). Within the bootstrapping approach, subsets of the original data were sampled with replacement and used to calculate the slopes. CI was defined as the range in which given percentage of 1-alpha of slopes lied excluding largest alpha/2 and smallest alpha/2 percentage of slopes. Results show, that assuming 90 CI, fewer than 50% of participants reveal consistent SNARC (about 35% and 45% for psychometric and bootstrapping estimations respectively). On the other hand, very few participants (< 5%) reveal consistent reversed SNARC. Remaining group seem not to reveal consistent SNARC. These results raise vital theoretical questions which need to be addressed in future studies: (i) whether the SNARC is an accurate measure of space-number associations (ii) whether space-number associations are universal across people. As regards the reliability issue, one more question needs to be addressed: if we assume that in individuals, who do not reveal the SNARC, the slope estimate reflects only the random noise, then – by definition – one should not expect it to be reliable. Therefore, it could be considered to estimate the reliability of the SNARC only in individuals who reveal consistent slopes (e.g., based on bootstrapping approach). Similarly, only those participants should be considered in studies aimed at investigating SNARC correlations.

Talk 3: **About the validity of the SNARC effect: The importance of working memory**
Jean-Philippe van Dijck; Wim Fias

It is commonly accepted that the processing of number and of space are tightly linked. This is evident from studies showing relations between math ability and visuospatial skill. Also, math instruction and education rely strongly on visuospatial tools and strategies. The dominant explanation for these number-space interactions is that the mental representation of numbers takes the shape of a mental number line with numbers positioned in ascending order according to our reading habits. A long-standing debate is whether the link between numbers and space can be considered as evidence for a spatial number representation in long-term semantic memory, or whether this spatial frame is a temporary representation that emerges in working memory (WM) during task execution. We here explore this issue using the SNARC effect. Whereas a pure Mental Number Line account cannot capture the complexity of observations reported in the literature, we here discuss how a working memory account can suffice. More precisely we will argue that the SNARC effect is a reflection of a more general principle of how ordinal information is spatially patterned in working memory.

Talk 4: **Flexible behavioral and neural modulations of the SNARC effects: Implications for construct validity**

Philipp Alexander Schroeder; Hans-Christoph Nuerk; Christian Plewnia

Experimental interventions are instrumental tools for understanding the general conditions and theoretical underpinnings that bring about behavioral effects. Observing changes in behavior due to independently manipulated variables of a task or a situation can provide insights into the involved cognitive processes. In case of the SNARC effect, interventions are particularly informative to juxtapose different theories on neurocognitive mechanisms. Moreover, conditions in which reliability is low or high may depend on task design according to the situated influences on spatial-numerical associations. Across a series of empirical studies, the neurocognitive underpinnings of different SNARC effects are investigated by means of experimental behavioral and neural interventions. Multiple cognitive operations are supposed to be involved in the SNARC effect. As one of them, importantly, working memory interventions are well-known for their impact on SNARC effects. Consequently, transient modulations of prefrontal brain activity impair spatial-numerical associations. Effects of the identical neuromodulation on other tasks can inform whether a shared neural circuit of spatial-numerical processing exists in fronto-parietal networks. Results reveal dissociations with explicit spatial processing and numerical magnitude processing. Interestingly, for SNARC effects based on non-numerical, ordinal stimuli (weekdays and months), opposite stimulation effects are provoked. On this empirical basis, a single construct appears untenable. All evidence points to a critical role of working memory and multiple codes are involved in the implicit activation of spatial information in SNARC effects, and potentially in other implicit associations as well. Future research will further disentangle the exact components involved in SNARC effects and their neurocognitive underpinnings.

Talk 5: **Is the SNARC effect a valid measure of numerical skills? Insights from its relation to mathematical abilities over the lifespan**

Carrie Georges; Danielle Hoffmann; Christine Schiltz

The SNARC effect is supposed to capture spatial aspects of number representation (Dehaene et al., 1993). Within the general framework of embodied numerical cognition, there is indeed ample evidence that numerical concepts relate to different facets of spatial processing (Hubbard et al., 2005; De Hevia et al., 2008). Relying on concrete spatial concepts and procedures when dealing with numerical representations and symbols might help, amongst others, to make these processes less abstract. Especially (young) children, who typically prefer concrete situations and problems, might profit from the existence of number-space associations when facing the challenges of math education. Here we consider evidence from developmental studies to examine how the SNARC effect develops with age and schooling (Hoffmann et al., 2013; Georges et al., 2017) and how it relates to mathematical abilities at different moments in life (Hoffmann et al., 2014; Georges et al., 2016). Beyond presenting the relations between the SNARC effect and arithmetical abilities at distinct ages, we will examine their robustness. Based on these data we will then discuss whether and to what extent the SNARC effect might be considered a valid index of a person’s numerical abilities.

Time: 10:30 – 12:00
Room: Room 6

Parallel session: **Arithmetic and beyond 3**

Chair: Avishai Henik

Talk 1: **The developmental of estimation skills across the life span**
Dana Ganor-Stern

Although formal schooling in math focuses on solving math problems exactly, in many real life circumstances an approximate answer is sufficient. The current study explores the development of estimation skills across the life span. Participants are presented with multidigit multiplication problems and they have to indicate whether the answer to each problem is larger or smaller than a given reference number. Speed and accuracy are enhanced for smaller (vs. larger) and for far (vs. close) reference numbers. Participants reported using mainly two strategies. (1) An approximated calculation strategy, which involves rounding one or two multiplicands, and comparing the product to the reference number. This strategy is slower and requires working memory resources, but can guarantee a correct response in all trials. (2) A sense of magnitude strategy, which relies on an intuitive coarse sense of magnitude built on the life long experience of solving multiplication problems. This strategy is faster and requires little working memory resources, but can guarantee a correct response only when the reference number is far. A life span investigation from the age of 10 until 70 reveals three clear patterns: (1) a continuous increase in accuracy from childhood to old adulthood, (2) an increase in speed from childhood to adulthood, and then a decrease in old adulthood, and (3) a stable increase in the use of the approximated calculation strategy from childhood to old adulthood. These patterns are discussed in the context of the development of mathematical skills and of general abilities such as working memory.

Talk 2: **Automatization of facts or automatization of procedure? The case of alphabet arithmetic verification.**
Jasinta Dewi; Catherine Thevenot

According to the instance theory of automatization, with each instance of learning, the algorithm-based strategy used initially to learn arithmetic facts will be replaced by memory-based strategy. The alphabet-arithmetic paradigm has been used to support this theory. In light of recent findings that adults may still apply counting strategy to solve very small additions (i.e. those involving addends from 1 to 4), we retook the alphabet-arithmetic paradigm to study the evolution of strategies used in addition. In 12 sessions, 24 adults were trained to verify alphabet-arithmetic equations (e.g. B + 3 = D), where 8 letters were combined with 5 addends (from 2 to 6). The results failed to reveal an automatization of alphabet-arithmetic facts and therefore call into question the instance theory. Even at the last session, the slope of response times as a function of addend was still significantly different from 0, indicating that counting remained the dominant strategy. The analyse of individual slopes demonstrated the role of processing speed in the acceleration of counting procedure. Factors that may explain the differences between the studies supporting the instance theory of automatization and ours will be discussed.

Talk 3: **The Numerical Approximation System's cognitive factors and calculation fluency**
Carlos Mera; Estibaliz Aragon; Manuel Aguilar; Manuel Garcia Sedeño; Gamal Cerda; Carlos Perez Wilson; José I. Navarro

Nowadays there is an extensive debate in the math-cognition current research about mechanisms supporting relationship between the accuracy of Numerical Approximation System (NAS; Halberda et al., 2008) and mathematic skills of school children. Recent research suggested a relatively high confidence of a relationship between the NAS accuracy and children performance in mathematics. However not all data are consistent with this statement. The main purpose of this study was to explore the relationship between the accuracy of the NAS and mathematical performance in a fluency calculation test in 3rd to 6th primary school children. We hypothesized that participants' performance in the NAS accuracy test would correlate with a measure of the calculation fluency. A total of 229 students from 3rd to 6th grade of primary education (M age = 123.54 months, SD = 14.22, 89 girls and 140 boys) participated in this study. They were evaluated in the accuracy of the Numerical Approximation System (NAS). Their processing speed was assessed by the Coding and Symbol Searchof the Wechsler Intelligence Scale for children WISCIV (Wechsler, 2005) and Woodcock-Johnson III Calculation Fluency (WJ-III). Results were within expected considering the development process of the analyzed variables. But data had different characteristics considering the school grades assessed. Considering the theoretical and experimental debate about NAS accuracy and mathematic skills, it seems convenient cautiously study the role of memory, fluid intelligence and language over fluency calculation.

Talk 4: **Struggling with single-digit multiplications: testing several hypotheses**
Juan Antonio Álvarez-Montesinos; Ismael Rodríguez-Montenegro; Marina Cuadra Jaime; Javier García-Orza

Single-digit multiplications are usually memorized without too many problems, however, it exists a percentage of children, between 5-10%, who suffers big difficulties in their learning (Geary, 2011). In accordance with previous studies, difficulties in learning multiplications would be related with interference-control problems. The more similar the multiplications are (e.g., 4x6=24; 4x7=28), the greater is the interference that occurs when remembering them. People who have interference-control problems, would not be able to adequately retrieve the solutions (e.g., Geary, 2011; De Visscher et al., 2014, 2015, 2016; Szücs & Myers, 2016). Furthermore, evidences suggest that inhibition would be a key cognitive mechanism underlying numerical development (Askenazi & Henik, 2010; Nath & Szücs, 2016). Another point of view defends that difficulties with basic numerical representations, or their access from symbolic formats (e.g., Arabic, verbal), would be the cause of the multiplication learning difficulties. The footprint in the memory of multiplication problems would be weakened because of an imprecise representation of the numbers and the result which compose them (e.g., Buttwerworth, 2005). This study explored whether the differences in multiplication fluency in adults are due to numerical or non-numerical abilities. High Fluency (N=17; Age=18-32) & Low Fluency (N=17; Age=18-37) groups were created according to their performance in a multiplication fluency test (High=Fluency>P85, Low=Fluency<P15). We used two tasks to assess symbolic and non-symbolic numerical representations, and two memory tasks to assess proactive and retroactive interference. To assess inhibitory control, we used the Attentional Network Task. Finally, we explore the interaction between numerical representations and inhibition using a numerical Stroop task. Results showed differences in numerical representation tasks between groups but not in interference-control measures. A reduced numerical Stroop effect in the Low Fluency group was also found. Taking together, we conclude that deficits in the numerical domain are in the basis of single-digit multiplication problems.

Talk 5: **Procedure learning without algorithmic speed up**
Jamie Campbell; Yalin Chen; Alicia Orr

We examined learning in alphabet arithmetic (e.g., C + 3 = C D E F). Adults practiced 12 alphabet arithmetic problems for 40 blocks. If learning reflected speed up of a counting algorithm, speed up should be proportional to the number of counting steps (+1, +2 or +3). Response time decreased across blocks, but there was no evidence of proportional speed up, at least early in practice. Near the end of practice, response times to +2 problems were similar to +3 problems, which suggests that speed up reflected a gradual shift to associative fact retrieval. The results raise questions for theories of cognitive procedure learning as algorithmic speed up.

Time: 12:00 – 14:00
Room: North school

Lunch

Time: 12:30 – 13:15
Room: South school

A lunch with the Editors:

Dr John Towse and Dr Barbara Sarnecka to discuss the Journal of Numerical Cognition and preregistered reports

Take your lunch and join the meeting.

Time: 12:00 – 14:00
Room: North school

Poster session 2

1. Same or different? The ERP signatures of uni- and crossmodal integration of number words and Arabic digits
Sabrina Finke; Ferenc Kemény; Corinna M. Perchtold; Silke M. Göbel; Karin Landerl

According to the triple-code model (Dehaene & Cohen, 1995), different numerical codes (i.e. visual Arabic, verbal word and analogue magnitude) are associated with specific brain areas. Translational paths support the interaction between these codes. Although the strength of the association between spoken number words and Arabic digits has been identified as a longitudinal predictor of arithmetic performance (Göbel et al., 2014), little is known about the underlying neural mechanisms. The present study investigated the neural signature of same or different single-digit number pairs in adult participants. Number pairs were presented unimodally (visual-visual or auditory-auditory) or crossmodally (visual-auditory or auditory-visual). The participants were asked to indicate whether the second number of a pair was larger or smaller than five (target) while not being required to respond to the first number (prime). For auditory target numbers, same number pairs elicited higher N400 amplitudes at frontal electrode sites compared to different number pairs, both in the unimodal (auditory-auditory) and crossmodal (visual-auditory) condition. Additionally, an increased positive slow potential for different number pairs was observed in both auditory conditions on parietal electrodes. For visual target numbers, different number pairs resulted in larger frontal N100 and centroparietal N300 amplitudes, also irrespective of whether the number pair was presented unimodally (visual-visual) or crossmodally (auditory-visual). Similar to the auditory target conditions, different numerical values elicited more positive slow waves on parietal channels. Results suggest that crossmodal integration of number words and digits is highly automatized in adults. Future studies should aim to investigate the developmental trajectory of this integration process.

2. Symbolic number processing and individual differences in adult's arithmetic performance

Laura Matilla; Rosario Sánchez; Josetxu Orrantia; David Múñez

Recent work has shown that symbolic number processing relates to individual differences in arithmetic. However, it remains unclear what attributes of symbolic number processing (magnitude processingor order processing) are crucial for success in mathematics. In the current study we question whether the relationship between symbolic number processing and mathematics achievement changes as a result of the task used to assess math achievement by focusing on single-digit arithmetic (subtraction and multiplication). To address this question, adult participants performed a numeral-ordering task that relied on symbol-symbol associations (order processing)and a dots-number word matching task thought to be a measure of symbol-magnitude associations (magnitude processing). The tasks were applied to university students, along with control tasks (intellectual ability, digit span, inhibitory control, non-numeric order processing, and general math achievement) and the arithmetic measures. Results showed that both magnitude processing and order processing tasks were uniquely related to single-digit arithmetic achievement, although findings differed across the tasks used to assess arithmetic achievement. The regression analysis using multiplication performance as a dependent variable was significant, $F(9, 84) = 4.65$, $p < .0001$, $R2 = .33$, and the experimental measures accounted for an additional 12% of the variance, $F(4, 84) = 3.84$, $p < .01$, but numeral-ordering (ß = .43) was the only significant predictor. The model predicting subtraction performance was also significant, $F(9, 84) = 10.16$, $p < .0001$, $R2 = .52$, and the experimental measures accounted for an additional 11% of the variance, $F(4, 84) = 4.66$, $p = .002$. In this case, both numeral-ordering (ß = .26) and dots-number word matching (ß = .29) were significant predictors. The current study provides strong evidence for the idea that symbolic number processing plays a role in adults' single-digit arithmetic. Nevertheless, findings also suggest that the mechanisms underlying symbolic number processing can play a different role depending on the type of single-digit arithmetic skills, probably due to demands involved in strategy use (direct memory retrieval vs. procedural strategies).

3. The effects of manipulatives in the instructional interventions of mathematics learning disabilities: a systematic review

Anne Lafay; Helena Patricia Osana

Manipulatives are concrete objects (e.g., blocks, plastic chips) often used by teachers in elementary grades to illustrate abstract mathematical concepts. The use of manipulatives is becoming increasingly popular with psychologists in their work of students with mathematics difficulties. A meta-analysis by Carbonneau, Marley, and Selig (2013) indicated that using manipulatives in mathematics instruction produces a small- to medium-sized effects on student learning when compared to instruction that incorporates formal written symbols alone. Despite the growing interest in the instructional affordances of manipulatives, little is known about the effects of manipulatives in the Mathematics Learning Disabilities (MLD) population, nor the instructional conditions under which any effects are optimized. The aim of this systematic review was to investigate the effectiveness of instructional interventions delivered with manipulatives on the learning of children with MLD. As a guide for conducting this review, we used the PRISMA Statement (Moher et al., 2009) for reporting systematic reviews of studies that evaluate health care interventions. We conducted a systematic search of publications in PubMed, PsycInfo, and ERIC. Without any limitations on publication date, we selected studies designed to assess the effectiveness of an intervention delivered with manipulatives on the mathematics learning of children with MLD. The search yielded 31 studies. The outcome measures in the sample were learning, maintenance, and transfer in mathematics, and the mathematical domains were precursor skills (such as counting), conceptual knowledge in the early grades (e.g., place value), arithmetical computation, word problem solving, and more advanced mathematics (as fractions, algebra, and geometry). The results suggested that interventions using manipulatives with children with MLD were effective for a variety of mathematical outcomes, including conceptual understanding, computational fluency, and problem solving in the contexts of whole number arithmetic, fractions, algebra, and geometry. Our analyses also highlighted great heterogeneity in the way child and instructional variables (such as grade/age, duration of intervention, instructional environments) influenced intervention outcomes. We used the results of this systematic review to address the characteristics, quality, and robustness of the studies included.

4. Improving the use of associativity shortcuts: Interventions using inversion problems
Joanne Eaves; Nina Attridge; Camilla Gilmore

Individuals who understand associativity can solve three-term arithmetic problems, e.g. “6 + 38 - 55" by performing the subtraction (38 - 35) before the addition (6 + 3). More than any other arithmetic concept, children and adults alike struggle with this principle, with nearly 70% of adolescents failing to use 'associativity shortcuts' (Dubé, 2014). Compared to shortcuts derived from other principles (e.g. commutativity), associativity is seldom applied (Robinson & LeFevre, 2012), slow to develop (Robinson & Dube, 2017) and preferred the least (Robinson & Dubé, 2012): Improving this is a key goal for mathematics education (National Advisory Panel, 2008). We report two pre-registered intervention studies conducted in university classrooms that investigated whether the use of associativity shortcuts could be increased. In each study, participants were randomly allocated to an intervention or control condition. In study 1 (N = 109), participants in the intervention condition first solved inversion problems of the form ‘a + b – b’ and ‘a + b – a’ and those in the control condition solved two-term arithmetic problems. In the second study (N = 257), there were three conditions, where participants either solved ‘a + b – b’ problems, or ‘a + b – a’ problems, or two-term arithmetic problems. It was found that there were more individuals who self-reported using the associativity shortcut in the ‘a + b – b’ condition than either of the other two conditions. We suggest that ‘a + b – b’ inversion problems provide perceptual cues that help individuals to notice the validity and efficiency of a right-to-left strategy on ‘a + b – c’ problems. These findings may be helpful for teachers in designing brief activities to encourage strategic thinking.

5. Neural Underpinnings of Nonsymbolic Numerical Comparison in Adolescents with Different Math Performance
Roberto A. Abreu-Mendoza; Yaira Chamorro; Daniel Zarabozo-Hurtado; Esmeralda Matute

At the end of junior high school, a substantial number of adolescents do not achieve appropriate mathematical literacy levels (46.8% in Mexico; INEE, 2015). Yet, some are able to develop sophisticated mathematical abilities that will allow them to go into mathematical demanding jobs.

What are the reasons for these individual differences? Studies have suggested that they are linked to our basic numerical comparison abilities; however, most of these studies have focused on the lower end of the continuum (mathematical difficulty, MD), while little attention has been given to the upper end (mathematical talent, MT). We investigated the differences in brain activations when comparing small and large quantities of 33 adolescents with distinct mathematical achievement. Adolescents were divided into three groups of the same size based on their performance in the WRAT Math Computation subtest: the MD group (< - 1.5 SD), the Typically Achievement (TA) group (between -1.5 and 1.5 SD) and the MT group (> 1.5 SD). Participants had normal IQ and reading ability. The experimental task consisted of an adaptation of the one used by Ansari et al. (2007). Participants had to judge the numerosity of small (1, 2, 3, 4), and large (10, 20, 30, 40) collections of dots. Behavioral results showed that, regardless of the numerical size of the collections, the MD group had a lower performance than the other two. Importantly, when contrasting brain activations across groups, we found greater activations in parietal and frontal regions of the MT group in comparison to the other two when comparing small quantities; however, when comparing large quantities, there were only differences between the MT and MD groups in these regions. Along with recent findings, this study shows that numerical comparison abilities are associated with the whole continuum of mathematical performance and provide insights about the neural underpinnings that support them.

6. Interaction Effects between BDNF Gene rs6265 Polymorphism and Parent-Involved Education on Primary School Children Basic Mathematical Ability: The Moderating Effect of Gender

Ming-Liang Zhang; Jiwei Si; Weixing Yang; Hongxia Li; Jiajia Zhang

In recent years, many studies from quantitative genetics adopting the twin-study design have been conducted to identify the heritability of performance related to mathematical ability and disability. Although its mechanism is poorly understood, qualitative behavior genetics study has shown mathematical abilities to be moderately heritable. However, the extant evidence has mainly came from quantitative genetic research, only a small amount of molecular genetic research specifically investigating mathematical ability or disability has been reported. To our knowledge, just one molecular genetic research investigated the gene×environment interactions on children’s mathematical ability. The present study aimed to extend the previous research by examining the interaction between BDNF gene rs6265 polymorphism and parent-involved education on primary school children’s basic mathematical ability, with a particular focus on the possible moderating effects of gender on the interaction, and further tested these two competing models (classic diathesis-stress model vs. newly-developed differential susceptibility model). Six hundred and two primary school children (male = 297, female = 305) from 23 classes ranged from grade 3 to grade 6 were tested. Basic mathematical ability was accessed using Chinese Rating Scale of Pupil’s Mathematic Abilities (C-RSPMA), and parents’ educational involvement was examined by employing Behavior Questionnaire of Pupils’ Parent-Involved Education (parents answered version). DNA samples of primary school children were extracted from saliva. Genotype at rs6265 polymorphism in the BDNF gene was performed in real time with MassARRAY RT software version 3.0.0.4 and analyzed using the MassARRAY Typer software version 4.0 (Sequenom company). Statistically, a series of linear regression analyses were conducted using the Statistical Package for Social Sciences 19.0 (SPSS 19.0), followed by the re-parameterized regression models to examine the interaction between BDNF gene rs6265 polymorphism and parent-involved education on primary school children’s basic mathematical ability and further test the two potential competing G×E hypotheses. Three major findings were obtained from this study: (1) Rs6265 polymorphism was significantly associated with male primary school children’s basic mathematical ability composed of various components (including arithmetic operation ability, logical thinking and spatial vision ability). Specifically, compared with primary school children carrying G allele, primary school children carrying AA genotype had better performance of basic mathematical ability, while such an association was only observed among males. (2) The interaction between rs6265 polymorphism and parent-involved education significantly predicted female primary school children's logical thinking and spatial vision ability. To be specific, parent-involved education behavior positively predicted female primary school children's logical thinking and spatial vision ability among carriers G allele but not AA genotype. (3) The indexes in re-parameterized regression models provided support for the strong diathesis-stress model. Taken together, by elaborating the moderating effect of parent-involved education and gender, the present study enriches the literature of the relation between BDNF gene rs6265 polymorphism and primary school children basic mathematical ability and further expands our knowledge about the G×E underpinnings of basic mathematical ability, and the new and developing methods are proved to be high-efficiency and quite legitimate.

7. The Dissociation between Pupil Dilation and Reaction Time in the Numerical Stroop Task
Ronen Hershman; Lisa Beckmann; Avishai Henik

The classical Stroop task (i.e., using color-words) has already shown the presence of both information and task conflicts. The information conflict is due to a mismatch between relevant and irrelevant information (i.e., ink color and word meaning) and task conflict is due to the need to carry out one task (i.e., report the ink color) and inhibit another task that is triggered automatically by the stimulus (i.e., reading words). The task conflict exists in both congruent and incongruent trials. We investigated both of these conflicts in a numerical Stroop task, using pupillometry as an indicator for cognitive load. Participants were presented with two digits and asked to decide, in separate blocks, which one (a) was numerically larger or (b) which one was physically larger. RTs for the physical and the numerical tasks showed congruency, interference and facilitation effects. In contrast, pupil dilation confirmed congruency, interference and reverse facilitation effects for the numerical task and congruency and interference effects for the physical task. The dissociation between pupil dilation and RT was indicated by a facilitation effect in RT and a reverse facilitation in pupil dilation. These results provide new evidence for the theoretical hypothesis about both information and task conflicts.

8. ERP analysis of hemispheric asymmetry for arithmetic tasks: A comparison of remembering, understanding, and applying-based tasks.
Kanok Panthong; Pattrawadee Makmee; Peera Wongupparaj

In this research, arithmetic tasks were divided into three tasks, that is, remembering, understanding, and applying-based tasks according to Bloom's revised taxonomy. This study examined the effect of the given tasks on the hemispheric asymmetry of event-related potentials (ERPs) from 40 secondary-school students aged 13-14 years (20 male). The ERPs were recorded from 64 scale sties while participants solving three arithmetic tasks. Comparison of area measures from waveforms at lateral frontal, central, parietal, and occipital electrode sites. The results indicated that the remembering-based task showed a significant higher P300 amplitude over the left parietal and occipital hemispheric than the right parietal and occipital hemispheric. In contrast, the understanding and applying-based tasks showed a significant higher P300 amplitude over the right frontal and central hemispheric than the left frontal and central hemispheric. Furthermore, the interaction effect between hemispheric asymmetry and gender on P300 amplitude over parietal electrode sites was significant. However, the hemispheric asymmetry was not found for P300 latency on any arithmetic tasks. Our results point to more efficient use of attentional control and processing among arithmetic tasks involving remembering, understanding, and applying and gender differences.

9. Nonsymbolic arithmetic with continuous magnitudes: Evidence from an artificial algebra paradigm.

Anna Wilson; Cam Hooson; Simon Kemp; Randolph Grace

Is our ability to add and multiply numerosity (e.g. McCrink & Spelke, 2010) specific to the numerosity domain, or does it extend to continuous magnitudes? In previous research (Grace et al., 2017), we have developed a nonsymbolic implicit 'artificial algebra' task, in which adult participants learned to estimate differences and ratios between continuous stimulus magnitudes (e.g. brightness, area), using nonsymbolic responses with approximate feedback. Participants learn to do this task highly accurately in the absence of explicit instructions or training. Here we tested if they could learn to estimate sums and products of stimulus magnitudes using the same paradigm. On each trial, participants see a pair of stimuli of varying magnitudes and responded by clicking on a horizontal response bar. Approximate feedback is provided based on how close the response was to either the sum or product of the magnitudes. Initial data using brightness show that average correlations between responses and trained values after a single session were very high (average r = .95) in both the addition and multiplication groups. Analyses showed that a weighted average model provided an excellent account of the data from both groups. The ease with which participants can learn to implicitly add and multiply stimulus magnitudes adds to evidence that this ability may be a fundamental property of our perceptual system, and not restricted to numerosity per se.

10. The Wicked Problem of Research in Mathematical Cognition: Elephants in the Room

Rene Grimes

Mathematical cognition research (MCR) is in some ways analogious to two elepant parables: The Blind Men and the Elephant; and, the elephant in the room. The former represents a situation in which developing a collective understanding of the whole is limited because those involved do not have a model in which to infuse their individual knowledge. The latter illustrates a situation in which a visible problem is not addressed. Marrying these analogies provides an opening to discuss a few wicked problems in MCR. Dynamic systems theory uses the term wicked problems to characterize seemingly insurmountable issues requring exploration in order to design self-sustaining environments hospitable to systemic change. The International Mind, Brain and Education Society (MBE) and the Mathematical Cognition and Learning Society share common goals and have provided rich opportunities to identify problems inherent in research. Where the parable of the blind men and the elephant may have been true in the past, those in the fields of MCR and MBE have built feedback loops (e.g., workshops, conferences, and special issue journals) necessary for healthy dynamic systems. However, in order for research to be applied at the classroom level, an elephant in the room remains to be acknowledged: the voice and expertise of teachers has been minimal. As a former classroom teacher, graduate of an MBE program, and current doctoral student, the goal of this paper is to provide a medium to discuss barriers (elephants) I have encountered; propose a concept for a collaborative research workshop; share identified areas of future research; and highlight one model I see as a viable MCR framework.

11. Associations between number processing and single-digit arithmetic: Effects of age, intelligence, operation mastery and SES?

Isabella Starling Alves; Mariuche Rodrigues de Almeida Gomides; Luciano da Silva Amorim; Vitor Geraldi Haase

Number processing has been associated with arithmetic performance in early school years. It is controversial to which extent arithmetic achievement is influenced by nonsymbolic number processing. We investigated associations between accuracy of non-symbolic comparison (w), number estimation (cv) and single-digit calculation in a sample of 99 Brazilian children attending from the 2nd to the 4th grades. All children were from middle SES. The sample did not include children from extremely affluent or below the poverty line families. Most children had already acquired mastery over addition operations (ceiling effect) but did not acquire mastery over multiplication (floor effect). Performance on the subtraction tasks was intermediate (normal distribution). A series of regression models showed that addition operations were associated with age (beta = .37, $p < .001$), intelligence (beta = .25, $p < .05$) and non-symbolic accuracy (w; beta = -.21, $p < .05$); subtraction was associated with age (beta = .35, $p < .001$), intelligence (beta = .30, $p < .01$), and number estimation (cv; beta = -.21, $p < .05$); and multiplication operations were also associated with age (beta = .37, $p < .001$), intelligence (beta = .22, $p < .05$), and number estimation (cv; beta = -.31, $p < .01$). All adjusted $R^2 > 0.23$. SES was correlated with cv ($r = -.23$, $p < .05$) but not with w ($r = .09$, $p = .39$), and did not enter the regression models. Variability in the already acquired addition operations may be more dependent on non-symbolic number processing. Variability in subtraction and multiplication abilities, which are in processing of acquisition, may be more dependent on both nonsymbolic and symbolic number processing. SES was associated with number estimation but not with nonsymbolic comparison. Effects of SES seem overridden by other variables in this sample with a restricted range of SES variability.

12. Neural processing of transitive relations predicts math growth in children

Flora Schwartz; Justine Epinat-Duclos; Jessica Léone; Jérôme Prado

Children with poor math achievement are at risk of school failure and may struggle later on in their personal and professional life. Because interventions aimed at remediating math difficulties are most effective early in development, it is critical to identify the neuro-cognitive markers that are associated with the growth of math skills in children. Notably, there is increasing evidence that the ability to understand and manipulate transitive relations (e.g., “All squares are rectangles, All rectangles have four sides, therefore All squares have four sides”) is a critical component of math learning in elementary school. Here we used fMRI coupled with a longitudinal design to determine whether the neural processing of transitive relations in 21 children from middle to late elementary school could predict long-term growth in their math skills. At baseline (T1), children processed transitive relations in an fMRI scanner and completed a battery of standardized math tests. Math skills were again measured 1.5 years later (T2). Using a machine learning approach with cross-validation, we found that patterns of brain activity associated with transitive reasoning in the parietal cortex accurately predicted change in standardized math score from T1 to T2. In contrast, behavioral measures of transitive reasoning, IQ or reading skills were not associated with math growth. Therefore, our study highlights the potential of neurobiological measures of transitive reasoning for forecasting math growth in children from elementary school.

13. Influences of basic numerical competencies on fraction processing

Thomas Dresler; Silke M. Bieck; Katharia Lambert; Korbinian Moeller

Fraction knowledge is crucial in children’s mathematical development. In fact, it is a valid predictor of actual and future mathematical achievement. As such fraction knowledge seems to provide a foundation for later mathematical learning. Yet, understanding the concept of fractions is difficult for students and adults including teachers. However, little is known about which basic numerical competencies predict successful fraction learning. Bailey et al. (2014) observed that knowledge of whole number magnitude and arithmetic in first grade predicted knowledge of fraction magnitude and arithmetic in middle school. As fraction knowledge seems important for later mathematical development, it is crucial to identify and differentiate basic numerical precursor competencies. This may facilitate fraction learning in children by strengthening the fundament of fraction learning.We investigated which basic numerical competencies predicted fraction knowledge in secondary school students. We analyzed data of 1167 German students from secondary and vocational schools. Each participant completed a paper-pencil test of basic numerical competencies (including basic arithmetic operations, number line estimation, non-symbolic magnitude comparison, conceptual knowledge, etc.). Scales only included numerical/mathematical content which participants should have acquired in primary school. Participants also completed a test of fraction knowledge including 10 items assessing different operations on fractions. Furthermore, general cognitive ability was assessed. Using multiple regression, we observed that children's fraction knowledge was predicted significantly by basic numerical competencies in number line estimation, multiplication, subtraction and conceptual number knowledge beyond influences of general cognitive ability. This indicates that basic numerical competencies acquired in primary school influence fraction knowledge. Strengthening these competencies should provide children with a broader fundament for fraction learning. However, such content is usually not reconsidered in secondary school curricula. Our data indicate that recapitulating these competencies in secondary school education may be beneficial for acquiring more complex mathematical concepts such as fractions.

14. The educational technology and innovation for children with math disability in Thailand: A systematic review

Jakkarin Chinsuwan; Piyathip Pradujprom; Parinya Ruengtip; Peera Wongupparaj

Learning difficulties in mathematics have been a major concern in education policies in Thailand. Furthermore, the recent research has indicated that the prevalence rate of math disability in Thailand was approximately 7%. This study aimed to review the evidence on intervention in children with mathematical learning difficulties aged 8-16 years in Thailand between 2005 and 2016. Thai-language articles addressing the interventions were searched through ThaiLIS (Thai Library Integrated System) and TCI (Thai-Journal Citation Index) databases and 264 studies were identified. All data were extracted and analyzed according to the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guideline and ten studies were included. The review makes three contributions: (1) it reviews existing interventions in children with math disability in terms of various educational technologies and innovations, (2) it reviews the psychometrics properties of existing instruments, and (3) it identifies gaps in measuring and designing future interventions for children with math disability in Thailand.

15. Persistent structural differences in developmental dyscalculia: a longitudinal morphometry study

Ursina McCaskey; Michael von Aster; Ruth O'Gorman Tuura; Karin Kucian

Developmental dyscalculia (DD) is a learning disability affecting the acquisition of numerical-arithmetical skills. Studies reveal persistent deficits in number processing, aberrant functional activation of the numerical network and differences in the structural brain of DD subjects. Reduced grey matter has been reported in DD for the posterior parietal cortex and intraparietal sulcus (IPS) - known as key areas for number processing - but also the frontal, and the occipito-temporal cortex. To date, the longitudinal development of these structural differences is unknown. The aim of the present study was to investigate the developmental trajectory of brain structures in children with and without DD. In this longitudinal study, neuropsychological measures and structural images were collected twice with an interval of 4 years from 15 DD and 11 typically developing (TD) children (7.9-10.4 years). Voxel-wise estimation of grey matter volumes was assessed by means of voxel-based morphometry for longitudinal data (Computational Anatomy Toolbox implemented in SPM). Our findings reveal that DD children show persistently reduced grey matter volumes over development in the left (pre)cuneus, left inferior parietal lobe, and right superior occipital gyrus extending into the IPS. Further differences were found in the anterior cingulate cortex and the right insula. Over the developmental course, a general decrease in the left precuneus and superior parietal lobe was revealed for TD and DD children. Our results are in line with evidence showing reduced grey matter volumes in the fronto-parietal regions of the numerical network for DD children. Our study further sheds light on the trajectory of brain development, revealing a decrease in grey matter that resembles the development of TD children. However, structural differences persist in children with DD from childhood into adolescence. In summary, our results underscore that DD is a persistent learning disorder accompanied by reduced grey matter volumes in number related brain areas.

16. Semantic networks support approximate computation

Mengyi Li; Yuxin Tan; Xinlin Zhou

Approximate arithmetic could be a typical representative for intuitive mathematical thinking. The visuo-spatial networks in brain are assumed to implement the numerical quantity processing underlying the approximate arithmetic, in contrast, the language networks are recruited for the verbal processing in the exact arithmetic. Previous research typically used single-digit arithmetic, which could show the dissociated brain networks for numerical quantity processing and retrieval of arithmetic facts. The present study used arithmetical computation problems to dissociate the brain organizations for strategy-based approximate computation and procedure-based exact computation. The semantic networks were hypothesized to be recruited for the selection and application of strategy during approximate computation. 28 college students participated in the experiment. Results showed that approximate computation relative to exact computation had greater activation typically in the inferior frontal gyrus, middle temporal gyrus, angular gyrus and dorsomedial prefrontal cortex. The brain regions overlapped with the general semantic networks that also support mathematical problem solving. In contrast, exact computation elicited greater activations in bilateral hippocampusand left rolandic operculum. Functional connectivity analysis with the psychophysiological interaction approach (PPI) showed thatthe connectivity among left parietal lobe to the regions that greater activated in approximate computation was stronger than in exact computation. The results suggest that the approximate computation based on the selection and application of strategy might be different from the single-digit approximate arithmetic in brain, and semantic networks could play a critical role in the approximate computation.

17. The common and differential neural developmental trajectories for approximate number system, arithmetic and word phonology

Yuxin Tan; Mengyi Li; Xinlin Zhou

There has been much research on the neural correlates for the development of different type of cognitive processing. Little is known about their common and differential neural basis. The current fMRI investigation recorded brain activity in 32 adults aged 19-27 and 20 children aged 7-11 on four tasks including single-digit subtraction, single-digit multiplication, numerosity comparison and word rhyming. The four tasks had very similar developmental brain activity pattern, including whole-brain activation level, activation mode, laterality, and functional connectivity. For example, children had smaller whole-brain activation coefficients than adults on all the tasks, which might correspond to their low efficiencies. Little specific neural developments were found. The results suggest that the general cognitive factors and neural maturation could monitor the neural development in different type of cognitive processing.

18. Cognitive heterogeneity of math difficulties: a bottom-up classification approach

Larissa Salvador; Vitor Haase

One of the main obstacles faced by neuropsychological research is the high variability of cognitive factors associated with math achievement, and the heterogeneity of deficits among children with math difficulties (MD). In the current study, a bottom-up, data-driven analytical approach was used to identify profiles of cognitive impairments underlying math difficulties. The Cluster Analysis based on visuoconstructional, visuospatial and phonological working memory and nonsymbolic and symbolic magnitude processing accuracy were used to form subgroups attending from 192 children with a mean age of 9.38 (sd = 0.84) years, from 3rd to 5th grades. Children scoring above the 25th percentile on a Brazilian arithmetic standardized test were classified as controls (n = 150) and those scoring below the 25th percentile as having math difficulties (MD, n = 42). All children had nonverbal intelligence above the 20th percentile and presented a broad spectrum of variation in math ability. External validity of subgroups was examined considering intelligence and math achievement. Four clusters were identified. Grups did not differ in age. Two groups with high incidence of MD and low performance in single digit operations were associated, respectively, with low visuospatial/visuoconstructional (n = 23) and low magnitude processing accuracy, composed with children with worst weber faction and symbolic magnitude processing accuracy (n = 36). One group with average cognitive performance also presented above average intelligence and a small incidence of MD (n = 79). A fourth group with high cognitive performance presented high math performance and high intelligence (n = 54). Phonological working memory was associated with high but not with low math achievement. MD may be related to complex patterns of associations and dissociations between intelligence and specific cognitive abilities in distinct subgroups. Consistency and stability of these subgroups must be further characterized. However, a combined bottom-up contribute to reducing cognitive complexity of MD.

19. The depth of numerical processing in Navon's paradigm
Inna Barkan; Dana Ganor-Stern; Joseph Tzelgov

In Navon's (1977) paradigm a large stimulus is built from small ones, that are either identical to or different from it (e.g., A made of A's or A made of B's). The participants have to process either the larger stimulus or its components. Typically, the irrelevant dimension interferes with the processing of the relevant dimension. This effect is more reliable when the relevant dimension is the larger stimulus. These findings are usually interpreted as reflecting perceptual stages of processing. We investigated how deep the processing of the irrelevant dimension is by applying Navon's paradigm to numerical cognition. Numbers are mentally represented in the order of their magnitudes. This is indicated by the distance effect – faster comparisons of their numerical difference the larger this difference is. Furthermore, such comparison are performed even when they not being part of the task requirements. In this study a large digit composed of smaller ones appeared in the center of the screen, and the participant named the large digit or its components. The difference between the large digit and its component's is also manipulated (e.g if the value of the relevant dimension was 8, the possible values of the irrelevant dimension were 7, 6 or 3). The implications of our findings are discussed.

20. The role of acquired visual cues in magnitude comparisons
Nirit Fooks Leichter; Nachshon Korem; Batsheva Hadad; Orly Rubinsten

Humans can estimate the veridical size of objects with great speed and accuracy, irrespective of their viewing distance. This size constancy is accomplished by using the relational information available in the scene, via direct perception, or by combining information about retinal image size together with estimated viewing distance. Here, we examined the sensitivity to subtle differences in size vary with the richness of monocular cues given for depth, specifically asking whether adding depth cues such as acquired contextual expectations (e.g., depth linear perspective), memorized or learnt information (e.g., visual scene of sky) influences size discrimination. Method: Two 3D-objects appeared vertically in the middle of the screen for a short period of time. Participants were asked to judge which one was bigger, in three separate experimental blocks [no cues, linear perspective and linear perspective with context (i.e. sky)]. JND and Weber's fraction were evaluated. Results: The linear perspective block complies with size constancy. JNDs for the upper object (i.e., appearing in the "distance") were lower compared with JNDs for the object below. Interestingly, this trend was intensified when contextual cues were added. In contrast, without cues, participants overestimated the size of the object below. Current findings point to the involvement of domain-general processes in magnitude perception apart from domain-specific components. Importantly, such findings may shed light also onto the numerical cognition field. It is commonly argued that the domain-specific systems including quantity, size or magnitude perception, acts the basis for numerical skills. However, recently, Hohol et al. (2017) emphasized the role of domain-general factors in numerical abilities. Current findings indeed suggest that domain-general processes may be fundamental even in basic aspects of number processing such as magnitude comparisons. Our initial pilot data with developmental dyscalculia (DD) participants hint that acquired visual domain-general cues, enhance DDs basic magnitude processing.

21. Who Gains More: Experts or Novices? The Benefits of Interaction under Numerical Uncertainty

Francesco Sella; Robert Blakey; Dan Bang; Bahador Bahrami; Roi Cohen Kadosh

Interacting to reach a shared decision is an omnipresent component of human collaboration. We explored the interaction between dyads of individuals with different levels of expertise. The members of the dyads completed a number line task privately, jointly and privately again. In the joint condition, dyad members shared their private estimates and then negotiated a joint estimate. Both dyad members averaged their private individual estimates to determine joint estimates, thereby showing a strong equality bias. Their performance in the joint condition exceeded the performance of the dyad’s best estimator, demonstrating interaction benefit, only when the dyad members had similar levels of expertise and when the averaged dyad performance was sufficiently accurate. At the end of the task, participants rated their and their partner’s level of competence. Participants were accurate in classifying themselves as the expert or the novice within the dyad. Nevertheless, novices tended to overestimate their ability as they admitted to being less competent but only slightly worse than their expert partner. Experts, instead, believed themselves to be more competent but were humble and considered their performance only marginally better than their partner. Overall, these results have important implications for settings in which people with different levels of expertise interact.

22. Dissociation of neuronal communication accompanying symbolic vs. non-symbolic numerical comparisons

Nachshon Korem; Naama Levin; Orly rubinsten

Recent evidence suggests that during numerical calculations, symbolic and non-symbolic processing are functionally dissimilar operations. Nevertheless, both recruit roughly the same brain areas (spatially overlapping networks in the parietal cortex) and happen at the same time (in the first few hundred milliseconds following numerical stimuli presentation). We tested the hypothesis that symbolic and non-symbolic processing are segregated by means of neuronal synchronization of the functionally relevant networks in different frequency ranges: high gamma (60 Hz and up) for symbolic processing and lower beta (12–20 Hz) for non-symbolic processing. EEG was recorded while participants compared either symbolic numbers, or non-symbolic quantities. We compared responses to deferent ratios using wavelet analysis. Results showed an increase in gamma-band power for symbolic more difficult comparisons (ratios of 0.8 between the two numbers) than for easier comparisons (ratios of 0.2). Similarly, beta-band power was larger for non-symbolic more difficult comparisons than for easier ones. These results confirm the existence of a functional dissociation in EEG oscillatory dynamics during numerical processing. This is compatible with the notion of a distinct processing of symbolic and non-symbolic numerical information.

23. Language influence on mathematics achievement in French-German biliterate ninth graders
Sophie Martini; Sonja Ugen

Cross-linguistic studies show that language affects numerical cognition and subsequent mathematical learning. Especially in multilingual contexts with altering instruction languages and multiple home languages, analysing language impact on mathematics is thus highly relevant. Luxembourg is such a setting, as the teaching language for mathematics changes from German in primary school to French in secondary education and students come from a wide variety of home languages. Large-scale studies such as PISA show that students' reading comprehension competency in the test language influences their mathematics score, and that both reading and mathematics competencies are highly influenced by students' home language (SCRIPT & LUCET n.d.). Therefore, these effects need to be disentangled from mathematical processes to provide a fair(er) evaluation of students' mathematical skills. While in PISA students had to choose the test language at the start of the test, in this study we analysed the results of the Luxembourgish national standardised test, taken by ninth graders (N = 4102), who could choose and continuously switch between test languages (German and French). We analysed reading comprehension skills (German/French scores from the national standardised tests) and socio-economic status (SES) as predictors for mathematics achievement for pupils from multiple home language backgrounds. Our results show significant differences in French, German and mathematics standardised test achievement and test language choice between students from different home language groups, and additionally that SES and reading comprehension in the test language are predictors for mathematics achievement. This indicates that proficiency in the instruction and test language matter for mathematics achievement and should be taken into account in a multilingual setting.

24. Does Pain Detriment Complex Arithmetic More Than Simple Arithmetic Performance?
Jayne Pickering; Nina Attridge; Matthew Inglis

Mathematical cognition relies upon both domain-specific and domain-general (e.g. attention, memory, reasoning) processes. Pain is a domain-general factor which detriments performance on cognitive tasks, but its specific effect on mathematical cognition is under-researched. Pain and attention are thought to share the same neural processes (shared-resources model) but pain's capturing of attention is prioritised to promote escape (primary-task paradigm). The shared-resources model predicts that the more complex a task is, the more resources it will need, and the more its performance will be impaired by pain. However, few studies have explicitly manipulated complexity levels to test this hypothesis. Factors affecting arithmetic difficulty have been widely researched, allowing complexity to be easily manipulated. Therefore, the current study tested 54 participants in a repeated-measures design. Participants completed four counterbalanced blocks of 'simple' two-digit plus two-digit addition questions with no decade crosses (e.g. 32 + 47) and four blocks of 'complex' three-digit plus two-digit addition questions with decade crosses (e.g. 523 + 89). Half of all blocks were completed in pain (hand in painful cold water) and the other half in no-pain (hand in warm water). Repeated-measures ANOVAs indicated that participants made more errors in the pain condition but did not attempt significantly more questions (Bonferroni-corrected alpha levels). Additionally, against predictions, there were no significant interactions between arithmetic complexity and pain condition.

(All analyses were preregistered at aspredicted.org (#6221)). This study confirms pain's adverse effect on cognition but challenges the underlying assumptions of the shared-resources model and the primary-task paradigm. It is important to try to unpick the conditions under which pain affects attention, so that future research can explore the mechanisms through which any disruption takes place and the effect of pain on mathematical cognition can be assessed.

25. Classroom-based executive function assessments predict kindergarten students' math achievement.

Sammy Ahmed; Barbara S. Dennis; Frederick Morrison

Despite a large body of literature demonstrating associations between children's executive function (EF) skills and their math achievement, many existing measures of child EF rely on individual assessments, usually in controlled lab-based settings. The lack of ecologically valid assessments, hinders our understanding of how EF components contribute to math development and achievement during early childhood. Drawing on a sample of 195 kindergarten students, we describe and validate newly developed classroom-based assessments of executive functions, and examine their relation to standardized tests of math achievement. These newly developed tasks were designed to capture executive function (EF) performance in a naturalistic group setting. These tasks involve inhibitory control, multistep instructions that capture working memory and have a substantial attentional component. All tasks were administered and video-taped by trained research assistants, and behavioral coding and inter-rater reliability were conducted in the laboratory. Measures: Inhibitory control: Head-to-Toes, Knees-to-Shoulders (HTKS) (Ponitz et al; 2008; Connor et al., 2007) game. Attention regulation: Pair Cancellation (Woodcock & Mather, 2000). Working memory: Backwards Digit Span (Wechsler, 1949; Wechsler, 1991). Math Achievement was measured using Applied Problems (Woodcock & Mather, 2000). Confirmatory factor analysis results confirm a three-factor EF structure among classroom based measures and a one-factor model among lab-based measures of EF. This might suggest that EF's multidimensionality can be detected using more sensitive, and ecologically valid measures of EF in children this age. Results from structural equation modeling suggests that these classroom games are positively and strongly related to both lab-based measures of EF and math achievement. This finding supports both the concurrent and predictive validity of these classroom games, and reveal substantial associations between classroom-based EF measures and math achievement. These findings underscore the importance of measurement context when studying EF and has implications for the way researchers conceptualize and measure executive function in young children.

26. Mental abacus training promotes number acuity

Rui Xiao; Jiaxin Cui; Mei Ma; Yan Chen; Li Yuan; Leinian Li; Xinlin Zhou

The number acuity or the ability of approximate number system has been treated as one of the significant cognitive correlates or even fundamental cognitive factors for the development of arithmetic abilities. The current investigation hypothesized that mental abacus training could substantially enhance the number acuity. We recruited 150 Chinese children. 75 children received mental abacus training, passing at least 6-level Mental Abacus Test (the 10-level as the lowest level and the 1-level as the highest level in amateur training). Others did not receive any mental abacus training. They completed 10 tasks including simple subtraction, numerosity comparison, figure matching, visual searching ,three-dimensional mental rotation, spatial working memory, verbal working memory ,nonverbal matrix reasoning, choice reaction time, and sentence completion. The abacus training group had better number acuity than controls, even after controlling for all other measures available in the current investigation. The number acuity could partially mediate the arithmetic improvement. This study suggests that the mental abacus training could be an effective approach for arithmetic instruction.

27. How and when children master the numerical content conveyed by verbal numbers and number gesture ?

Line Vossius; Marie-Pascale Noël; Laurence Rousselle

Several authors claim that children's ability to use their fingers in numerical contexts contributes to the development of basic numerical skills (Fayol & Seron, 2005 ; Gunderson et al, 2015) while other suggest that children learn to use number gestures as arbitrary symbols and do not benefit from this iconic tool (Nicoladis, Pika and Marentette, 2010). In this study, we examined longitudinally how and, more importantly, when children master the numerical content conveyed by verbal numbers and number gestures. This was carried out in order to determine whether children go through a stage where they are able to express numerical information with their fingers, which they are not yet able to express verbally or inversely. Fifty preschoolers were tested four times in total, every four months from the age of 3 years old, using tasks assessing three skills : the counting skill, the understanding of succession functions (one task assessing the understanding of directional properties and one task assessing the understanding of successional properties of numbers) and the understanding of cardinality (one « Give me » task and one « Equivalence judgement » task). Preliminary results seem to show that gestures help children, more and more through time between three and four years old, to be more precise in the representation of numbers in some tasks such as the counting task or the « Give me » task.

28. Tactile Enumeration and Embodied Numerosity Among the Deaf

Shachar Hochman; Zahira Cohen; Avishai Henik

The representations of fingers are embodied in our cognition and influence performance in enumeration tasks. Among deaf signers, the fingers also serve as a tool for communication in sign language, which conveys embodied representations as well. Previous studies in normal hearing (NH) participants showed effects of embodiment (i.e., embodied numerosity) on tactile enumeration using the fingers of one hand. In this study, we examined the influence on tactile enumeration of extensive visuo-manual use of the fingers among the deaf and their improved tactile processing. We carried out three enumeration task experiments using 1-5 stimuli on a profoundly deaf group (n=16) and a matched NH group (n=15): 1) tactile enumeration using one hand, 2) tactile enumeration using two hands, and 3) visual enumeration of dots. In the tactile tasks, results showed faster enumeration and salient embodied effects in the deaf group compared to the control (NH) group. The findings reveal the influence of rich visuo-manual experiences on embodied representations.We further elaborate on the role of the embodied representations in the development of mathematical thinking.

29. Brain mechanisms related to processing of numerals: A magnetoencephaplography (MEG) study

Victoria Simms; Paul Boyce; Yogesh Meena; Hubert Cecotti; Girijesh Prasad

Background: This study aimed to investigate the brain mechanisms related to the detection of numerical representations using MEG. The influential Triple-code Model by Dehaene (1997) suggests that spoken and written numerals are mapped onto a core representation of numerosity in the intraparietal sulcus (IPS). It is likely that symbolic and concrete depictions of number are linked together in the adult human brain, perhaps in the form of notation-independent assemblies of neurons coding for number at a purely conceptual level. Previous research has mainly utilised functional magnetic resonance imaging (fMRI) to assess this proposal, MEG surpasses fMRI in terms of its spatio-temporal resolution. Method: 17 adult participants were recruited and completed a series of intra and inter modal quantity comparison tasks (i.e. dot vs dot, digit vs digit, word vs word, dot vs digit, dot vs word, digit vs word stimuli), in which they were asked to indicate which of two stimuli was larger whilst electroencephalography (EEG) and MEG data were recorded. Results: Behavioural results show a significant effect of stimuli type on accuracy, response time and d-prime scores. This was mainly driven by the presence of non-symbolic (dot) stimuli. In terms of response times intra-modal conditions were often significantly slower than inter-modal conditions. The arabic digit condition resulted in the fastest response times among the inter-modal conditions. EEG analysis revealed that ERP responses for amplitude and latency at epochs of 50-150ms, 150-250ms, 250-500ms that varied across all comparison tasks. MEG data indicated that the intra-parietal sulcus was activated to a varying degree across tasks. Discussion: These results will discussed in relation to the neural underpinnings of quantity discrimination and it's relation to the Triple-code Model of numerical cognition. Specifically, the recruitment of additional neural systems when translations between codes are conducted will be discussed.

30. Effects of Math Anxiety and Math Ability on University Mathematics Engagement
Richard Daker; Sylvia Gattas; Helen M Sokolowski; Ian Lyons

Upon entering university, North American students experience a great deal of academic freedom. For many, this is the first time they are able to exert a significant amount of control over what courses they take. Given the important role that math and math education can play in shaping the trajectory of students' academic careers, we recruited 186 incoming first-year University of Western Ontario students to complete a series of math-relevant questionnaires and cognitive tasks in order to assess what would predict the number of math courses students chose to take. Key predictors of interest included self-reported math ability, performance on in-lab math tasks, math anxiety, and math academic achievement in high school. Our findings suggest that both math-related affect and ability play an important role in determining the degree to which university students pursue mathematics.

31. The relation between the processing of space and ordinal information in working memory: a tDCS-EEG study.
Sophie Antoine; James G. Sheffield; Wim Gevers; Roi Cohen Kadosh

Recent evidences suggest that, akin to numbers, ordinal information in verbal working memory is spatially represented (see Abrahamse et al., 2014). In line with this idea, we observed that brain-damaged patients with deficits of space processing (hemispatial neglect) are also impaired when judging the ordinal relations of items maintained in working memory (Antoine et al., 2018). To further explore how hemispatial neglect relates to order impairments, we applied bilateral transcranial direct current stimulation (tDCS) over the left and right posterior parietal cortices, a montage known to induce hemispatial neglect in healthy participants (e.g., Giglia et al. 2011). While receiving stimulation, participants had to perform a spatial task (indicate the midpoint of a horizontal line) and an order task (indicate whether the target letters are in the same order as in the memorised sequence). Contrary to what we expected, tDCS did not induce neglect in the spatial task. Importantly, in line with our hypothesis, we found that resting connectivity in the theta band between frontal and parietal areas, as recorded by EEG, can serve as a physiological marker of the processing of ordinal information in working memory. Interestingly, other studies have shown that patients with hemispatial neglect have a reduced fronto-parietal connectivity in the same frequency band (e.g., Fellrath et al., 2016). Combined, these observations suggest that reduced theta connectivity between the frontal and parietal areas may underlie behavioural impairments for both space and order processing.

32. Dimensioned Thinking as Foundation for Teaching Math and Computer Programming and Psychology

Julia Shaw; Jianhao Chen; Sen Zhang; Jayleen Wangle; Geoffrey O'Shea

In The Critique of Pure Reason, philosopher Emmanuel Kant posited that representations of space, time, and causality are a priori intuitions (Kant, 1787/2007). Developmentalist Jean Piaget showed how these intuitions develop from vague schemas into well-formed concepts from early childhood through adolescence (Piaget, 1950). These two intellectual giants, among others, demonstrate that metacognitive foundations of time and space are essential to our cognitions, our reflections, and our communications. Systematic human endeavors are based on organization of information within temporal and spatial frameworks, here called Dimensional Thinking, with creation of units of measure within a scale, dimensions built with those units of measure, and intersections of dimensions into multidimensional cognitive spaces. Three examples follow. 1) In Euclidean measurement of physical space, creating dimensions using uniform units of measure (meters) within a physical scale (a room), aligned as dimensions (length, width, or height), and intersected to create volume. 2) In multiplication, the abstraction of 3X4 represents three rows of four units, or four rows of three units. 3) In musical notation, the unit of measure as a musical note; one dimension as a melody (horizontal), and another dimension as a chord (vertical). In each case, a notation captures the dimensional structures within the domain. We demonstrate that knowledge that human systems are constructed on dimensional thinking helps in teaching complex concepts such as those in basic mathematics (i.e., functions) and computer programming, guiding creation of effective learning materials in these areas, identifying visible and sometimes hidden dimensions that position the concepts, and create the metrics to measure, locate, describe, differentiate and contrast them.

33. Contributions of inhibitory control to decimal processing and mathematics achievement

Linsah Coulanges; Sashank Varma; Miriam Rosenberg-Lee

Understanding decimal proportions is a crucial part of the elementary school curriculum, yet relative to other representations of rational numbers (i.e., fractions), decimals processing remains an understudied topic in the math cognition literature. The semantic interference effect (Varma & Karl, 2013), refers to the robust finding of slower and less accurate responses when selecting the larger of '.27' and '.9', than when comparing '.87' and '.2'. Successfully answering these inconsistent problems requires inhibiting the previously learned association (which holds in whole numbers): more digits correspond to a larger number. Thus, we hypothesize that performance on these problems would be related to individual differences in the executive function component of inhibitory control and that both factors would be related to mathematics achievement. 35 college students completed a decimals comparison task, the Math Fluency and Calculations subtests of the Woodcock-Johnson and three measures of executive function (inhibitory control, task switching and visual spatial working memory). We found a strong semantic interference effect, with inconsistent pairs on average 120 ms slower than consistent problems and significantly less accurate (77% vs. 90%). Correlational analyses revealed that accuracy on the inconsistent trials predicted performance on both standardized math measures and that inhibitory control was the only executive function measure to correlate with both inconsistent decimal processing and math achievement. These findings highlight the importance of inhibitory control when processing decimal proportions and suggest the need for increased consideration of basic cognitive capacities when expanding conceptual understanding beyond whole numbers (Ni & Zhou, 2005).

34. Spatial Reasoning in Middle School Children: Two-dimensional Representations of Three-dimensional Shapes
İpek Saralar

Spatial reasoning concerns the positions, shapes and movements of objects and the spatial relations between them. Spatial reasoning includes one's ability to reason by comparing, manipulating and transforming mental pictures in order to suit problem-solving process (Bahr & Garcia, 2010; Clements & Battista, 1992; Hegarty & Waller, 2005; Newcombe & Shipley, 2015). It involves one's ability to understand and remember the positions of the objects, then, to mentally manipulate and rotate them. It is composed of two main components: spatial orientation (comparing the shapes when they change the position in plane/space) and spatial visualisation (looking at a fixed shape from different points of view). Although there is an ongoing debate on whether spatial reasoning is an innate ability or it can be improved, many researchers have developed activities such as tesselations, isometric dot paper and block building activities to improve children's spatial reasoning, and those activities took their places is many geometry curricula including English, French, and German. The balance of evidence suggests that there is a link between geometry and spatial reasoning and these two have a mutually beneficial relationship (Battista, 2007; Gergelitsova, 2007; Jones, 2002). In the present study, a worksheet having two parts of questions which require spatial reasoning was prepared to assess middle school students' understanding of two-dimensional representations of three-dimensional shapes. The worksheet had 10 questions, being 5 in each part. In the first part, students were given isometric drawings of five shapes constructed from unit cubes and asked to draw the orthogonal views of those shapes. In the second part, they were provided with the orthogonal views of five shapes constructed from unit cubes and asked to make five isometric drawings. The preliminary results of a study with 199 students show that middle school students performed better in the first part than the second.

Time: 14:00 – 15:30
Room: South school

Symposium: **The development of symbolic fraction knowledge – Processes and proponents**

Organisers: Jake McMullen; Percival Matthews; Edward Hubbard

Overview: The ultimate measure of success in teaching about rational number concepts is in learners' competence with symbolic fractions. Symbolic fractions understanding is not built solely on a foundation of nonsymbolic ratios and spontaneous relational processes, but it also depends heavily on prior knowledge and instructional interventions. It depends in part on robust understanding of whole number properties, including whole number magnitude (e.g. Siegler, Thompson, & Schneider, 2011), which may interfere with understanding fractions as relational magnitudes (Obersteiner et al., 2015). Targeted interventions have been shown to be effective in overcoming cognitive constraints, such as working memory, in learning about fractions (Fuchs et al., 2013). Moreover, teaching methods that maximize attention to ratios and fractions' magnitudes and minimize attention to counting and whole number processes may be particularly useful for learning fractions (Ninaus, Kiili, McMullen, & Moeller, 2017). This symposium will focus specifically on symbolic fractions competence, both in terms of interventions and in terms of insights on how symbolic learning and competence are reflected in the brain. In a series of four talks: First, Hubbard et al. will provide a bridge between the basic ratio processing and symbolic fraction processing by examining the role of ratio processing in fraction magnitude understanding using brain-imagining to assess developmental changes and individual differences, in the RPS and in symbolic fraction processing. Second, Kiili and colleagues present the results from a study using a serious game to support fraction understanding. Results suggest that the number line training provided by the Semideus game is supportive of students' fraction and decimal understanding, especially with those aspects of rational number knowledge that are in conflict with natural number features. Third, Jordan and colleagues will present a number line-based intervention designed explicitly for students at-risk for poor learning outcomes with fractions. Results reveal substantial gains in multiple aspects fraction knowledge. This research both presents an effective intervention and provides a platform for theorizing about how individual differences may affect fractions learning. Finally, Bieck and colleagues will present neuroimaging findings from a 5-day number-line based fractions training intervention. Using a pretest-intervention-posttest design, they demonstrated that behavioral improvements on fraction tasks were accompanied by more focal activation of bilateral intraparietal areas after the training. Results will be discussed in terms of neurofunctional plasticity involved with fraction learning.

Talk 1: **The ratio processing system underpins symbolic fraction understanding: Developmental neuroimaging investigations**

Edward M. Hubbard; John V. Binzak; Yunji Park; Priya Kalra; Elizabeth Y. Toomarian

One of the key predictions of the ratio processing system (RPS) account is that non-symbolic ratio sensitivity and symbolic fractions sensitivity should utilize overlapping brain regions, specifically the intraparietal sulcus (IPS) and prefrontal cortex (PFC). We have recently tested this prediction by collecting brain imaging data on children who either have or have not yet had extensive instruction on fractions. We collected usable data from 20 2nd-grade (7-8 y.o) and 20 5th-grade (10-11 y.o) children, and 24 adults. Participants compared the magnitudes of two fractions in three conditions (symbolic fractions, line ratios, or mixed pairs) during an event-related fMRI paradigm. Distance effects were observed in all three notation conditions; participants were faster and more accurate as the numerical distance between pairs increased. Our data demonstrate that, in adults, all three notations overlap in a common network including IPS and PFC. In 2nd graders, however, we see evidence for neural specialization only for non-symbolic ratios in the bilateral IPS. In 5th grades, we see evidence for emerging specializations for symbolic fractions that partially overlap with non-symbolic ratio processing systems. In this talk, we will also review ongoing analyses into individual differences in RPS sensitivity and how this relates to math outcomes.

Talk 2: **Evaluating Learning Outcomes of a Game-Based Rational Number Training**

Kristian Kiili; Antti Koskinen; Korbinian Moeller; Manuel Ninaus

The overall aim of this research was to evaluate the effectiveness of a game-based training of conceptual rational number knowledge. The employed research instrument "Semideus School" is founded on number line estimation, magnitude comparison, and magnitude ordering game mechanics. Besides our interest in overall improvement of conceptual rational number knowledge from pre- to posttest, we were particularly interested in evaluating a new feedback mechanism in comparison tasks. Feedback provided in conventional digital comparison task seem to neglect the possibility to foster part-whole and measurement interpretation, two forms of conceptual interpretations most relevant in developing rational number knowledge (Hecht & Vagi, 2010). Moreover, in a previous similar game-based rational number training overall training effects were driven by number line estimation and ordering task improvement, while students' comparison performance did not improve (Kiili et al., accepted). Therefore, the current game provided feedback of compared magnitudes also as bar chart or number line visualizations to trigger reflective processes on compared magnitudes and foster the development of rational number understanding. We expected that this new visual feedback channel will facilitate learning gains in comparison tasks. 70 Finnish 5th graders played the game approximately 2.5 hours. Using a paired t-test we examined students' potential improvement from pretest (M=57.19; SE=1.57) to posttest (M=73.58; SE=1.70) assessment, i.e. number line estimation, comparison, and ordering tasks performance. Students' level of conceptual rational number knowledge improved significantly, t(69)=11.675, p<.001, Cohen's d=1.19 indicating that the game-based training was effective. Moreover, as expected a paired t-test showed that students' comparison performance was significantly higher in posttest (M=92.60%, SE=1.20) than in the pretest (M=76.97, SE=2.54), t(69)=6.855, p<.001, Cohen's d=.94. Our talk will provide more detailed results about our training studies and we will conclude by presenting a new task that merges mechanics of number line estimation and magnitude comparison tasks to further improve future training outcomes.

Talk 3: **Effects of a number line approach for improving fraction understanding in students with math disabilities**

Nancy C. Jordan; Nancy Dyson; Christina Barbieri; Jessica Rodrigues

The effectiveness of a fraction intervention was evaluated. The intervention was centered on the number line and incorporated key learning principles. Sixth graders (N = 51) who struggled with fraction concepts were randomly assigned at the student level to the experimental intervention or a business-as-usual control who received their school's intervention. The intervention occurred over six weeks (27 lessons). Fraction concepts, number line estimation, magnitude comparisons, and arithmetic were assessed at pre-, post- and delayed posttest. The experimental intervention group demonstrated significantly more learning than the control group from pre- to posttest, with large effect sizes on measures of fraction concepts (g = 1.09), number line estimation (g = -.85), and magnitude comparisons (g = .82). These improvements held at delayed posttest. A significant interaction was found between math teachers' ratings of classroom attention and intervention group on fraction concepts at posttest, suggesting a buffering effect of the experimental intervention on the normally negative impact of low attentive behavior on learning. A number-line centered approach to teaching fractions, along with the implementation of research-based learning strategies, helped struggling learners to make durable gains in their conceptual understanding of fractions.

Talk 4: **Neurofunctional plasticity in fraction learning assessed by pre-post intervention fMRI**

Silke M. Bieck; Manuel Ninaus; Elise Klein; Kristian Kiili; Johannes Bloechle; Julia Bahnmueller; Thomas Dresler; Korbinian Moeller

To assess neurofunctional plasticity in fraction learning, neural activation of 48 participants was measured by fMRI before and after a five-day computerized number line estimation training of fractions. In this training, proper fractions consisting of single- and two-digit numbers had to be located on a number line ranging from 0 to 1. We expected that this mental number line estimation training would improve participants' magnitude representation of fractions (e.g., Siegler et al., 2011). In pre- and post-test, behavioural and neurofunctional data were collected on a symbolic fraction magnitude comparison task (e.g., 1/3 vs. 3/4), a non-symbolic fraction magnitude comparison task (comparing proportions of lines) and a task, in which symbolic fraction magnitudes had to be matched with non-symbolic proportions of lines. In all tasks, half of the tested proportions were also used in the training. Behavioral data indicated significant improvements for all three tasks, with more pronounced improvements for trained as compared to untrained items. Additionally, we observed significant changes in activation patterns within the fronto-parietal network of number magnitude processing. We discuss in how far magnitude-related activation was modulated by our number line estimation training of fractions in terms of neurofunctional plasticity underlying fraction learning.

Time: 14:00 – 15:30
Room: East school

Symposium: **Math Anxiety: from psychophysiology to interventions, through genetic and learning**

Organisers: Sara Caviola; Ann Dowker

Overview: Research in developmental and cognitive psychology is offering an increasing number of examples of how negative feelings towards maths (math anxiety - MA) can deeply interfere with a successful mathematical learning. The present Symposium will examine the implications of research focused on different aspects of MA on both adults and children. Regarding MA measures, self-reported data (collected through questionnaires) seems to be the primary measure. Although the psychometric characteristics of most MA questionnaires appear to be good different measures need to be found that can measure MA without relying on self-reported information. The first two presentations attempt to find such measures in adults. Rubinsten and co-authors measured changes in electrodermal activity in students while they were exposed to either arithmetic or to non-arithmetic stimuli. Their levels of both MA and trait anxiety were measured by standardized questionnaires. The results indicate that their reported MA-levels were correlated with increased physiological arousal while participants solved the arithmetic task. This correlation was not significant during the non-arithmetic task. Similarly, Caviola and Szűcs investigated physiological parameters related to characteristics of eye-movements that could indicate MA indirectly. An increase in stress due to time pressure conditions and task difficulties, during a computerized calculation task, was associated to an increase in anxiety levels (MA and general anxiety): all physiological parameters resulted to be sensitive to induced stress through time pressure and task difficulty in a comparable way. Another relatively neglected area of research in mathematics anxiety is its nature and development in young children. Most studies have focused on secondary pupils and adults. Petronzi will discuss MA in children in the early years of primary school; ways of assessing it quantitatively and qualitatively; and the factors that may lead to its emergence. Although MA has been recognized to have a detrimental effect on math achievement from early on, there is very little literature on interventions specifically addressing MA and almost none with primary-school children. Passolunghi and Pellizzoni compared the effects of two types of training on 4th-graders: one targeted at cognitive strategies aimed to regulate MA and one targeted at improving numeracy strategies. The results showed that both interventions decreased MA, but only the training specifically targeted at improving numeracy strategies had a specific effect on math performance. The final presentation by Kovas and Bloniewski will take a broader perspective, exploring the genetic and environmental factors contributing to differences in the MA levels. They will also present research on the genetic and environmental mechanisms that may link MA with brain activity.

Talk 1: **The psychophysiology of math anxiety: Evidence from skin conductance measurement**
Orly Rubinsten; Hili Eidlin Levy; Nachshon Korem

The phenomenon of math anxiety (MA) has been highly investigated over the last decades. Trait anxiety in general, is widely held to involve changes in behavioral as well as in physiological systems. It is not clear however, just how tightly coupled these changes are, in cases of math anxiety. To examine this issue, we measured physiological activations (i.e., changes in electrodermal activity) of university students while they were exposed to either arithmetic (equations) or to non-arithmetic (e.g., word) stimuli. The degree of MA and trait anxiety were measured by explicit questionnaires. The results indicated that while participants solve arithmetic equations, their reported MA levels were correlated with increased physiological activation. This correlation between MA levels and physiological activation was not significant during a non-arithmetic task. These results suggest that physiological responses in math anxiety are associated with numerical stimuli and activities. That is, math anxiety explicit behaviors are tightly coupled with physiological responses, similar to previous reports in cases of trait anxiety.

Talk 2: **Time pressure and eye-movements: A new physiological measures of math anxiety**
Sara Caviola; Dénes Szűcs

The negative emotional state and discomfort felt during performance of mathematical tasks are commonly referred to as math anxiety (MA). Most of the research measures MA levels through self-report questionnaires detecting a sort of "offline" measure. This assessment of MA implicitly leads one to assume that it is a lasting anxiety (trait) rather than an "on-line" anxiety state experienced whilst facing maths tasks. To address this matter, using a non-invasive physiological technique and manipulating stress inductions during a mathematical task, we tried to elicit and detect an "on-line" anxiety state that allows accurate analysis of how anxiety can disrupt or interfere with arithmetic task execution. Eye movements were gathered from 90 participants while they solved complex addition problems in two different time-pressure conditions (high vs. low). Analyses of the eye-data have shown that specific physiological parameters are more likely to be associated with (negative) emotional aspects, whereas other parameters are more likely related to mathematics performance. In particular, an increase in stress due to time pressure conditions and task difficulties was associated with an increase in changing in pupil sizes. Due to the novelty of this research, educational and clinical implications are discussed.

Talk 3: **Acquisition, development and maintenance of maths anxiety in young children**
Dominic Petronzi

Although a well-researched construct in adult populations, a definitive foundation for maths anxiety has yet to be identified. However, there is now emerging research with a focus on the primary school years and the influence of early negative experiences in the classroom is becoming widely accepted as a key factor in maths anxiety development. This presentation will discuss the development of the Numeracy Apprehension Scale (NAS) which was validated with 307 and 163 children aged 4-7 years, across a total of 6 schools in the UK to test the validity and reliability of items through factor analysis. Scale items were based on preliminary research exploring children's numeracy experiences and attiudes via focus groups, as well as the observations of parents, teachers and maths experts. Insight from children and primary care providers suggests that numeracy apprehension is an early development issue and 'numeracy apprehension' is proposed as an affective component that may underlie math anxiety at older ages. The predictive validity of the NAS was also tested by comparing scale scores against numeracy performance on a numeracy task. A significant negative correlation was observed between the NAS and numeracy performance scores, suggesting that apprehensive children demonstrate a performance deficit early in education. The current 19-item iteration of the NAS relates to a single factor of Online Number Apprehension (engaging in number based tasks). This is associated with the experience of an entire numeracy lesson, including first entering the classroom, completing a task, explaining an answer and making mistakes. To conclude, the 19-item NAS appears to be a reliable assessment of children's numeracy apprehension ($\alpha = .87$) and has been shown to predict numeracy performance. This research points towards the origins of maths anxiety in the form of numeracy apprehension when number is first encountered.

Talk 4: **Math anxiety and numeracy training in fourth-grade children**
Maria Chiara Passolunghi; Sandra Pellizzoni

Although Math Anxiety (MA) has been recognized to have an early detrimental effect in math achievement (Ramirez et al., 2013; Vukovic et al., 2013) that increase with age (Ma & Kishor; Dowker, 2005), literature on training specifically targeted on the contrast of math anxiety is very scarce (Supekar et al., 2015) and refers especially on high school or university students (Ramirez & Beilock, 2011; Park et al., 2014). To fill this gap in the literature, we compare the effect of two specific type of training: one targeted on cognitive strategies aimed to regulate MA and one targeted to improve numeracy strategies. Both training include eight sessions, lasting one hour each, with a weekly frequency. Children attending 4th grade were randomly assigned to one of the three group conditions (math anxiety, numeracy and control group) and assessed, pre- and post-training phase, with measures of math achievement (standardized math tests, Amoretti, Bazzini, Pesci, & Reggiani, 2007) and math anxiety (AMAS, Hopko et al., 2003). The results showed that both training has effects in decreasing math anxiety, but only the training specifically targeted on the acquisition on numeracy strategies had an effect on math performance. These outcomes seem to corroborate Supekar and colleague (2015) findings, showing that enhancing numerical and mathematical skills has also a positive effect in reducing math anxiety. Our results are discussed in terms of specific programs that could enhance early treatment of math anxiety and could have implications for improving math achievement, school performance and professional opportunities.

Talk 5: **Development of math anxiety and its longitudinal relationships with arithmetic achievement among primary school children.**
Riikka Sorvo; Tuire Koponen; Helena Viholainen; Tuija Aro; Eija Räikkönen; Pilvi Peura; Asko Tolvanen; Mikko Aro

The aim of this longitudinal study was to examine the development of math anxiety and its cross-lagged relationship with arithmetic achievement. The participants were 1,327 Finnish children from grades 2 to 5. Two aspects of math anxiety, anxiety about math-related situations and anxiety about failure in math, as well as arithmetic fluency, were assessed two times during 1 year. The development of math anxiety was studied from two perspectives: mean level of anxiety and rank-order stability of individuals. The mean level of anxiety about math-related situations decreased among second, third, and fourth graders, and the level of anxiety about failure in math declined among third, fourth, and fifth graders. The rank-order of individuals was more stable in arithmetic achievement than in either aspect of math anxiety. Arithmetic achievement predicted later anxiety about failure in math, but neither aspect of math anxiety predicted later achievement. The results of the present study underline the importance of paying attention to math anxiety, because anxiety about math-related situations seems to be as stable in primary school as it has been found to be in secondary school students. It is important to provide sufficient educational support and take into account affective factors related to learning from the beginning of schooling.

Talk 6: **Genetic, Environmental and Neural underpinnings of Mathematical Anxiety**
Yulia Kovas; Tomasz Bloniewski

This talks present recent findings from genetically informative studies into the aetiology of mathematical anxiety and its association with general anxiety and spatial anxiety. Several findings from the UK representative Twins Early Development Study will be discussed: (1) All anxiety measures are moderately heritable (30% to 41%), and non-shared environmental factors explain the remaining variance; (2) Spatial anxiety is a multifactorial construct, including two components: navigation anxiety and rotation/visualization anxiety; (3) Although some genetic and environmental factors contribute to all anxiety measures, a substantial portion of genetic and non-shared environmental influences are specific to each anxiety construct. We also present the results from an EEG study into neurophysiological correlates of mathematical anxiety in a sample of MZ and DZ twins. Overall, the results suggest that anxiety is a multifactorial construct phenotypically and aetiologically, highlighting the importance of studying anxiety within specific contexts.

Time: 14:00 – 15:30
Room: Room 6

Parallel session: **Numerical processing 3**

Chair: Minna Hannula-Sormunen

Talk 1: **Analog Magnitude representations are precise contents with epistemic limitations**
Justin Halberda

In this presentation, I invite a re-understanding of the contents of our analog magnitude representations (e.g., approximate number, duration, distance). As my main example, I consider the Approximate Number System (ANS), which supports numerical representations that are widely described as "fuzzy", "noisy", and "limited in their representational power". I contend that these characterizations are largely based on misunderstandings of psychophysical theory. Specifically, I propose that what has been called "noise" and "fuzziness" in these representations (e.g., approximately 7) is actually an important epistemic signal of confidence in my estimate of the value (e.g., 7, with confidence intervals). Rather than the ANS having noisy or fuzzy numerical content, I urge that the ANS has exquisitely precise numerical content that is subject to epistemic limitations. I will discuss how this new understanding of ANS representations recasts fundamental questions of the learnability of number and of the conceptual changes that children must accomplish in the number domain. As just one example, such epistemically-limited ANS representations could support beliefs in precise values, while being marked for epistemic considerations: e.g., a belief such as, there is a correct numerical value to describe the number of dots in that display, but I'm just not sure what it is, has precise content with epistemic limitations. Understood in this way, the contributions that ANS representations make to learning challenges may also change. For instance, while previously we might have believed that a challenge for the child may involve building the expectation that numbers are precise (i.e., learning new content), the new understanding of the challenge might be that the child already expects numbers to be precise, but they may to work out an understanding of how to assess these precise values (i.e., learning new procedures). For additional breadth in this talk, I will also discuss how similar considerations will work for other analog representations (e.g., distance, duration, etc), and I will make a specific argument for precise contents with epistemic limitations for our analog sense of distance – one piece of our geometric sense.

Talk 2: **The Time Course of Central Executive Loads Affect Adults' Strategy Execution in Arithmetic with Different Level of Approximate Number System Acuity**
Hongxia Li; Mingliang Zhang; Shuang Cui; Jiwei Si

Abstract It's well known that approximate number system (ANS), as one of the human basic mathematics skills, has an important effect on individuals' math performance. Unknown is whether this effect is varying from task to task. In the present study, thirsty adult participants with different level of ANS acuity were asked to finish two-digit subtraction tasks under three different conditions in

central executive load. Behavioral data found that individuals' response time in strategy execution was affected by central executive loads. ERPs data showed that differences of subtraction strategy execution between high and low ANS acuity participants mainly occurred in earlier and later time windows (i.e., 50~150 ms, 150~250 ms, 1300~1800 ms, 1800~2300 ms). Specifically, in the 50~150 ms window, in the case of zero central execution load, high ANS acuity individuals activated a wide range of brain regions almost at the same time (anterior regions: 93.53ms，central regions: 92.38ms, posterior regions: 92.76ms). However low ANS acuity individuals activated central (89.22 ms) and anterior regions (93.76 ms), then posterior regions (111.38 ms). Moreover, the time at which greater cerebral activities were most apparent in posterior regions was from 92.76 ms after stimulus in high ANS acuity participants, which was significant shorter than that in low ANS acuity individuals (111.38 ms). In the case of low and high CE loads, no significant differences between two groups participants. Furthermore, in the 1800~2300 ms window, the mean amplitude was larger in the posterior regions for high ANS acuity individuals when executing indirect addition strategy, no significant difference was found in low ANS acuity individuals. These results suggested that differences between two groups appeared in the stimulus encoding phases and post-execution processed stage. In addition, processing of arithmetic problems may depend on specific regions not on general regions. These findings have significant implications to further our understanding of ANS acuity related differences under different central executive load conditions during arithmetic strategy execution.

Talk 3: **Executive functions and the mapping between nonsymbolic and symbolic mathematics.**
Ilse Coolen; Julie Castronovo; Kevin Riggs; Myfanwy Bugler

Research has demonstrated that adults and children as young as newborns possess an approximate number system (ANS) that represents and processes large nonsymbolic quantities in an approximate way. Additionally, a number of studies suggested this ANS to be related to mathematics abilities, which children acquire through instructions. If ANS is related to exact calculations, it could be assumed that children at some point learn to correspond nonsymbolic quantities with exact symbolic numbers. This process is called the mapping process between nonsymbolic and symbolic quantities and can be measured through an estimation task. In such task, participants are asked to estimate the number of dots when presented with a display of dots, too short to count. Evidence supports that this estimation skill mediates the relation between ANS and mathematics, suggesting that this skill truly reflects the mapping between nonsymbolic and symbolic quantities. However, research concerning ANS should be interpreted cautiously, since some studies found the link between ANS and mathematics to disappear when controlling for domain general capacities such as executive functions. This study will look at how executive functions might influence the mapping process between ANS and mathematics. The results confirm that general cognitive abilities and executive functions such as inhibitory control, shifting skills and visuospatial working memory might partly mediate the relationship between ANS acuity and mathematics achievement. Additionally, ANS measures do not remain significantly predictive of the mapping process as well as mathematics achievement when controlling for domain general cognitive abilities. Nevertheless, the mapping process does remain predictive of mathematics achievement after controlling for domain general abilities. As secondary aim, this study also shows that visuospatial working memory is predictive of informal mathematics, but not formal, while inhibition and shifting skills seem more related to formal mathematics.

Talk 4: **Developmental Trajectory Of Numerical Acuity In Pakistan**
Saeeda Khanum; Tayyaba Abid

Neuropsychological and developmental research evidence reveals that approximate number system is shared across development and species. Numerical cognitive abilities play important role in survival across species. Approximate number system is functional early in development and operates across modalities in literate and non-literate cultures independent of language. Research studies conducted with children and adults have shown that approximate number system acuity is correlated with formally learned mathematics. Training and longitudinal resaerch evidence suggests that approximate number system plays foundational role in later symbolic mathematics. Research evidence has revealed its developmental trend in western culture showing that its resolution continuous to increase throughout the development. However, there is yet no evidence found from Asian population; especially from Pakistan. Through this study developmental trajectory of numerical acuity have been investigated from 261 participants from Pakistan ranging from 5 to 72 years. Age groups comprised of 5-10, 10-15, 15-20, 20-25, 30-35, 40-45, 45- 50, 50-55, 55-60 and 65 and above. Panamath task was administered following standard instructions across all age groups. Results revealed that numerical acuity got sophisticated and precise with increase in age. These findings support the previous research evidence suggesting that the acuity of approximate number system increases with age. This research has important implications for understanding development of number sense cross culturally keeping in view the evidence from various cultures.

Talk 5: **The Relationship Between Symbolic and Non-Symbolic Number Processing Inside and Outside of the Subitizing Range**

Jane Hutchison; Ian Lyons

A prominent theory of how children learn the meaning of number symbols posits that children learn the symbolic number sequence by linking numerical symbols (e.g., Indo-Arabic numerals) to their non-symbolic counterparts (e.g., arrays of dots) primarily within the subitizing range (1-4) and that they then extend these rules to larger numbers without having to directly access their underlying magnitudes. One implication of this view is that the symbolic and non-symbolic number systems should be more closely related within the subitizing range than within larger numbers; however, this hypothesis has yet to be explicitly tested. In the current study, we administered symbolic and non-symbolic comparison tasks to a sample of 529 kindergarteners, at the beginning and end of kindergarten. At both time points, symbolic and non-symbolic performance was more strongly related within the subitizing range relative to comparisons involving quantities outside the subitizing range. This result lends support to the hypothesis that children process symbolic and nonsymbolic quantities more similarly for magnitudes within the subitizing range. Longitudinal analyses showed that symbolic performance at the outset of kindergarten predicted growth in non-symbolic performance over the course of the school year to a greater extent than the reverse; however, this was not modulated by numerical size. These findings suggest that the strong link between symbolic and non-symbolic quantities within the subitizing range, while developmentally stable and robust, may nevertheless be primarily a reflection of earlier developmental processes that were involved in the initial acquisition of the meanings of number symbols. That is, the strong link between systems in the subitizing range may not play a major influential role in the further development of these symbolic and nonsymbolic numerical comparison skills.

Time: 15:30 – 16:00
Room: North school

Coffee/Tea break

<u>Time:</u> 16:00 – 17:30
<u>Room:</u> South school

Symposium: **Foundations for fractions – Non-symbolic ratio processes and relational reasoning**

Organisers: Percival Matthews; Edward Hubbard; Jake McMullen

Overview: Recent research has shown that there may be fundamental features of human cognition that support the understanding of fractions, such as non-symbolic ratio processing. For example, multiple studies have shown a sensitivity to nonsymbolic ratios in children (Möhring, Newcombe, Levine & Frick, 2015), adult humans (Matthews & Chesney, 2015), and even non-human primates (Drucker, Rossa and Brannon, 2016; Valentin & Nieder, 2008, 2010. Additionally, recent work has started to demonstrate links this sensitivity to nonsymbolic ratios and individual differences in symbolic fractions performance (Matthews, Lewis and Hubbard, 2016; Möhring et al., 2015; Hansen et al., 2015). In parallel, some recent work has shown that adults spontaneously focus on ratio (Bonn & Cantlon, 2016) and that differences in this spontaneous focus on multiplicative relations (SFOR) predicts the development of rational number abilities (McMullen, Hannula-Sormunen, Laakkonen & Lehtinen, 2016). This symposium will present cutting edge research on the functioning of non-symbolic ratio and SFOR processes and how a deeper understanding of each can contribute to general theories of numerical cognition. In a series of four talks: First, Bonn and Cantlon will present ongoing research showing that humans spontaneously extract fine-grained, relative magnitude information – including rank and ratio – when comparing sequences of stimuli within and across sensory modalities. They will discuss these spontaneously extracted relational information as potential bases for a generalized magnitude system. Second, Attridge and colleagues examine the automaticity of the ratio processing system alongside the automaticity of the ANS by manipulating time constraint and secondary loads in comparison tasks. Results will be discussed in terms of the comparative merits of each system to serve as grounding for symbolic numbers. Third, McMullen and Siegler will present a study examining the precision of ratio encoding from narrative vignettes into symbolic fractions in relation to participants' tendencies to recognize multiplicative relations in non-explicitly mathematical situations (i.e., SFOR tendency) and how both factors relate to conceptual knowledge of rational number. Discussion will focus on the role nonsymbolic ratio and relational reasoning may play in promoting comprehension of rational numbers. Finally, Resnick, Goldwater, and Newcombe explore how measurement models of fractions – models integrally tied to number line representations – promote understanding of symbolic fractions magnitudes. Findings indicate that number line estimation with symbolic fractions is correlated with nonsymbolic proportional reasoning skills. On balance, these findings suggest that nonsymbolic proportional reasoning and symbolic estimation skills interact to support mathematical achievement.

Talk 1: **Spontaneous Abstraction of Ratios and Ranks Across Magnitude Dimensions**
Cory D. Bonn; Jessica F. Cantlon

A growing body of literature suggests that different magnitude dimensions interact via one or more common representations, under the umbrella term 'generalized magnitude system.' This system remain poorly understood because few explicit descriptions of candidate formats for such representations have been proposed. I will discuss both published and ongoing work showing that humans spontaneously extract fine-grained, relative magnitude information to compare sequences of stimuli within and across sensory modalities and across magnitude dimensions. These abstract, ratio- and rank-based representations underlying this behavior qualify as candidate formats for a generalized magnitude representation because they are dimensionless: they are equally meaningful across all ratio scales. Most importantly, our work shows that humans are sensitive to the loss of ratio information across stimulus sequences when only rank-ordering information is preserved, suggesting that the ratio may be the preferred representation format for comparing relative magnitudes across dimensions. In addition to our own ongoing work, I will discuss how other researchers may reuse our experimental designs and variants of our regression models to extract parametric descriptions of individual differences to use as predictors in cross-sectional or longitudinal work.

Talk 2: **Is the Non-Symbolic Ratio Processing System Automatic in Adults?**
Nina Attridge; Jayne Pickering; Joanne Eaves; Grace Huyton; Matthew Inglis; Camilla Gilmore; Iro Xenidou-Dervou

It has been proposed that the non-symbolic Ratio Processing System may support fraction learning, similarly to how the Approximate Number System may support whole number learning. We conducted two studies to test the automaticity of the RPS and ANS. In Experiment 1, participants performed a ratio comparison task and a quantity comparison task under three stimuli presentation times: 1500ms, 750ms and 375ms for the ratio task and 750ms, 375ms and 187ms for the quantity task. The ratio task showed a greater decline in accuracy as the stimuli presentation time decreased than the quantity task, but performance was significantly above chance level in all conditions. In Experiment 2, participants performed a ratio comparison task and a quantity comparison task in four conditions: no load, attentional load, low working memory load and high working memory load. The experiment is ongoing, but if both the RPS and ANS are automatic, performance should not be affected by the secondary load and should remain above chance level in all conditions.

Talk 3: **Precise Encoding of Relations and Spontaneous Focusing on Multiplicative Relations Support Fraction Magnitude Knowledge**
Jake McMullen; Robert Siegler

Thompson & Siegler (2010) found that those who expressed a more linear representation of the mental number line also were more accurate in their recall of the numerical magnitudes of numbers embedded in a short narrative vignette. It is hypothesized that those students with a higher tendency of Spontaneous Focusing On multiplicative Relations (SFOR) may gain extra practice with reasoning about multiplicative relations in and out of the classroom, leading to improvements in rational number knowledge (McMullen et al., 2016). It is possible that the advantages gained with a higher SFOR tendency may be mediated by a more exact mental encoding of relations. We aim to examine if those sixth grade students (n = 112) who were better at representing whole number relations embedded in narrative vignettes as fractions (i.e. encoding of relations) were also more likely to accurately represent fractional magnitudes on a number line, and whether this relation would mediate the relation between SFOR tendency and fraction knowledge. Based on a preregistered analysis plan (https://osf.io/b66nf/), we found that both encoding of relations and SFOR explained variation in fraction magnitude estimation. Additional analysis revealed that the relation between SFOR and fraction magnitude estimation was partially mediated (20%) by encoding of relations. These results suggest that advantages offered by a higher tendency to recognize multiplicative relations in non-explicitly mathematical situations may be in part via an increase in the precision with which students can encode the fractional relations embedded in everyday contexts. The more exact encodings of relations in messy everyday contexts may then support more accurate representations of symbolic fractions.

Talk 4: **Reasoning About Fraction Magnitudes and Proportions When Curriculum Supports a Measurement Model of Fraction Understanding: An Australian Sample**
Ilyse Resnick; Micah Goldwater; Nora Newcombe

Most research examining the relation between fraction number line estimation (NLE) and mathematics achievement has taken place in the United States. There is one cross-cultural study looking at 6th and 8th grade students from China, Belgium, and the United States (Torbeyns et al., 2015). Here, we extend these findings to 4th and 6th grade students from a country that is more culturally similar to the United States: Australia. Australian curriculum includes both measurement and part-whole models of fractions, whereas the United States instruction predominantly focuses on a part-whole model. We found that the Australian students had more accurate fraction number line estimations compared to previously reported samples from the United States. This suggests that measurement models of fraction leads to better fraction understanding. Fraction number line estimation was also correlated with proportional reasoning. This suggests that students rely on overlapping cognitive skills when completing both tasks. We will discuss how fraction number line estimation and proportional reasoning interact to support concurrent mathematics achievement.

Time: 16:00 – 17:30
Room: East school

Symposium: **Unpacking the Role of Numerical Ordinal Processing in the Development of Early Math Abilities**

Organisers: Chang Xu; Ian Lyons

Overview: How and when does children's numerical ordinal processing develop and how does it relate to the development of their math skills? The five talks in this symposium address several questions related to the development of numerical ordinal processing. They provide a useful springboard for extensive discussion about critical questions pertaining to numerical ordinal processing and its potential role in mathematical development more broadly. Previous work has primarily assessed symbolic ordinal processing in elementary-age children. Bakker et al. thus push our understanding earlier in development by examining children's numerical ordinal knowledge in a sample of over 400 four-year-old children. They show how symbolic ordinal processing relates to other commonly assessed early numeracy competencies. The strongest correlations were with number recognition and counting, suggesting important ties between ordinal processing and rapid access to verbal and visual numerical forms. In a longitudinal study with nearly 500 Kindergarteners, Lyons et al. present new evidence for an important conceptual milestone in children's understanding of ordinality: Kindergarteners actively mis-classified ordered sequences in which the numbers are not adjacent (e.g., 2-4-6) despite explicit instructions and examples to the contrary. This pattern persisted over the course of the school year, indicating resistance to an important conceptual milestone in children's numerical development: that numbers do not have to be adjacent in the count-list to form an ordered set. Both Sasanguie et al. and Xu and LeFevre provide converging evidence for a shift from grades 1-2 in the explanatory role from cardinal to ordinal processing in understanding how children do arithmetic. Sasanguie et al. show that for children in grade 1, cardinal processing (digit-comparison) mediated the relationship between ordinal processing (digit-ordering) and arithmetic, but the opposite was true in grade-2 children: ordinal processing mediated the relationship between cardinal processing and arithmetic. Xu and LeFevre provide converging evidence for the mediating role of digit-ordering between digit-comparison and arithmetic for children in grade-2 (but not for grade-1 children). Furthermore, digit-ordering uniquely predicted the growth of arithmetic over the course of grade 2. Taken together, this consistent set of results suggests that the shift in the predictive value for arithmetic from cardinal to ordinal processing may be related to change in how children do arithmetic – e.g., different strategies such as increasing reliance on relational and retrieval-based processes – from grades 1-2. Lastly, Morsanyi et al. examined dyscalculic and typically-developing (TD) children ages 8-11. They show that numerical and non-numerical ordering abilities significantly contribute to a model capable of distinguishing dyscalculic and TD children with 82.5% accuracy. Ordering abilities uniquely predicted individual differences in mathematical achievement in TD children.

Talk 1: **Ordinal numerical processing in 4-year-old preschool children: Associations with other early numerical competencies and gender differences**

Merel Bakker; Joke Torbeyns; Nore Wijns; Lieven Verschaffel; Bert De Smedt

Background: Preschool represents a formative stage for children's later mathematical development (Purpura & Lonigan, 2013). Before receiving formal math instruction, children have already developed a wealth of early numerical competencies (Jordan et al., 2007). Ordinal numerical processing is one of these early numerical competencies, which has received increased attention. For example, children's understanding of ordinality has been found to be a robust predictor of more advanced mathematical skills in primary school children (Lyons et al., 2014). We investigated 4-year-old children's ordinality knowledge and examined its associations with other early numerical competencies. We also aimed to investigate whether any gender differences on these numerical tasks could be observed at this young age. Methodology: Participants were 402 4-year-old children attending preschool in Flanders. A number order task consisting of eight items was used to measure children's understanding of ordinality (Purpura & Lonigan, 2013). They were asked to name the number that comes before and the number that comes after a presented Arabic numeral (i.e., 3, 7, 12, and 16). The following numerical tasks were also administered: verbal counting, object counting, numeral recognition, symbolic and non-symbolic comparison, dot enumeration, and nonverbal calculation. Results/Discussion: On average, children solved 2.89 items (range: 0-8) of the number order task correctly. As expected, children were significantly better in naming the number that comes after an Arabic numeral ($M = 2.03$, $SD = 1.33$), compared to naming the number that comes before it ($M = 0.86$, $SD = 1.16$) ($t(401) = 17.73$, $p < .001$). Children's ordinal numerical processing correlated moderately (ranging from .372 to .680) with the other numerical competencies. We observed via Bayesian analyses that there was substantial evidence for gender equality for the number order task, and for six of the seven remaining numerical tasks. Implications and directions for future research will be discussed.

Talk 2: **Kindergarteners reliably mis-classify ordered sequences of non-adjacent numbers**

Ian M. Lyons; Jane E. Hutchison; Stephanie Bugden; Celia Goffin; Daniel Ansari

Recent evidence has demonstrated that children's understanding of numerical order is an important aspect of development, and the ability to judge the ordinality of number symbols is highly predictive of more complex arithmetic processing from grade-school through adulthood. Here we present evidence of a major conceptual gap in children's ordinal understanding in the majority of children as late as the end of Kindergarten. 484 children completed a symbolic numerical ordering task at the beginning and end of Kindergarten. At the beginning of Kindergarten (i.e., at the outset of formal education), children were able to tell that adjacent numbers (e.g., 3-4-5) were in order, and that permutations thereof (e.g., 4-5-3) were not. Performance on both types of judgements improved substantially by the end of Kindergarten. On the other hand, the clear majority of children judged non-adjacent sequences (e.g., 2-4-6) to be not in order, despite explicit instructions and examples showing that these numbers should be considered in order. This behavior persisted through the end of Kindergarten with no detectable change in performance, indicating lack of conceptual change across the school year. Children judged non-adjacent, non-ordered sequences (4-6-2) to be not in order, and their ability to do so improved across the school year. Multi-dimensional scaling (MDS) based on correlation patterns between conditions indicated that children treated 2-4-6 items more like 4-5-3 and 4-6-2 items than 3-4-5 items, but only when we recoded responses from the perspective that 2-4-6 items should be considered 'not-in-order'. Together, these data demonstrate that Kindergarten children actively mis-classify non-adjacent ordered sequences, indicating resistance to an important conceptual milestone in children's numerical development: that numbers do not have to be adjacent in the count-list to form an ordered set. We discuss this pending conceptual shift and implications for future research

Talk 3: **Unpacking the relation between comparison and arithmetic in both adults and children**
Delphine Sasanguie; Ian M. Lyons; Bert De Smedt; Bert Reynvoet; Helene Vos

Symbolic number – or digit – comparison has been a central tool in the domain of numerical cognition for decades. More recently, individual differences in performance on this task have been shown to robustly relate to individual differences in more complex math processing – a result that has been replicated across many different age groups. In two studies, we 'unpacked' the underlying components of digit comparison (i.e. digit identification, digit to number-word matching, digit ordering and general comparison). In a sample with adults, a first experiment showed that digit comparison performance was most strongly related to digit ordering ability – i.e., the ability to judge whether symbolic numbers are in numerical order. Furthermore, path analyses indicated that the relation between digit comparison and arithmetic was partly mediated by digit ordering and fully mediated when non-numerical (letter) ordering was also entered into the model. A second experiment examined whether a general order working memory component could account for the relation between digit comparison and arithmetic. It could not. Instead, results were more consistent with the notion that fluent access and activation of long-term stored associations between numbers explains the relation between arithmetic and both digit comparison and digit ordering tasks. In a sample with second graders, the results were similar as in adults: digit ordering fully mediated the relation between comparison and arithmetic. However, in first graders, this was not the case. For them, the reverse was true and digit comparison fully mediated the relation between digit ordering and arithmetic. Therefore, these children' data suggest that between first and second grade, there is a shift in the predictive value for arithmetic from cardinal processing and procedural knowledge to ordinal processing and retrieving declarative knowledge from memory; a process which is possibly due to a change in arithmetic strategies at that age.

Talk 4: **Integration of number relations for children in grades 1-2**
Chang Xu; Jo-Anne LeFevre

What are crucial roles of cardinal and ordinal processing in the development of arithmetic? In the present paper, children (n = 146) from grades 1 and 2 completed a symbolic number comparison task (e.g., which number is bigger, 4 or 5?) as an index of their cardinal knowledge. They also completed two novel order tasks: (a) missing number (e.g., which number is missing, e.g., 1 _ 3 4?), and (b) number ordering (i.e., order the three digits from the smallest to the largest, e.g., 4 5 3 or 2 7 9). Last, children's arithmetic skill (e.g., speed and accuracy of solving problems such as 4 + 5 or 7 + 6) was measured twice in the school year. Multiple-group path analysis showed that for children in grade 1, number ordering was strongly predicted by number comparison but not by the missing number task, suggesting that both require cardinal rather than ordinal knowledge. Further, performance on the number comparison and missing number task independently predicted addition at Time 1, supporting the view that these tasks assess different aspects of number knowledge. In contrast, number ordering was not related to addition. In contrast, for children in grade 2, variance in the number ordering task was shared between the number comparison task and missing number task, supporting the view that the number ordering task integrated cardinal and ordinal knowledge. Consistent with this perspective, the number ordering task mediated the relations between these two tasks and arithmetic. Also, number ordering was the best unique predictor of arithmetic for children in grade 2 and it also predicted the growth of addition from Time 1 to Time 2. Taken together, the different patterns of results from grades 1 to 2 may reflect different stages in the ongoing integration of the symbolic numerical associations.

Talk 5: **The role of numerical and non-numerical ordering abilities in mathematics: Evidence from children with dyscalculia and typically developing children**

Kinga Morsanyi; Bianca van Bers; Teresa McCormack; Patrick O'Connor

Recent evidence (e.g., Lyons & Beilock, 2011) has highlighted the important role that number ordering skills play in mathematics abilities. Nevertheless, there are still several questions that remain to be answered regarding the relation between ordering abilities and mathematics. We present the results of two studies which included children between the ages of 8-11. In Study 1, children with developmental dyscalculia (DD; n=20), and a closely matched control group (n=20) participated. We hypothesised that children with DD would perform worse than controls on our measures of ordering ability, which included both numerical and non-numerical tasks. The children were also administered several other tasks that measured magnitude processing/estimation abilities and inhibition skills. The findings revealed differences between the groups in ordering, with both numerical and non-numerical ordering skills impaired in DD. Magnitude processing abilities were also impaired in this group, but there was no evidence of inhibition problems. Logistic regression analyses indicated that a combination of the order judgment tasks and the number line task discriminated most reliably between dyscalculic and non-dyscalculic participants. Study 2 included the same measures as Study 1, but only children without mathematics difficulties were included (n=100). The aim of the study was to identify the strongest predictors of mathematics performance, once the effect of children's age and general intelligence was taken into account. The results showed that number ordering, order working memory and performance on the number line task were the strongest predictors of maths performance, and no other task explained significant variance in maths skills, once the effect of these tasks was taken into account. The results of these studies extend the recent literature on the role of ordering abilities in children's mathematics performance, and also draw attention to the individual contribution of different types of ordering tasks.

<u>Time:</u> 16:00 – 17:30

<u>Room:</u> Room 6

Parallel session: **Maths achievements 3**

Chair: Miriam Rosenberg-Lee

Talk 1: **Old brains and their money. Anatomical substrates and neurocognitive predictors of financial abilities in Mild Cognitive Impairment.**

Carlo Semenza; Francesca Burgio; Micaela Mitolo; Giorgio Arcara; Annalena Venneri; Francesca Meneghello; Roberta Toffano; Silvia Benavides-Varela

Deficits in financial abilities (FA) contribute to the difficulties experienced by patients with mild cognitive impairment (MCI) in everyday life. While there is increasing evidence of the link between cognitive decay in aging and bad financial decisions (Arcara, Burgio et al., 2017) the anatomical correlates of this association is still poorly understood.The present study aims at exploring this issue by means of the Numerical Activities of Daily Living Financial (NADL-F) (Arcara, Burgio et al., 2017), and structural MRI volumetrics among normal and abnormal (MCI) older adults. The study included 44 MCI patients and 37 healthy controls that completed the NADL-F together with a comprehensive neuropsychological assessment. A surprising and potentially novel result of this study is, in MCI with respect to controls, a major involvement of limbic structures (rather than neocortical structures) in financial tasks. It is hard, at present time, to provide a full and detailed interpretation of such result. It looks as if, when cortical areas deteriorate and cognitive decline takes over, emotional aspects emerge in front of tasks pertaining to a domain where desire normally plays a major role. As a consequence, MCI patients, when confronted with financial matters, are at risk of behaving less rationally. This may result in non-mindful, unwise decisions and higher gullibility, ultimately leading to a disadvantageous course of action.

Talk 2: **Exploring Diagrams Influence on Students' Mental Models of Mathematical Story Problems**

Anna Bartel; Martha Alibali

Across studies, diagrams have been demonstrated to be both beneficial and harmful to students' mathematical learning. Different types of diagrams may support student learning in different ways. This study investigated the effects of different types of diagrams in supporting students' ability to symbolize mathematical relationships in two-operator algebraic story problems. Adult participants ($N = 121$) were randomly assigned to receive the problems in one of three conditions: (1) with no diagram, (2) with an integrated diagram, which displayed the relations between the two operations, or (3) with a discrete diagram, which displayed the distinct operations but not how they were related. We examined whether participants' ability to successfully symbolize the story problems in two-operator equations depended on diagram condition (none, discrete, integrated), mathematics ability (assessed via self-reported SAT/ACT scores), and spatial ability (assessed via the validated Paper Folding Task). The integrated diagram increased the probability of correctly symbolizing the problems, for students with low mathematics ability, $b = .41$, $X2(1) = 4.71$, $p = .029$, but there were no differences for students with low spatial ability, $b = -.50$, $X2(1) = 3.47$, $p = .06$. There were no differences between the two diagram conditions for participants of high math ability, $X2(1) = .01$, $p = .89$, but for students with high spatial ability, the discrete diagram was detrimental to performance, $b = .52$, $X2(1) = 11.76$, $p = .0006$. In sum, different types of diagram differentially altered the likelihood of correctly symbolizing the problems, presumably by influencing students' mental models of the mathematical situation. However, effects of the diagrams depended on characteristics of the students. Therefore, when designing materials to support performance in mathematics, it is important to consider, not only how a provided visual representation may help, but also whom the visual representation is intended to help.

Talk 3: **Predicting mathematical ability before school: A link between ROBO1, parietal cortex volume and numerical reasoning**

Michael Skeide; Katharina Wehrmann; Angela Friederici

Mathematical achievement is trainable, but genetically constrained (Oliver et al., 2004). Drawing on this evidence, several candidate genes have been recently identified (Docherty et al., 2010; Mascheretti et al., 2014; Baron-Cohen et al., 2014; Chen et al., 2017). It is unknown, however, which intermediate phenotypes could explain how these genes influence mathematical cognition. Here we analyzed the gene-wise joints effects of previously reported single nucleotide polymorphisms in a discovery sample of 101 children. Before entering school (at an age as young as 3-6 years), participants also underwent T1-weighted magnetic resonance imaging to compute grey matter volume using voxel-based morphometry. Psychometric test scores quantifying later mathematical skills in second grade (at age 8-9 years) were available for 34 children. The gene ROBO1 was significantly associated with grey matter volume of the right inferior parietal cortex ($\chi^2 = 47.11$; $P < 0.001$, FWE-corrected; controlled for age, sex, handedness and total intracranial volume). Individual volumes within this area were significantly positively related to numerical reasoning skills ($R2 = 0.21$, $P = 0.033$, FWE-corrected), but not to arithmetic skills, non-verbal IQ, reading, spelling and maternal education. Our findings, which require replication in a larger sample, suggest that more than a fifth of the variance in basic numerical reasoning skills can be predicted by early individual differences in parietal cortex volume which in turn relate to a gene that is known to regulate prenatal migration of neurons into cortical target layers (Gonda et al., 2013).

Talk 4: **The Neurochemistry of Mathematical Development**

George Zacharopoulos; Francesco Sella; Roi Cohen Kadosh

Mathematical achievement throughout child development is a key predictor of later academic achievement. Previous findings have focused on the link between mathematical achievement and brain development at the structural and functional level. Recently, it has been suggested that the interplay between excitation and inhibition at the neural level affect sensitive period in development and brain plasticity, and subsequent behavioural phenotype. Here we examined the link between cognitive achievement and neurochemicals that are associated with excitation and inhibition in the child and adult brains. Using magnetic resonance spectroscopy, we quantified glutamate and GABA (gamma-aminobutyric acid), as a proxy for cortical excitation and inhibition in the frontal and parietal cortices, key brain regions for mathematical learning and cognition. We correlated standardized mathematics scores with these neurochemicals in these regions. Previous studies have suggested that as a function of mathematical development, there is a shift from frontal to parietal regions. We found that indeed mathematical achievement is linked with neurochemicals in the children's prefrontal cortex, while mathematical achievement in is linked to the neurochemicals in the adults' parietal cortex. These findings reveal the differential involvement of these neurochemicals as a function of neurodevelopment, and highlight the connection between excitation and inhibition, a marker of neuroplasticity, and cognitive development and achievement.

Talk 5: **Understanding number line estimation performance in Down Syndrome and Williams Syndrome**

Victoria Simms; Annette Karmiloff-Smith; Jo Van Herwegen

The number line estimation task has been used as a measure of numerical representations with a variety of populations. Previous research has suggested that individuals with Down's Syndrome (DS) have similar estimation profiles to age matched controls (Lafranchi et al., 2015). Individuals with

Williams Syndrome (WS) have been reported to have delayed and atypical performance on the number line estimation task (Opfer & Martens, 2012). This study aimed to a) compare number line estimation performance across syndromes using developmentally appropriate scales; b) assess the relationship between number line estimation and mathematical achievement in DS and WS and c) assess the skills that contribute to number line estimation in DS and WS. 25 participants with DS, 28 participants with WS and 25 typically developing (TD) children were recruited for the study. The groups were matched for non-verbal IQ scores, thus the TD group was significantly younger (Mage= 74 months) than the DS (Mage = 258 months) and WS (Mage = 245 months) groups (all p's< .001). Participants completed 0-10 and 0-100 number line estimation tasks as well as a mathematical achievement test, a pattern construction task and a battery of short tasks to assess number familiarity. The metric used for number line estimation was percent absolute error. There were no significant group differences in 0-10 or 0-100 number line estimation performance or mathematical achievement. Number line estimation performance was significantly correlated with mathematical achievement for all groups (r's ranging from -.40 to -.77) with better number line estimation skills associated with increased mathematical achievement. Linear regressions were conducted for the DS and WS group separately, using age, pattern construction and number familiarity as predictors. For the WS group, number familiarity was a significant unique predictor of number line estimation on both the 0-10 (β= -.63, p=.001) and 0-100 (β= -.50, p=.015) scales. For the DS group, pattern construction was a significant unique predictor for the 0-10 scale only (β= -.55, p=.04). The results will be discussed in the context of the importance of task selection when working with atypically developing groups and implications for intervention.

Time: 16:00 – 17:00
Room: Room 7

Parallel session: **Philosophy**

Chair: Aaron Sloman

Talk 1: **Ordinals vs. Cardinals in ℕ and Beyond**
Aviv Keren

I will present a preliminary abstract framework of object-representation (in terms of humans' interaction with objects), that makes room for the representation of mathematical objects on par with that of non-mathematical (mainly physical) ones. This framework serves as a bridge, through which the vast scientific knowledge concerning the latter can guide our understanding concerning the former. Using this framework, I will provide a novel account of the intricate interaction between ordinals, cardinals, and natural numbers, between the finite and the infinite. The account will dispute the classic mathematical tale of what actual infinity supposedly did to our concept of numbers and substantiate a different view: From the very beginning, even in the finite, ordinals and cardinals are inherently – mathematically – distinct; different types of objects. The restricted domain of the finite, however, allows for merging the two and bringing about the compound objects that numbers actually are and and automating the handling of the finite ordinals and cardinals themselves and the interaction between them. But the finite is simply the implicit context in which these mathematical objects happen to first be experienced and discovered or taught (akin to a piece of geometric reasoning that inconspicuously depends on the drawn triangle being acute-angled). It is a contingent, empirical statistic rather than an absolute mathematical necessity – that the cognitive system nonetheless, by its nature, comes to process equivalently. The introduction of actual infinity, much later on, merely forces us to notice the notions' distinctness. Foundationally, that distinction is already at the heart of things – and of their mental representation too.

Talk 2: **Intuition and Higher Mathematical Cognition**
Francesco Beccuti

'Intuition', even within the realm of mathematics, is a polysemous word and different authors attach different meanings to it. A well-known fact is that formalism in philosophy of mathematics rejects all-together the role of intuition (or state that it can be eliminated by means of formalization). In this paper, I will consider Turing's notion of mathematical intuition in connection with the incompleteness phenomenon of mathematical logic which brought Turing to the conclusion that the role of intuition cannot be entirely circumvented in mathematical practice (as opposed to his notion of mathematical ingenuity, which can be reduced to rule-following procedures). Furthermore, speculating on the possibility of constructing a thinking machine, Turing made a case for the development of cognitive (embodied) models of the evolving mathematical mind as an effective way of endowing machines with mathematical intuition. On the other hand, I will overview some familiar empirical results (obtained by Dehaene et alii) which corroborate the belief in a primitive human "number sense" which is geometrical or spatial in nature, a natural candidate for being a fundamental component in Turing's notion of intuition (and in Turing's notion of ingenuity too). In sum, both empirical findings and theoretical considerations seem to converge to the same conclusion with regard to intuition: it is an unavoidable concept in the understanding of higher mathematical reasoning. In view of this, I will highlight the special importance to the field of mathematical cognition of both introspective and historical accounts of mathematical practice.

Talk 3: **Evolution -- the blind mathematician producing increasingly sophisticated users of mathematical discoveries**
Aaron Sloman

After a degree in Maths and Physics I switched to a philosophy DPhil (Oxford, 1962) defending Kant's claim that mathematical discoveries are non-empirical, non-contingent, and non-analytic (despite the evidence that our space is not Euclidean, wrongly thought by many to demolish Kant). Later, after being introduced to AI by an inspiring vision researcher (Max Clowes), and learning to program, I hoped to build a baby robot that could "grow up" to be a mathematician like ancient mathematicians (e.g. Archimedes, Euclid, Zeno, etc.), to produce a much stronger defence of Kant. Nearly half a century later, with a varied collection of examples of the sorts of mathematical discoveries, and evidence of proto-mathematical competences in toddlers, weaver birds, squirrels, elephants and other intelligent animals, neither I nor anyone else (as far as I can tell) knows how to create such a machine, and I believe there are no adequate explanatory theories/models in psychology or neuroscience either. (E.g. statistics-based/probabilistic learning mechanisms *cannot* establish necessary truths and impossibilities, and logical theorem provers starting from Euclid's axioms *cannot* replicate the original non-logical discoveries leading to those axioms.) In 2011, while commenting on Turing's 1952 paper on chemical morphogenesis for a centenary volume, I began to wonder what Turing would have done if he had not died in 1954. Perhaps the "Meta-Morphogenesis" (M-M) project: trying to discover or guess at relevant varieties of evolved information processing mechanism between the very simplest organisms (or pre-biotic forms) and the most sophisticated, hoping to identify previously unnoticed layers of mechanism that might be needed to enable eventual evolution of (e.g.) Archimedes-like organisms (and before that squirrels, octopuses, etc.). The project has collected examples of evolution's mathematical discoveries (e.g. uses of homeostatic control mechanisms) and other biologically useful mathematical (mostly non-numerical) discoveries not necessarily previously documented, and informally explored abilities of colleagues and students to make those discoveries (e.g. if ABC is a planar triangle what happens to the size of angle A if A moves away from the side BC along a line that passes between B and C?, and many others involving topology and geometry including non-metrical relations such as partial orderings -- extending Gibson's theory of affordances). The forms of reasoning used don't seem to map onto any known mechanism, so, using many such examples, I have begun to collect requirements for evolved mechanisms that might provide a basis for implementing the required capabilities. E.g. instead of a discrete TM-tape, or logical axioms, or arrays of bits, it may be necessary to have multiple movable and deformable surfaces (sub-neural virtual membranes?) on which structures can be projected then moved and deformed relative to one another, and possibilities and impossibilities discovered (generalising manipulations of discrete logical structures). Whether this Super-Turing mental-diagram machine can be implemented as a virtual machine on digital computers would be a secondary question. I invite collaboration on the task of assembling requirements and possible solutions, and collecting evidence. I already have a lot of online examples and conjectures, and now need collaborators. http://goo.gl/9eN8Ks

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Time: 17:45 – 18:45
Room: South school

Business meeting (open to all members)
