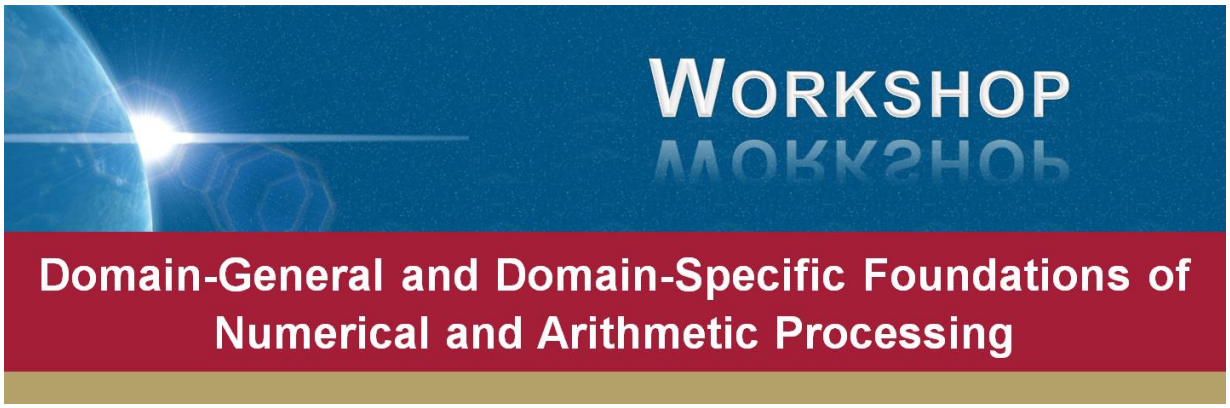
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN



Domain-General and Domain-Specific Foundations of Numerical and Arithmetic Processing

28th - 30th September 2016

University of Tübingen, Germany

DFG

LEAD
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Domain-General and Domain-Specific Foundations of Numerical and Arithmetic Processing

WORKSHOP

28TH - 30TH SEPTEMBER 2016

UNIVERSITY OF TÜBINGEN

TÜBINGEN, GERMANY

Contents

1 Preface

Dear colleagues,

It is our greatest pleasure to welcome you to the Workshop on Domain-General and Domain-Specific Foundations of Numerical and Arithmetic Processing that will be held in Tübingen, Germany from 28th till 30th September, 2016.

Arithmetic skills are one of important factors determining scholastic success and the quality of daily life. In recent decades, intensive research in psychology, cognitive neuroscience and educational sciences shed some new light on our understanding of processes and structures underlying numerical and arithmetic performance. For actual math performance, however, basic numerical operations need to interact with domain-general cognitive functions, such as speed of processing, working memory efficiency, executive functions, attentional processes, fluid intelligence, and metacognition. Math performance may be thus considered as a result of an interaction between domain-general and domain–specific factors. In order to explain the phenomenon of math performance, both need to be considered. Due to the relevance of numerical competencies for scholastic success, both domain-general and domain–specific foundations are intensively investigated from educational, developmental, cognitive, and neuroscientific perspectives. Our aim is to address the international research community interested in the intersection between these approaches.

For this year's workshop, we thus invite you to spend three days in Tübingen discussing this timely topic and we are delighted to welcome your many contributions. Keynote talks by ten leading researchers and one selected PhD-student talk will give a broad overview of current research topics of different disciplines. Participants will also get the opportunity to present their own works within poster sessions and to discuss them with experts.

Besides that, Tübingen offers a wealth of historical sites and cultural highlights, so we are pleased to offer you some of them in an attractive framework program: e. g., a brief sightseeing walk and a trip by a punting boat.

Finally, we wish to thank our sponsors for the generous funding that enabled us to conduct the workshop without collecting registration fees, to invite internationally recognized researchers, and even to cover the accommodation for the most motivated PhD students. This was possible thank to the Deutsche Forschungsgemeinschaft, Universität Tübingen, ZUK (ZUK63). We are also grateful for the support of the LEAD Graduate School & Research Network and the Leibniz-Institut für Wissensmedien (IWM) in Tübingen.

We look forward to meeting you in Tübingen and hope that you enjoy the workshop.

The Organizing Committee

2 Organizing Committee

Julia Bahnmüller
Krzysztof Cipora
Gabriella Daróczy
Thomas Dresler
Urszula Mihułowicz
Vesna Milicevic
Katarzyna Patro
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3 Our Sponsors

Deutsche Forschungsgemeinschaft, ZUK63

LEAD Graduate School & Research Network

Institut für Wissensmedien (IWM)

4 General Information

4.1 Workshop venue

Psychologisches Institut
Eberhardt Karls Universität Tübingen
Schleichstraße 4
D-72076 Tübingen
Lecture Hall / Room 4.329
Tel.: +49 (0)7071 29-78345

4.2 WiFi

There is a free WiFi access at the venue:

SSID: Guest
user name: neuroscience
password: tuebingen

4.3 Poster sessions

The posters will be presented in a room next to the lecture hall. The poster walls are numbered from A1 to A17 and from B1 to B17 for the two poster sessions A (Wednesday 16:15 – 17:45) and B (Thursday 16:00 – 17:30). You can find your number in the overview of posters in the booklet.
Please deliver you poster on Wednesday. If you want to remove your poster feel free to collect it on Friday so that all the posters can be presented during the whole workshop. The presenting authors are asked to be attendant during the poster session.

Best poster awards will be given to the authors of the three best judged posters. The rating will be undertaken by the poster committee consisting of Lisser Rye Ejersbo (Aarhus University, Denmark), Torkel Klingberg (Karolinska Institutet, Sweden), and Elida Laski (Boston College, USA). The award ceremony will take place on Friday after the general discussion.

4.4 Coffee breaks, lunch, and dinner

In the coffee breaks, hot and cold drinks as well as some snacks will be offered. Lunch snacks will also be served at the venue, so you don't need to worry about finding a nearby restaurant.
On Wednesday evening, the speakers will be having dinner in the Wirtshaus Casino (Wöhrdstraße 25).
On Thursday evening, all participants of the workshop are invited to join for a dinner in Neckarmüller (Gartenstraße 4) at their own expense. Because we are going to be a very large group, the restaurant needs to know the orders in advance. Please confirm if you are joining us and choose your meal at the reception desk by Thursday morning.

4.5 Sightseeing walk through Tübingen

On the way to dinner on Thursday evening you are welcome to join us for a short walk trough the most beautiful corners of the Tübingen old town.

4.6 Punting boat trip

A true landmark of Tübingen are the punting boats on the Neckar river. If you have registered for the punting boat trip on Friday, please confirm it at the reception desk and pay 5 EUR. For those, who had not preregistered for the trip but would like to participate, there will be a waiting list, so let us know at the reception. For the punting boat trip we leave the workshop venue at 1:25 pm.

5 About Tübingen

Small steps, narrow alleys and pointed gables shape the silhouette of old Tübingen on the way up to its castle. The Swabian University town of 87,000 inhabitants combines the flair of a lovingly restored medieval town centre with the colorful bustle and typical atmosphere of a young and cosmopolitan students' town.
Tübingen has witnessed almost a millennium of history, with the castle, the historic old town and the medieval buildings of the different institutes. In 1078 Tübingen was mentioned in writing for the first time, and in the middle of the 13th century Tübingen achieved town status and civil liberty under the Palatine Counts of Tübingen.
Many well-known personalities have resided in Tübingen over the past few centuries. They came in order to teach, to study, to find space in the town for their artistic, scientific or political goals. The University has set the cornerstone for numerous great careers, and has itself been molded and enriched by the subsequent activities and events.
Discover the treasures of the historic old town: the protestant collegiate, in which Hölderlin, Schelling and Hegel once shared a study. Or the city hall in the marketplace, that is more than 500 years old. The Hölderlin Tower on the Neckar invites you to linger with a line of "Stocherkähne" (punting boats unique to Tübingen), at the tower's feet, ready for a ride on the Neckar. Numerous sidewalk cafes, wine taverns and cozy students' pubs, special shops and restaurants invite visitors to stroll around and to pause here and there.
To learn more about what Tübingen offers visit *https://www.tuebingen.de/en*.

6 About the University of Tübingen

„Tübingen does not have a university, it is a university“, is a common expression for a good reason: With its palm tree symbol and Duke Eberhard's motto “Attempto!” (“I dare”), the university and its more than 28,000 students certainly shape the city image. Its 450 professors and 4,000 academics make it the second largest university in Baden-Württemberg, following Heidelberg. More than 280 courses are on offer. The seven institutes are spread throughout the city. In the old town there is hardly a single building or location not associated with a famous scholar - Hegel, Hölderlin and Schelling, Mörike and Uhland, Kepler and Schickard among them. Furthermore, nine Nobel laureates are associated with the University of Tübingen.

The Eberhard Karls University Tübingen is one of Europe's oldest universities. Several hundred years of history in the sciences and humanities have been written here. The University's history began in 1477, when Count Eberhard “the Bearded” of Württemberg founded the University. The latest chapter of the University's history is marked by its success in the Excellence Initiative of the German federal and state governments. One Graduate School, one Excellence Cluster and the University's Institutional Strategy were successful in the major funding program - also making Tübingen one of Germany's eleven universities in the top “Excellent” class. The University has partnerships with more than 150 educational institutions in 45 countries, particularly in North America, Asia and Latin America, as well as with all the countries in Europe. Some 12.6 percent of students in Tübingen come from abroad, and many of the University's German students pursue part of their studies in another country.

To learn more about the University of Tübingen visit *https://www.uni-tuebingen.de/en*.

7 Timetable

WEDNESDAY, 28TH OF SEPTEMBER 2016

13:00	Registration
14:00 – 14:15	Opening
14:15 – 15:00	**Linguistic influences on numerical cognition and arithmetic: Towards a taxonomy** *Hans-Christoph Nuerk*
15:00 – 15:45	**Categories in magnitude estimation of multidigit numerals** *David Landy*
15:45 – 16:15	Coffee Break
16:15 – 17:45	Poster Session A
17:45 – 18:30	General Discussion
19:30	Dinner for speakers

THURSDAY, 29TH OF SEPTEMBER 2016

9:00 – 9:45	**What determines individual differences in arithmetic fluency? The role of symbolic numerical processing (and domain-general factors)** *Bert de Smedt*
9:45 – 10:30	**Understanding atypical mathematical development: What counts for children born very preterm?** *Victoria Simms*
10:30 – 11:00	Coffee Break
11:00 – 11:45	**Neurocognitive investigation of arithmetic processing and learning during development** *Thomas Dresler*
11:45 – 12:30	**White matter matters: Neural correlates of domain-specific and domain-general number processing** *Elise Klein*
12:30 – 14:00	Lunch Break

THURSDAY, 29TH OF SEPTEMBER 2016

14:00 – 14:45	**Causal role of spatial-attentional mechanisms in solving arithmetical problems: Behavioural and neuropsychological evidence** *Nicolas Masson*
14:45 – 15:30	**Nobody really knows how much is 3 + 2** *Catherine Thevenot*
15:30 – 16:00	Coffee Break
16:00 – 17:30	Poster Session B
17:30 – 18:30	General Discussion
19:30	Dinner

FRIDAY, 30TH OF SEPTEMBER 2016

9:00 – 9:45	**From DOTS to DICE - Numerical processing and decision making** *Margarete Delazer*
9:45 – 10:30	**Non-spatial sensory and motor mappings in approximate number processing** *Oliver Lindemann*
10:30 – 11:00	Coffee Break
11:00 – 11:45	**Psychophysics framework to study numerical cognition** *Samuel Shaki*
11:45 – 12:30	Final Discussion
12:30	Snacks & End of Scientific Programme
13:25 – 15:00	Punting Boat Trip

8 Keynote Lectures

Linguistic influences on numerical cognition and arithmetic: Towards a taxonomy

Hans-Christoph Nuerk
University of Tübingen, Germany

One major domain-general influence on numerical cognition is the influence of language and linguistic properties, which seems to affect almost all tasks and representations. So far, much of this research has been demonstration research - it is usually demonstrated that some linguistic factor influences some task in arithmetic or numerical processing in some way at some age. In the current talk, I will try to categorize the different influences both on the linguistic and the numerical side systematically and show examples of how they were examined. Based on this research I will outline what we know and where there is still work left in the field. Finally, I will outline possible mechanisms on how language and linguistic properties can exert their influences on numerical tasks and possibly activation of numerical processes and representations.

Categories in magnitude estimation of multidigit numerals

David Landy
Indiana University Bloomington, United States of America

Despite their importance in public discourse, numbers in the range of 1 million to 1 trillion are notoriously difficult to understand. I will present research exploring the variety of common methods people use when interpreting these big numbers in laboratory, classroom, and political contexts. I will argue that culturally developed representations enable precise, fluid reasoning about quantities that seem to be otherwise conceptually inaccessible, but that these same representations lead to systematic errors. I will present data from a magnitude estimation task in which college undergraduates and adults place large numbers on a number line. Contrary to logarithmic models common in developmental psychology and economics, most patterns of errors and correct responses conformed to a surface strategy account. Participants placed 1 million approximately halfway between 1 thousand and 1 billion, but placed numbers linearly across each range. This pattern conforms to our number word system, which introduces special words up to 999, then recycles this system using scale words such as thousand, million, and billion. In a classroom study, we find that a short intervention has a lasting effect on how college undergraduates interpret federal budget cuts. Finally, we explore how large number interpretations may affect actual political outcomes by examining voter behavior. These results have direct implications for lawmakers and scientists hoping to communicate effectively with the public, as well as for educators; they also add to a growing literature suggesting that mathematical reasoning is continuous with reasoning about physical environments.

What determines individual differences in arithmetic fluency? The role of symbolic numerical processing (and domain–general factors)

Berd De Smedt
University of Leuven, Belgium

Being fluent and efficient in performing basic calculations has been regarded as an important building block for the development of mathematical skills. On the other hand, deficits in retrieving arithmetic facts from memory are the hallmark of children with dyscalculia. The ability to represent symbolic numerical magnitudes has been put forward as a major determinant of childrens general mathematics achievement. Does this factor then also contribute to the specific mathematical skills of arithmetic fluency, its development and its impairments? In this talk, I will present a series of recent cross-sectional and longitudinal studies in typically developing children, studies in children with dyscalculia and studies in children with genetic disorders all of which have investigated the role of numerical magnitude processing in the development of arithmetic fluency or the transition towards arithmetic fact retrieval. These studies also investigated the potential contributions of domain–general factors, such as working memory or inhibitory control. The key message from these studies is that particularly childrens symbolic magnitude processing skills are a unique and very stable predictor of childrens arithmetic (fact retrieval) development. These data all suggest that screening childrens symbolic processing skills is useful for detecting children at risk children and I will present data from a recent large-scale validation of such a screening measure.

Understanding atypical mathematical development: What counts for children born very preterm?

Victoria Simms
Ulster University, United Kingdom

Annually there are increasing numbers of children born very preterm ($<$ 32 weeks gestation) across the globe. As a group, these children present with a variety of cognitive, behavioural and academic difficulties (McKAy, Smith, Dobbie & Pell, 2010; Bhutta, Cleves, Casey, Cradock & Anand, 2002). Most strikingly, children born very preterm have particular difficulties with mathematics (Simms, Cragg, Gilmore, Marlow & Johnson, 2013). However, there is debate surrounding the underlying causes of these difficulties. In this talk I will discuss our research that has investigated the potential domain-general and domain–specific skills that may contribute to mathematical difficulties in this population. By utilising a wide range of measures these studies have attempted to inform our theoretical understanding of mathematical development and to assist in the targeting of interventions. I will highlight our key findings and also discuss methodological issues when working with children with atypical cognitive profiles.

Neurocognitive investigation of arithmetic processing and learning during development

Thomas Dresler
University of Tübingen, Germany

In adulthood, for most of us basic arithmetic processing just takes place rather effortless. This is the case because we acquire the specific skills during individual development and substantially improve their application by curricular education. Children, who do not succeed in this endeavor, will struggle with arithmetic throughout their life and further career. Therefore, knowledge about the underlying processes during development and learning is essential to provide appropriate remedies. Most neuroscientific knowledge on development of arithmetic stem from studies with adult samples and still little is known about whether these findings generalize to children. During recent years, research programs began to focus more on this blind spot in the field of numerical cognition. In this lecture, important findings from neurocognitive investigations of arithmetic development and learning in children will be presented and discussed regarding their relevance for educational neuroscience. In addition, ecologically valid methodological approaches will be introduced as one mean to bridge the gap between neuroscience and education.

White matter matters: Neural correlates of domain–specific and domain–general number processing

Elise Klein
Leibniz-Institut für Wissensmedien, Germany

To date, the majority of neuro-scientific studies was focused on identifying which cortical areas subserve specific cognitive functions. However, this approach has recently been criticized as corticocentric myopia, because it does not take into account that any given brain function depends on the integrity of a widespread network integrating cortical areas across the entire brain. Therefore, attempts to explain typical and atypical cognitive functioning have to combine (i) localized neural correlates of cognitive functions in circumscribed grey matter areas and (ii) the connectivity of these cortical areas via white matter pathways to other cortical and subcortical areas.

Causal role of spatial-attentional mechanisms in solving arithmetical problems: Behavioural and neuropsychological evidence

Nicolas Masson
University of Leuven, Belgium

Objectives: Recent findings suggest that mental arithmetic involves shifting attention on a mental continuum where numbers would be ordered from left to right, from small to large numbers, with addition and subtraction causing rightward or leftward shifts respectively. Neuropsychological data showing that brain-damaged patients with left neglect experience difficulties in solving subtraction but not addition problems support this hypothesis. However, the reverse dissociation is needed to establish the causal role of spatial attention in mental arithmetic. Method: We conducted a case study a 65-year-old left brain-damaged patient (JPB), exhibiting right unilateral visuo-spatial and representational neglect, was tested with various numerical tasks including numerical comparison, arithmetic problem solving and numerical interval bisection. Results: In numerical comparison, JPB showed a selective response latency increase when judging numbers larger than the references while his performance was normal for smaller numbers. In the arithmetic task, JPB was impaired in solving addition but not subtraction problems. In contrast, performance in number bisection suggests greater difficulties in keeping track of small numbers than large numbers. Conclusion: These results establish a double dissociation between subtraction and addition solving in patients with left vs. right neglect, and demonstrate clear evidence that attentional mechanisms are crucial for mental arithmetic. We suggest that attention shifts are involved whenever a number is represented relative to another on a mental continuum, be it during numerical comparison or arithmetic problem solving. His performance in numerical interval bisection indicates that this task measures other processes than those involved in number comparison and mental arithmetic.

Nobody really knows how much is 3 + 2

Catherine Thevenot
University of Geneva, Switzerland

Almost all researchers in the domain of numerical cognition consider that the answer of very simple addition problems such as 3 + 2 are retrieved from long-term memory by educated adults. Nevertheless, I will present some evidence suggesting that it might not be the case. Instead, such very simple problems could be solved by experts through the use of compiled and unconscious arithmetic procedures.

From DOTS to DICE - Numerical processing and decision making

Margarete Delazer
Medical University Innsbruck, Austria

Often we are confronted with risky decisions which require numerical understanding. For example, patients are asked to read, consider and eventually sign consent forms describing risks and benefits before undergoing treatment or participating in clinical research trials. Information material typically contains not only simple quantitative measures, but more complex concepts such as ratios, proportions, probabilities, risks or survival rates. Our research suggests that healthy people in advanced age have significant difficulties in understanding ratio or probability concepts. The difficulties are more pronounced in patients with mild cognitive dysfunction. Poor understanding of ratios may lead to disadvantageous decisions under risk. Indeed, our results indicate that executive functions and basic mental calculation capacities predict ratio processing and that ratio processing predicts decision making under risk. Poor understanding of ratio and probability concepts leads not only to less advantageous decisions, but also to enhanced framing effects in evaluating treatment options. A study with healthy young participants showed that individuals with above average mathematical competence performed better in decision making than individuals with average mathematical competence. Several objective measures of mathematical competence as well as the subjective rating of numeracy correlated with advantageous performance in decision making. Performance in decision making improved when individuals were encouraged to reflect about risks, gains, and losses. Differential effects were observed for average and above average mathematicians. Recent findings suggest that also neurological patients with mild cognitive deficits profit from numerical training and improve their decision making abilities.

Non-spatial sensory and motor mappings in approximate number processing

Oliver Lindemann
University of Potsdam, Germany

Number cognition research has been strongly influenced in the last two decades by the mental number line hypothesis. As a consequence, our current theoretical knowledge about the foundations of approximate number processing is mainly informed by experiments using spatial measurements and the interpretation of spatial effects in behaviour. Several number cognition theories, however, suggest that our 'sense of numbers' has been primarily shaped by direct non-spatial associations of number concepts with bodily experiences about size and magnitude.

I present different experiments that examine numerical and arithmetic processing by using non-spatial within-magnitude associations and demonstrate that established effects that are typically attributed to the spatial nature of number representations also emerge in absence of any spatial task demands. For instance, interactions between analogue magnitude codes and response features, as indicated by the SNARC effect, emerge even stronger and probably more reliable, if participants indicate their decisions in a number classification task by unilateral intensity-modulating responses, that is, by pressing or grasping an object with different motor forces. Reading numbers has been moreover found to impact directly the grip force that participants apply to passively hold an object. I finally demonstrate that also spatial effects in mental arithmetic, such the tendency to overestimate the outcomes of addition as compared to subtraction problems (so-called Operational Momentum effect) can be also observed in children and adults when employing a non-spatial sensory task such as numerosity productions. Taken together, I will argue that the reported experiments suggest that the semantic representation of numerical magnitudes is based on a non-spatial magnitude metric shared by perception, action and cognition.

Psychophysics framework to study numerical cognition

Samuel Shaki
Ariel University, Israel

Mental chronometry is one of the core paradigms of cognitive psychology. Indeed, most of the known effects in the field of numerical cognition were found by comparison between RTs of different conditions (distance effect; SNARC effect; range effect; Unit-decade compatibility effect etc.). Recently, however, classical psychophysical methods, such as 'magnitude estimation' and pseudo 'magnitude production' (pointing to location task) methods were used, revealing some novel effects (Operational momentum; Logarithmic to linear shift; Operand order effect; etc.). We revisited some of the above effects by using strict version of the psychophysical 'magnitude production' method, and observed surprising violations of different mathematical axioms on number meaning. In light of the findings, I will discuss different contextual factors influencing numerical and arithmetic processing.

9 Poster Presentations

Poster Session A – Wednesday, 28th of September 2016, 16:15-17:45

A1 - Following the finger: Studying mental representations of the number line
Anat Feldman & Andrea Berger

A2 - Incidental counting - Speeded number naming through finger movements
Elena Sixtus, Oliver Lindemann, & Martin H. Fischer

A3 - Personal sense of power influences magnitude estimation
Johannes Bloechle, Stefan Huber, Tanja Dackermann, Annika Scholl, Kai Sassenberg, & Korbinian Moeller

A4 - Stability of individual differences in number sense acuity during infancy
Elin Schröder & Marcus Lindskog

A5 - Sources of noise in the approximate number system
Cory D. Bonn & Véronique Izard

A6 - Stimuli size affects SNARC effect in preliterate children
Sarah Dolscheid

A7 - Magnitude or multitude: What counts more?
Martin Lachmair, Susana Ruiz Fernandez, Korbinian Moeller, Hans-Christoph Nuerk, & Barbara Kaup

A8 - SNARC and MARC over the Web - a large scale online study
Krzysztof Cipora, Mojtaba Soltanlou, Ulrich Reips, & Hans-Christoph Nuerk

A9 - First things first - first things 'right'? Prefrontal modulation with tDCS dissociates spatial associations of numerical and non-numerical sequences
Philipp A. Schroeder, Hans-Christoph Nuerk, & Christian Plewnia

A10 - An eye for mathematics: The visual system is retrained to see algebraic structure in notations
Tyler Marghetis, David Landy, & Robert L. Goldstone

A11 - Arithmetic processing: pupil dilation data
Maciej Haman & Katarzyna Lipowska

A12 - The effect of arrangement on enumeration speed and its early and sensory event related brain potentials
Shadi Akbari, Hartmut Leuthold, Mojtaba Soltanlou, Hassan Sabourimoghddam, Jalil Babapour, & Hans-Christoph Nuerk

A13 - Integration and distance effect between spoken number words and Arabic digits in a passive task - an EEG study
Chia-Yuan Lin & Silke Göbel

A14 - Neurophysiological changes during arithmetic learning in children
Mojtaba Soltanlou, Christina Artemenko, Thomas Dresler, Andreas J. Fallgatter, Hans-Christoph Nuerk, & Ann-Christine Ehlis

A15 - Whats behind a + sign? Neural bases and development of automated calculation procedures
Romain Mathieu, Justine Epinat-Duclos, Jessica Léone, Michel Fayol, Catherine Thevenot, & Jérôme Prado

A16 - Specialization of the right intraparietal sulcus for processing mathematics during development
Margot Schel & Torkel Klingberg

A17 - Parietal activation during approximate calculation tasks in left- and right-handed students assessed with functional near-infrared spectroscopy (fNIRS)
Maria Sitnikova, Christina Artemenko, Mojtaba Soltanlou, Julia Bahnmueller, Thomas Dresler, & Hans-Christoph Nuerk

Poster Session B – Thursday, 29th of September 2016, 16:00-17:30

B1 - Assessing finger-based versus rote verbal multiplication facts interventions - a pilot study
Avital Rotem & Rinat Nessing

B3 - Integrating SFON enhancement with computerized arithmetical training Pilot study
Minna Hannula-Sormunen, Anna Alanen, Jake McMullen, & Erno Lehtinen

B4 - Mathematics training to foster process based competencies? A randomized controlled trial.
Franziska Rebholz, Jessika Golle, Stefanie Rösch, Ulrich Trautwein, & Korbinan Moeller

B5 - Preschool mathematical skill profiles of prematurely and full-term born children
Cristina Nanu, Minna M. Hannula-Sormunen, Eero Laakkonen, Petriina Munck, & Pipari Study group

B6 - Differential influences of domain-general and domain–specific abilities on number line estimation in children with and without mathematical learning difficulties
Christin Schwenk, Tanja Dackermann, Korbinian Moeoller, & Jörg-Tobias Kuhn

B7 - Number development in ASD. A critical review
Erica Ranzato & Jo Van Herwegen

B8 - Are individual differences in arithmetic fact retrieval in children related to inhibition?
Elien Bellon, Wim Fias, & Bert De Smedt

B9 - Pre-school predictors of 6 year olds arithmetic skills: The importance of knowing your numbers
Stefanie Habermann, Chris Donlan, & Charles Hulme

B10 - Different aspects of spatial skills and their relation to early mathematics
Vronique Cornu, Caroline Hornung, Christine Schiltz, & Romain Martin

B11 - The co-development of working memory, intelligence and early numerical ability and their predictive roles in arithmetic word problem solving: A 3-year longitudinal study from kindergarten to elementary school
Finja Gallit, Anne Wyschkon, & Günter Esser

B12 - Children's understanding of relative magnitude: Domain–general or domain–specific improvement?
Elida V. Laski & Joanna Schiffman

B13 - Strategies in addition: An educational perspective
Pernille Bødtker Sunde

B14 - Reading and solving arithmetic word problems in children and adults
Gabriella Daroczy, Magdalena Wolska, Detmar Meurers, & Hans-Christoph Nuerk

B15 - Individual differences in spatial representations of fractions relate to basic math abilities but not algebra
Elizabeth Y. Toomarian & Edward M. Hubbard

B16 - Contribution of domain-general factors in complex multiplication in adults: Role of planning and self-control

Parvin Nemati, Johanna Schmid, Mojtaba Soltanlou, Julian-Till Krimly, Hans-Christoph Nuerk, & Caterina Gawrilow

9.1 Poster Session A

A1 - Following the finger: Studying mental representations of the number line

Anat Feldman, Andrea Berger

Department of Psychology, Ben-Gurion University of the Negev, Israel

The development and maturation of the mental number line (MNL) are highly necessary processes for learning basic mathematical concepts. Researchers show that the individual differences in numerical processing skills are predictive of later arithmetic achievements (e.g., De Smedt, 2009; Desoete, 2012; Laski, 2014; Sasanguie, 2013; Vanbinst, 2015). We investigated mental number line representations using a number-to-position task implemented on a touchscreen. This task continuously monitors the participants finger , from the moment the number appears on the screen to its final placement on a number line. This paradigm allows us to follow the entire cognitive process that guides participants in determining where to place a number at a particular location on an external physical number line. This study aims to understand the translation process from the basic mental number line representation to the external visual number line and the developmental changes during the elementary school years. This understanding will create the basis for further research on mathematical abilities. Our experiment included 154 children from 2nd to 6th grade. To prevent any location biases, we presented a list of numbers equally distributed on the number line. Consistent with the literature, our results showed developmental trends of the endpoint distributions, indicating a logarithmic to a linear shift of mental representation of numbers (Siegler, 2003). Moreover, by following the traceable finger trajectories, we could observe diverse patterns of translation paths for different numbers.

A2 - Incidental counting - Speeded number naming through finger movements

Elena Sixtus, Oliver Lindemann, Martin H. Fischer

University of Potsdam, Germany

BACKGROUND: Opinions differ on the question whether finger counting in children is a habit to be encouraged or to be avoided as soon as possible. In any case, the first numerical steps are usually done in conjunction with fingers. Following the assumption that abstract concepts stay associated with the sensory-motor information that was present during their acquisition and consolidation, mental number representations should always be associated with the respective finger counting components. We tested whether finger movements that imply finger counting actually prime the corresponding number concepts.
METHOD: As is usual in Western finger counting, all 30 adult participants from our sample showed number 1 with the thumb, sequentially ascending until showing number 5 with the pinkie. Thus, these constitute congruent finger-number pairs. In the experiment, participants pressed five buttons sequentially and repeatedly from thumb to pinkie, thus implying finger counting movements. Following each button press, a random number between 1 and 5 appeared on the computer screen, resulting in 20% congruent and 80% incongruent finger-number mappings. Participants named all numbers.
RESULTS: Naming latencies were shorter for congruent than incongruent finger-number combinations. The study thereby provides further evidence that number representations are strongly associated with finger counting experience. This persistent association indicates that fingers are an effective tool for understanding numbers. This novel finding has implications for math education.

A3 - Personal sense of power influences magnitude estimation

Johannes Bloechle, Stefan Huber, Tanja Dackermann, Annika Scholl, Kai Sassenberg, Korbinian Moeller

Leibniz-Institut für Wissensmedien, Tübingen, Germany

Recent findings on action-specific-perception indicate that our perception of the physical world is influenced by inter-individual traits and situated states associated with our ability to act on the physical environment. Social power is per definition characterized by differences in the opportunity for action. Individuals who experience high power have control over resources and thus a wide scope of action, whereas lack of power is characterized by restricted opportunity for action. In line with the action-specific-perception account, it was demonstrated that social power influences the way we perceive the physical environment. Individuals who experience social power perceive a loaded box to be physically lighter than individuals who experience a lack of social power. Although there is clear evidence that magnitude estimation is influenced by perceived social power, numerical cognition research has neglected this phenomenon so far. The present study therefore took a first step to investigate whether perceived social power affects magnitude estimation in a line length production task. Our results indicated that experiencing low social power lead to an overestimation of physical line length when strategies cannot be applied, whereas experiencing high social power resulted in a smaller estimation bias. This confirms the suggestion that social power alters not only the perception of physical magnitudes but generalizes to numerical ones. Moreover, high (compared to low) social power seems to help people to overcome biases in estimating magnitudes.

A4 - Stability of individual differences in number sense acuity during infancy

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Humans and other animals have an intuitive sense of number (Dehaene, 1997), supported by an approximate number system (ANS). Previous studies in children and adults have found individual differences in the precision of the ANS, which correlate with mathematics performance (Halberda et al., 2012). However, little is known about individual differences in the ANS in infancy. In the current study we aimed at a fine grained analysis of individual differences in numerical discrimination during infancy by adopting a method which tests infants at multiple levels of difficulty, similarly to methods used to determine discrimination thresholds in adults and older children. Using eye-tracking, 96 infants were tested on a numerical change detection paradigm. The task was administered at three difficulty levels, determined by the ratio between the two alternating numerosities (1:4, 1:2 and 2:3). Infants were tested on all three ratios both at 6- and 10-months of age. Preference scores were calculated by dividing looking time to the numerically changing stream by the total looking time to both streams. Results showed that only preference scores on the most difficult ratio (2:3) at 6 months could predict numerical discrimination preference scores on the same ratio at 10 months, indicating that stability in individual differences is primarily found on ratios that are more difficult (2:3), possibly due to better discriminability of the test at this ratio. We also find stability in infants discrimination profiles, as indexed by the slope of the preference scores across the three ratios, between 6- and 10-months of age.

A5 - Sources of noise in the approximate number system

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Humans and many other non-human animals can estimate the number of objects in auditory and visual scenes. Individual differences in the accuracy of this noisy number sense are thought to affect levels of success in understanding mathematical concepts in early childhood and continue to predict performance on standardized measures of mathematical ability into adulthood. However, what exactly contributes to noise levels remains unspecified: dot arrays, which are usually used to test approximate-number acuity, are a complex stimulus which could be subject to variable processing limitations at multiple levels of the visual hierarchy. We report results from an ongoing project probing how experimenter-controlled stimulus noise affects approximate numerical discrimination in adults. In one set of experiments, we show that blurring the stimulus at low intensities produces a small deficit, indicating a role for early visual processing mechanisms in contributing to accurate numerical estimation, consistent with recent studies from other labs. In addition, with blurs of increasing intensity, subjects begin to rely more heavily on (and be misled by) cues that are usually correlated with number, such as total surface area, despite the fact that they do not reliably correlate with number across trials in the experiment. Another experiment in which we manipulated the variability of the distribution of dot sizes revealed a more complex pattern of results. Averaging across trial types, increased dot size variance seems not to affect numerical estimation, but in fact size variance may help or hinder estimation depending on the density of the scene.

A6 - Stimuli size affects SNARC effect in preliterate children

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There is evidence that adults and children associate numbers and horizontal space (i.e. larger numbers with the right, smaller numbers with the left side). This association has often been demonstrated by the so-called SNARC-effect (Spatial-Numerical Association of Response Codes), in which participants respond faster to larger numbers with their right hand and to smaller numbers with their left hand. A SNARC-like effect has also been reported for preliterate children. However, the question arises whether this effect can solely be attributed to numerosity or whether other factors such as physical size of the stimuli also play a role. To find out, we tested preschoolers in a non-symbolic number comparison task. Children had to indicate which side contained more dots by pressing the corresponding button (left vs. right). On half of the trials, the larger set of dots took up more total surface area (area correlated trials), and on the other half, the smaller number of items had more total surface area (area anti-correlated trials). Our results reveal SNARC-like effects only for congruent (i.e. area-correlated) trials, suggesting that preschoolers associations between horizontal space and number may be biased by size information (i.e. the amount of surface area). These findings hint at the possibility of common mechanisms between space, number and size in preliterate children.

A7 - Magnitude or multitude: What counts more?

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Recent studies indicated that processing high or low numbers (9,1) interacts with the subsequent processing of words referring to entities typically found in upper or lower space (e.g. Dach/roof, Wurzel/root). It was argued that this interaction of numbers and words related to vertical space is due to overlapping spatial representations which are grounded on general physical constraints like gravity. Moreover, another line of research revealed an association of grammatical number (denoted by the flexion of a word) and physical space: singular words were associated with the left whereas plural words were associated with the right side of space. This resembles spatial-numerical associations of low numbers to the left and high numbers to the right. The present study aimed at integrating both lines of research: in a lexical decision task, participants were presented with pairs of a numerical cue (2,3,8,9) and a subsequent plural noun. For spatially related nouns (e.g., Dächer/roofs, Wurzeln/roots) numbers were expected to serve as spatial cues due to their magnitude. For spatially neutral nouns (e.g., Tische/tables) numbers were expected to cue multitude. Results showed the expected congruency-effect between numbers and spatially related nouns with faster reaction times for congruent number-word pairs (2,3/down-word, 8,9/up-word) compared to incongruent number-word pairs (2,3/up-words, 8,9/down-words). However for spatially neutral plural nouns no effect of number has been found. This seems to indicate that the representation of words related to vertical space is related closer to the magnitude of numbers than grammatical number is to the multitude reflected by numbers.

A8 - SNARC and MARC over the web - a large scale online study

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The aim of the presented study was to replicate Spatial-Numerical Association of Response Codes (SNARC) and Markedness of Response Codes (MARC) effects in an online setting and to replicate relationships between these phenomena and other factors that are reported in the current literature. We also tested for several domain–specific and domain-general factors, which may influence these effects. Complete data was available from 1056 participants.
We observed robust SNARC and MARC effects on the group level. We also replicated that the strength of the SNARC effect increases with increasing reaction time and intra-individual variability in reaction times.
Further analysis revealed a significant effect of starting-hand for finger counting, with left starters showing a larger SNARC effect. Surprisingly, contradictory to some previous studies, the SNARC was not related to reported age, gender, math grade, field of study, educational level, handedness, and reading direction. The large power we achieved by conducting the experiment online allow us to firmly draw this conclusion.
The MARC effect correlated with mean reaction time and intra-individual variability in reaction times. It was more pronounced in individuals who start a finger counting sequence with their right hand. It was marginally stronger in males compared to females. The MARC effect was reversed in left-handed individuals. It was also smaller in participants who use a right-to-left script.
Overall, these findings show that the SNARC and MARC effects are robust and can be investigated in online experiments. Furthermore, the results suggest that

sources of individual variability in these phenomena need to be further investigated, and call for further replication efforts.

A9 - First things first - first things 'right'? Prefrontal modulation with tDCS dissociates spatial associations of numerical and non-numerical sequences

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The working memory (WM) account of the SNARC effect proposes binding of sequence positions to a spatial template. For different sequences, early positions facilitate left-hand and late positions facilitate right-hand responses (and they interfere in opposite combinations), which produces response patterns similar to the SNARC effect with number symbols. Thus, recently, it was proposed that the representation of numerical quantity could be grounded in the processing of sequential order. With the current study, this proposal is investigated by modulations of prefrontal activity concurrent to SNARC tasks with different numerical and non-numerical sequential stimuli (e.g., numbers and weekdays). In sharp contrast to a general WM account, by administration of transcranial direct current stimulation (tDCS) to the left prefrontal cortex, we here demonstrate that increasing prefrontal activity can reverse the mental alignment of the weekday sequence, but concurrently results in an opposite aggravation of the left-to-right mental number line, corroborating our previous research on SNARC. Moreover, the polarity-dependent neuromodulation effects appear to be highly susceptible to manipulations of conceptual saliency in different order and number tasks. Whereas a WM account of spatial associations from order representations is bolstered by this malleability in general, a unified neurocognitive mechanism does not resolve the differential modulation effects. In addition, stimulation effects are barely correlated for different stimuli in the same participants. Therefore, the study challenges current conceptualizations on the neurocognitive entanglement of order and number, and unified working memory accounts of spatial-sequential processing.

A10 - An eye for mathematics: The visual system is retrained to see algebraic structure in notations

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Formal mathematics is a paragon of abstractness. It thus seems natural to assume that the mathematical expert should rely more on symbolic or conceptual processes, and less on perception and action. We argue instead that mathematical proficiency relies on perceptual systems that have been retrained to implement mathematical skills. Specifically, we investigated whether the visual systemin particular, object-based attentionis retrained so that parsing algebraic expressions and evaluating algebraic validity are accomplished by visual processing. Object-based attention occurs when the visual system organizes the world into discrete objects, which then guide the deployment of attention. One classic signature of object-based attention is better perceptual discrimination within, rather than between, visual objects. The current study reports that object-based attention occurs not only for simple shapes but also for symbolic mathematical elements within algebraic expressionsbut only among individuals who have mastered the hierarchical syntax of algebra. Moreover, among these individuals, increased object-based attention within algebraic expressions is associated with a better ability to evaluate algebraic validity. These results suggest that, in mastering the rules of algebra, people retrain their visual system to represent and evaluate abstract mathematical structure. We thus argue that algebraic expertise involves the regimentation and reuse of evolutionarily-ancient perceptual processes. Our findings implicate the visual system as central to learning and reasoning in mathematics, leading us to favor educational approaches to mathematics and related STEM fields that encourage students to adaptnot abandontheir use of perception.

A11 - Arithmetic processing: pupil dilation data

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Operational Momentum (OM) is a tendency to overestimate the results of addition and underestimate the results of subtraction [1]. It is believed to be one of the forms of space-number associations, as it may be explained as an effect of moving along mental numberline [2].

In this study, we investigate factors influencing arithmetic processing, using pupillometry. Pupil size has been shown to increase more for more difficult tasks [3] and is related to attentional processes. For that reason, pupillometry may provide insight into OM.

The following were included in the study design:

- direction of operands' motion: left-to-right, right-to-left;
- type of operation conducted: addition, subtraction;
- type of result: underestimated, correct, overestimated and
- speed: quick (400 ms), slow (800 ms).

Forty adults were tested with a Tobii TX-300 eye-tracker. The stimuli presented consisted of overall 324 operations on two-digit numbers. Participants reacted to incorrect results by pressing SPACE. The results indicate that change in pupil dilation is influenced by type of result and speed of presentation in interactions with type of operation and direction of operands motion, respectively.

1. McCrink et al. (2007). Perc. & Psychophysics, 69 (8), 1324-1333.
2. Thornton, I. M., & Hubbard, T. L. (2002). Visual Cognition, 9(1-2), 1-7.
3. Porter, G., et al. (2007). Quarterly Journal of Experimental Psychology, 60(2), 211229."

A12 - The effect of arrangement on enumeration speed and its early and sensory event related brain potentials

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Counting performance is influenced by visual characteristics of the sets counted. This suggests that counting is not a skill independent of perceptual characteristics and resulting strategies. We investigated the effect of arrangement on enumeration speed and early event related potential (ERP) processing components (<300 ms) to address two main questions: first, how arrangement affects enumeration speed and second, whether any stage of early processing will take effect of arrangement differences? ERPs were recorded from 37 healthy participants enumerating dots in irregular and two different types of regular arrangements which differed in the shape of their illusory dot lattices while proximity and sparsity were controlled. According to our results, enumeration speed is affected by both the arrangement and the set magnitude. Irregularity and the ambiguity of lattices caused slower enumeration. In addition, the amplitude of the parietal N2 component was larger for irregular than regular arrangements which had more stable lattices, whereas sensory P1 and N1 components were not affected. We suggest that a regular lattice formation facilitates grouping and subsequent subitizing. This in turn accelerates the enumeration process, whereas ambiguity in lattice formation slows it down. Based on P1 and N1 results, we conclude that arrangement effects do not arise at the level of early sensory processing. By contrast, we assume that present arrangement effect observed in N2 component, reflects the extent of subsequent but still early visual-cognitive processing during enumeration, affected by this complex

characteristic of visual stimuli.

A13 - Integration and distance effect between spoken number words and Arabic digits in a passive task - an EEG study

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Arabic digits and spoken number words are commonly used to communicate numerosities. This study investigated the relationship between these two codes in adults with a passive task. We recorded participants brain responses with EEG while they completed a computerised oddball paradigm. In the auditory condition, only spoken number words (e.g. /five/) were presented. During the audiovisual condition, number words were presented auditorily and Arabic digits (e.g., 5) were presented visually. In each condition the standard (/five/) was presented 400 times and the deviant 96 times. Half of the deviants were numbers with large (/one/, /nine/), half with small (/four/, /six/) numerical distance. Participants were instructed to perform a categorisation task when a picture was displayed on screen by pressing corresponding keyboard buttons, but not to numerical stimuli. Our analyses focused on the amplitude of mismatch negativity (MMN, around 170 ms) in audiovisual and auditory conditions for investigating integration (Froyen et al. 2008), and the peak latency for small and large distances for studying distance effect. The results showed that the audiovisual condition was found a more negative MMN amplitude than the auditory condition. A faster peak latency was found in large distance than in small distance. These results suggest that: Firstly in adults cross-format integration happens in an early component (MMN). Secondly the meaning of numerical stimuli is processed earlier for large distance than small distance. As a passive task was used in the current experiment, this result supports that the semantic processing of numerical symbols is automatic.

A14 - Neurophysiological changes during arithmetic learning in children

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Studies in adults revealed neurophysiological activation changes after short-time arithmetic learning. These changes have been indicated by increases in theta and lower alpha bands in oscillatory electroencephalography (EEG) studies. However, it is still unclear whether these findings can be generalized to children, the time that we learn most of our mathematical knowledge.
To address this question, 24 typically developing children solved multiplication problems repeatedly for six times in one training session against computer, while ongoing EEG was recorded from 21 electrodes covering the whole brain.
Behavioral data revealed that the performance of children improved after six repetitions. They made fewer errors, while their response time did not change. The oscillatory EEG indicated increased power of theta (4–7 Hz) and lower alpha (8–10 Hz) bands, which were more dominant in posterior sites. No significant effect was observed in the upper alpha band (10–13 Hz).
The findings demonstrate similar neurophysiological changes in children via arithmetic training compared to previous arithmetic training studies in adults. The increased power of theta and lower alpha subserve as a function of shift from slow procedural strategies to fast compact procedural strategies, which lead to more efficient performance after a short training in children. We conclude that increased theta power is associated to domain-general demands of procedural and retrieval

strategies using in arithmetic problem solving and increased lower alpha power is associated with reduction of cognitive work load.

A15 - Whats behind a "+" sign? Neural bases and development of automated calculation procedures

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It is well admitted that adults solve single-digit addition and multiplication by fact retrieval. Recent behavioral studies have challenged this idea by suggesting that retrieval would be restricted to multiplication. Addition may instead be solved by means of fast and automated calculation procedures. These studies proposed that such procedures would be activated by the simple presentation of the addition sign. These studies make the hypotheses that (1) the neuro-cognitive mechanisms underlying automatized procedures should be activated by the simple preview of a "+" sign in adults and that (2) these automatic activation associated to the arithmetic sign should appear over development with the increasing efficiency in mental arithmetic. Here, we used fMRI to test these hypotheses. Adults and children from 8 to 15 years were presented with single-digit additions and multiplications. In order to isolate activity associated with the arithmetic sign, we included trials during which only an arithmetic sign was presented (+ or x). In adults, we found that the simple presentation of a "+" sign (compared to a "x") recruited brain regions of the PSPL, FEF and MOG, overlapping with the dorsal attention network identified in an independent localizer. This suggests that addition signs are associated with automatic activation of procedures that may be spatial in nature. In children, the right hippocampus was increasingly recruited in response to a "+" sign as a function of grade. We propose that the hippocampus might play a transient but crucial role in the acquisition of math fluency by supporting the automatization of calculation procedures.

A16 - Specialization of the right intraparietal sulcus for processing mathematics during development

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Mathematical ability, especially perception of numbers and performance of arithmetics, is known to rely on the activation of intraparietal sulcus (IPS). However, reasoning ability and working memory, two highly associated abilities also activate partly overlapping regions. Most studies aimed at localizing mathematical function have used group averages, where individual variability is averaged out, thus confounding the anatomical specificity when localizing cognitive functions. Here, we analyze the functional anatomy of the intraparietal cortex by using individual analysis of subregions of IPS based on how they are structurally connected to frontal, parietal and occipital cortex. Analysis of cortical thickness showed that the right anterior IPS, defined by its connections to the frontal lobe, was associated with both visuospatial working memory and mathematics in 6-year-old children. This region specialized during development to be specifically related to mathematics, but not visuospatial working memory in adolescents and adults. This could be an example of interactive specialization, where interacting with the environment in combination with interactions between cortical regions leads from a more general role of right anterior IPS in spatial processing, to a specialization of this region for mathematics.

A17 - Parietal activation during approximate calculation tasks in left- and right-handed students assessed with functional near-infrared spectroscopy (fNIRS)

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Functional asymmetry can be considered as one of underlying factors that can influence different cognitive abilities. The most transparent type of the asymmetry reported in human beings is handedness. Left-handed individuals fall within the normal range of human diversity: they represent from 10-12% of healthy human population. Neurocognitive differences between left- and right-handers exist, but were systematically investigated mostly in language studies. Here, we examine whether such differences also exist in arithmetic processing of basic operations by means of functional near-infrared spectroscopy (fNIRS). 33 left-handed native German-speaking students performed approximate calculation tasks (verifying between two solutions) and were compared to 31 right-handed students from an earlier study. Tasks included addition and subtraction (without and with carry/borrow operation, respectively) and varied in difficulty level. The results showed statistically significant increased activation in right superior parietal areas in left-handers and in left superior parietal areas in right-handers for small and large addition problems. However, for small and large subtraction increased activation in left inferior parietal areas in left-handers and in right inferior parietal areas in right-handers was observed. The activation differences suggest that the neurocognitive

foundations of arithmetic processing differ for left- and right-handers. Given the usual sample characteristics (most or all right handers), this implies that our neurocognitive models of number processing may be true for right-handers but not or less for left-handers.

9.2 Poster Session B

B1 - Assessing finger-based versus rote verbal multiplication facts interventions - a pilot study

Avital Rotem

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Eighteen fourth graders with arithmetic deficiencies (AD) participated in a pilot multiplication facts intervention program for six weeks. Six participants learned a multiplication finger-based trick, six participants practiced the 10 x 10 multiplication table by rote verbal learning, and six participants were an AD business as usual control group. Participants were tested pre- and post-intervention. In addition, the two intervention groups were also tested a month and a year after the intervention terminated, and were verbally tested every week during the intervention. Typically achieving second, third and fourth graders were also tested before the beginning of the intervention and their results served as an age-typical performance reference. Both intervention groups improved in multiplication accuracy. Nevertheless, the improvement in the finger-trick participants was larger than in the rote-verbal participants, especially on difficult problems (i.e., problems with at least one operand $>$5). Interestingly, their accuracy kept improving after the intervention was terminated and informal observations showed that their motivation increased, too. The finger trick completely replaced other (less efficient) procedural solving strategies. These results suggest that integrating finger-based strategies in math education may improve arithmetic facts in children with arithmetic deficiencies. Yet, the current study was a pilot study, so it should be examined with larger samples of participants.

B3 - Integrating SFON enhancement with computerized arithmetical training a pilot study

Minna Hannula-Sormunen, Anna Alanen, Jake McMullen, Erno Lehtinen

University of Turku, Finland

This study is based on previous studies demonstrating substantial individual differences in childrens own spontaneous focusing on numerosity (SFON) suggesting that the quantity and quality of childrens own numerical activities can make a difference in the development of numerical skills from early childhood to the end of primary school (e.g., Hannula & Lehtinen, 2005). Providing deliberate variation in the aspect of number occurring in everyday surroundings can be an effective way of enhancing childrens focusing on numerosity and subsequent development of numerical skills (Hannula, Mattinen & Lehtinen, 2005). The bodily experience of numbers and number combinations has been successfully promoted in a computer game Fingu, which aims at developing childrens awareness of arithmetical combinations of numbers from one to ten (Lindström et. al., 2012) In the current pilot study, we created activities that bridge the skills trained in the computer game with childrens everyday activities and investigate whether childrens arithmetical skills and their SFON tendency develop as a result of a four week intensive playing of Fingu iPad game integrated with everyday activities and SFON enhancement. Participants were 15 children (7 pre-kindergartners and 8 kindergartners) in a private daycare centre and an age- and skill-matched group of 15 children from two other private daycare centres in the same neighborhood in Finland. A quasi-experimental design with a 4-week training and business as usual control group and pre-, post-, and delayed post-tests following the training after three months was used. The results of pre- and post-tests show a clear developmental advantage for the training group over the control group in arithmetical skills. It can be concluded that an intensive period of SFON enhancement integrated with arithmetic training in a computer game and everyday activities seems like a promising and motivating mathematics learning environment for kindergartners.

B4 - Mathematics training to foster process based competencies? A randomized controlled trial.

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In numerical cognition research there is an ongoing debate on the influence of domain-general and domain–specific numerical factors to numerical development. Interestingly, this differentiation is somewhat reflected in official mathematical education plans of Germany which distinguish between process- and content-related competencies. In the present study we evaluated the effectiveness of a mathematics training that focused on promoting process-related competencies (e.g., problem solving and communication) in elementary school mathematics. As part of an extracurricular enrichment program the intervention consisted of 8 modules, each designed for a 90 minutes session, and targeting topics such as combinatorics or logicals. To evaluate the effectiveness of the training a randomized controlled trial was used. Data of 97 3rd and 4th Grade students were collected (68 male, age: M = 8.79, SD = .69, control group N = 45, training group N =52). To assess training effects on content-related competencies we used a standardized test of basic arithmetic operations. Training effects on process-related competencies were measured by childrens performance in the German Mathematical Olympiad. Furthermore, we assessed additional control variables such as school grades, general cognitive abilities, self-concept or interest in mathematics. In line with the goal of our training, results indicated significant effects of our training on childrens process-related competences whereas there were no effects on childrens content-related competences. In sum, this indicated that effects of a training of process-related competencies, which resemble the idea of domain-general abilities, does not necessarily generalize to content-related, and thus, domain–specific competences such as arithmetic performance.

B5 - Preschool mathematical skill profiles of prematurely and full-term born children

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Preterm birth is associated with low mathematical skills. This study on five-year-old Finnish children investigated whether mathematical skill profiles would differ between prematurely and full-term born children and how such profiles and other cognitive skills would be related. Mathematical skills included digit knowledge, spontaneous focusing on numerosity, arithmetic, counting and geometric skills. The investigated cognitive skills were phonological processing, working memory, instruction comprehension, speeded naming, inhibition and visuomotor skills. The participants were 119 preterm children with very low birth weight and 100 full-term born children. The results showed these groups differences in both number and shape of latent mathematical skill profiles, indicating quantitative and qualitative disparities. After controlling for gestational weeks and maternal education, phonological processing, visuospatial working memory, speeded naming and inhibition were associated with prematurely born childrens five mathematical profiles. Among full-term born children, only phonological processing and verbal working memory were related to their three mathematical profiles.

B6 - Differential influences of domain-general and domain-specific abilities on number line estimation in children with and without mathematical learning difficulties

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Performance in number line estimation (NLE) was shown to be associated with arithmetic competencies. In particular, children with mathematical learning difficulties (MLD) were repeatedly observed to present with lower estimation accuracy compared to typically developing controls. Recent research suggested that this performance difference may be due to less developed estimation strategies. We evaluated this hypothesis in a sample of 123 children (MLD: n = 42) from second to fourth grade. Inspection of childrens NLE performance revealed higher estimation errors in MLD children but indicated no differences in the usage of proportion-based estimation strategies. We conducted separate stepwise regression analyses for typically and atypically developing children to differentiate between influences of basic numerical/arithmetic and domain-general abilities on childrens NLE performance. Results indicated that NLE performance in typically developing children increased with increasing working memory capacity, age, attention and basic numerical abilities (R=.54), whereas the final model for children with MLD only considered working memory and attention (R=.48) as significant predictors. Subsequent analyses substantiated the finding that only for typically developing children basic numerical/arithmetic abilities were associated with NLE performance. Taken together, our results indicate that children with MLD also seem to use proportion-based strategies in NLE. However, the missing association between their basic numerical/arithmetic abilities and their NLE performance suggests that they may not be able to recruit these domain–specific abilities when applying proportion-based strategies. Results rather suggest that for children with MLD domain-general processes such as working memory and attention seem to be crucial for solving the NLE.

B7 - Number development in ASD. A critical review

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Autism Spectrum Disorder (ASD) is a common neurodevelopmental syndrome characterised by two core impairments in communication or social behaviour and repetitive behaviours from early childhood onwards. Although mathematical abilities are a basic skill important in all aspects of live, including job opportunities, research on mathematical abilities in ASD is sparse. ASD has often been associated with superior mathematical ability and incredible feats of rapid numerical estimation, and indeed some individuals with ASD have shown extraordinary powers of calculation and mathematical reasoning (Howlin et al., 2009; Treffert, 2009; Baron-Cohen et al., 2007). Other studies have documented mathematics as an area of relatively spared or even enhanced performance in a large proportion of individuals with ASD (Luculano et al., 2014; Jones et al., 2009; Wei et al. 2015). However, clinical practice, teachers and therapists often consider mathematics as one of the difficult subject matters for children with ASD (Department for Education and Skills, 2001). In this study we present a systematic review of the research to date on number abilities in ASD. Our analysis indicates that (1) most of the studies focus on domain–specific skills, such as counting and digit knowledge, but not on domain–general abilities that have been found to predict number abilities in typically developing populations, (2) studies show a conflicting pattern of results. Our findings also demonstrate a lack of studies investigating both number foundations and the influence of environmental factors on mathematics abilities. This review will highlight directions for future studies on number development in ASD.

B8 - Are individual differences in arithmetic fact retrieval in children related to inhibition?

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Executive functions (e.g., inhibition) play an important role in scholastic learning, such as mathematics. Although it has been proposed that inhibition is related to individual differences in mathematical achievement, it is not clear how it is related to specific aspects of mathematical skills, such as arithmetic fact retrieval. However, such association can be theoretically postulated, as incorrect but competing answers have to be inhibited during fact retrieval, since arithmetic facts are stored in an associative network in semantic memory. The present study therefore investigated the association between inhibition and arithmetic fact retrieval and further examined the unique role of inhibition in individual differences in arithmetic fact retrieval, in addition to numerical magnitude processing. We administered measures of cognitive and behavioural inhibition, as well as numerical magnitude processing and arithmetic fact retrieval in 86 typically developing third graders. We used correlational, regression and Bayesian analyses. This study failed to observe a significant association between inhibition and arithmetic fact retrieval. Consequently, our results did not reveal a unique contribution of inhibition to arithmetic fact retrieval in addition to numerical magnitude processing. On the other hand, symbolic numerical magnitude processing turned out to be a very powerful predictor of arithmetic fact retrieval, as indicated by both frequentist and Bayesian approaches.

B9 - Pre-school predictors of 6 year olds arithmetic skills: The importance of knowing your numbers

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We present the results of a new multivariate 20-month longitudinal study examining the precursors of early arithmetic skills in English-speaking children beginning when children were 4 years of age. The study focuses on measures of the approximate number sense (ANS), language comprehension and knowledge of the Arabic numeral system in particular.

Structural equation path models, investigating the predictive importance of cognitive, numeracy and language abilities, confirmed knowledge of the Arabic numeral system at 4 years as a powerful long-term predictor of the growth in addition as well as subtraction skills. However, neither language comprehension nor variations of the approximate number sense played an additional role in predicting childrens performance of early arithmetic skills. These results suggest that childrens understanding of Arabic numeral system and their ability to translate between numerals and verbal codes may be of critical importance when it comes to early arithmetic skills.

The presented findings will provide valuable information contributing to developmental and educational perspectives on language and numeracy which may help to create intervention programs and aid the development of a screening tool for being at risk of early numeracy deficiencies.

B10 - Different aspects of spatial skills and their relation to early mathematics

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We aimed at investigating the predictive role of spatial skills for arithmetic and number line estimation in kindergarten children (N = 125). Several studies report a relation between spatial skills and mathematics. However, due to their non-unitary nature, different aspects of spatial skills need to be differentiated to clarify the relative importance of different aspects of spatial skills for mathematics. In the present study, at time 1, a spatial perception task, a spatial visualization task and visuo-motor integration task were administered to assess different aspects of spatial skills. Furthermore we assessed domain–specific skills and verbal domain-general skills. Four months later, the same children performed an arithmetic task and a number line estimation task to evaluate how the abilities measured at time 1 predict early mathematics. Hierarchical regression modelling revealed that childrens performance on the spatial perception task was predictive of their performance in both arithmetic and number line estimation, whereas visuo-motor integration and knowledge of the Arabic numerals significantly predicted arithmetic. The predictive relation between spatial perception and arithmetic was partially mediated by the number line estimation task. Our findings emphasize the role of spatial skills, notably spatial perception, in mathematical development. These results reveal the importance to differentiate within the construct of spatial skills when studying their role for numerical development. The development and implementation of pre-school interventions fostering childrens spatial perception and visuo-motor integration might thus be a promising approach for providing children with a sound foundation for later mathematical learning.

B11 - The co-development of working memory, intelligence and early numerical ability and their predictive roles in arithmetic word problem solving: A 3-year longitudinal study from kindergarten to elementary school

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There is ample evidence for the predictive roles of domain-general cognitive abilities such as working memory and intelligence in later arithmetic word problem solving. However, some previous studies might have overestimated their influences, because early numerical knowledge has not been considered simultaneously. Moreover, it is still not clear whether and to which extent these variables might influence each other during their early development. Therefore, the aims of the present longitudinal study are 1) to examine the predictive roles of domain-general cognitive abilities and early numerical knowledge in later arithmetic word problem solving and 2) to investigate the cross-lagged relations of those predictors during kindergarten. The current study is based on data from a large epidemiological longitudinal study (called SCHUES) that had its outset in 2011. We tested about 1,900 children on working memory, intelligence and early numerical knowledge two years before entering elementary school and at their last year of kindergarten. The same children were tested again on word problem solving ability at their first year of elementary school. Preliminary results reveal that at the last year of kindergarten each predictor is related to word problem solving ability. Even two years before the school entry working memory and early numerical knowledge show direct effects on later word problem solving. In addition, our results support the view of a mutual influence between domain-general cognitive abilities and early numerical knowledge.

B12 - Children's understanding of relative magnitude: domain-general or domain-specific improvement?

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Childrens understanding of numerical magnitudes is crucial for their mathematics performance and future math learning. Children make accurate judgments of numerical magnitude in small numerical ranges before they do so in larger numerical ranges. This study examined whether this developmental change reflects increasing experience with larger numbers or an increasing understanding of scale. A within-subjects design was used in which kindergartners (N = 18; mean age = 6.17, SD = .38), first graders (N = 21; mean age = 7.01, SD = .30), and second graders (N = 23; mean age = 8.15, SD = .40) completed two categorization tasks: numerical categorization and circle categorization. In the numerical categorization task, children categorized numbers within three numerical scales (0-to-20, 0-to-50, and 0-to-100) as low, medium, or high. In the circle categorization task, children categorized circles as small, medium, or big within the same three scales (0-20in, 0-50in, and 0-100in). The dimensions of the circles were proportionally equivalent to the numerical stimuli used in the numerical categorization task. Results revealed no differences between childrens accuracy on number and circle categorization on the 0-20 scale. There were also no grade differences in childrens accuracy on the 0-20 scale across the two contexts children in kindergarten, first, and second grades were roughly equally accurate in categorizing numbers and circles in the smallest range. On both the 0-50 and 0-100 scales, kindergartners were less accurate on number than on circle categorization, while first and second graders performed equivalently on the two tasks. When asked to categorize circles, students performed equivalently to each other across the contexts, regardless of their age. In other words, younger students likelihood to categorize circles accurately was roughly equal to that of older students. In addition, young participants estimates of circle size did not decrease in accuracy as the context became higher in magnitude. The results suggest that even kindergartners are able to appropriately adjust judgments of size based on scale; thus, developmental changes in relative numerical magni-

tude judgments may reflect greater experience with numbers in increasingly larger numerical ranges.

B13 - Strategies in addition: An educational perspective

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Knowledge on developmental pathways of strategies in arithmetic is important since mental calculation strategies early in school has shown to be valid predictors of later mathematical achievements and difficulties. This study presents developmental pathways in the perspective of educational research and the results are discussed in relation to students further mathematical development, e.g. the development of multiplicative thinking. I present a longitudinal analysis of strategy use specific to problem type and school age in 123 Danish students (1st-4th grade). Data on strategy use was obtained through one-to-one assessment interviews. Students were presented for flashcards with all possible addition problems with numbers 2-9. Problem solving categories were 1) Error: gives up or miscalculates, 2) Counting: all varieties of counting procedures, 3) Direct retrieval: the sum is automatized and 4) Decomposition: the addends are decomposed and automatized sums are used to calculate the answer (e.g. 4+5=4+4+1 or 5+5-1). Addition problems were categorized according to problem types (sum$<$10; tie sums e.g. 3+3; sum=10; sum$<$=10). The probability that a given strategy was used as a function of gender, problem type and school age were modelled with Generalized Linear Mixed Models (student nested within class as random effect). The results indicate that developmental pathways of strategy use are related to problem characteristics and gender. Furthermore, the developmental pattern is complex with decomposition, and not direct retrieval, playing a key role for further development in mathematical thinking.

B14 - Reading and solving arithmetic word problems in children and adults

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Word problems are considered as one of the most difficult problems in arithmetic learning and their difficulty are influenced by the complexity of linguistic, mathematical factor. To investigate these factors linguistics and numerical variables were manipulated in two studies (children and adults) while eye movement data was recorded. For exploring the role to arithmetic difficulty, the numbers and operations themselves were manipulated while the text remained largely identical; likewise linguistic factors were manipulated, while the complexity of arithmetic problem solving was kept constant. In both studies specific capabilities (arithmetic, reading, text comprehension, and working memory) were assessed. The behavioral as well as the eye movement data support the idea that numerical and linguistics factors interact. The preliminary results of the eye movement analysis shows that although adults and children share many reading patterns (e.g.: sequential reading, non-sequential reading, skipping the question, starting reading with the second sentence) sequentially and that both groups spend a great amount of time looking at the numbers there are also differences: e.g. compared to adults children tend to read more often. Reading patterns with performance and individual capabilities were also correlated to answer whether individual reading patterns exists and how these depend on the condition. The hypothesis is that solution strategies and performance depend both on individual capabilities as well as on the mathematical and linguistics conditions and it depends on the specific capabilities of the persons and the specific properties of the word problem, if the problem is difficult or not.

B15 - Individual differences in spatial representations of fractions relate to basic math abilities but not algebra

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Recent studies have successfully linked cognitive numerical processes to formal tests of mathematics achievement and other behavioral and neural measures. Specifically, fraction magnitude knowledge predicts individual differences in both fraction arithmetic and standardized math test scores (Siegler & Pyke, 2013), and individual differences in white matter correlate with performance on a math aptitude test (Matejko et al., 2013). The present study investigated how individual spatial representations of fractions are related to a range of domain-general and domain–specific abilities. Adult participants completed a simple comparison task in which they compared the magnitude of single digit, irreducible fractions to ½, a task that has reliably produced a Spatial-Numerical Association of Response Codes (SNARC) effect in our previous work. In the same session, participants completed additional numerical and cognitive tasks. We observed significant group-level distance and SNARC effects based on overall fraction magnitude, but these measures were not correlated and there was notable individual variability. Performance on an explicit number line estimation task was the only significant predictor of individual SNARC slopes. We found no relationship between SNARC slopes and explicit fraction knowledge, overall intelligence, or algebra scores, but there was a correlation between individual SNARC slopes and basic math ability-participants who associated increasing fraction magnitude with the right side of space had higher overall scores on standardized math test. These relationships illuminate the nature of individual differences in spatial numerical associations and the relationship to formal math knowledge, an association supported by structural and functional differences in parietal regions.

B16 - Contribution of domain-general factors in complex multiplication in adults: role of planning and self-control

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Working memory (WM) is the ability to monitor and update recent information and underlies various cognitive processes and behaviors including planning, self-regulation, and self-control. Previous studies suggested that WM is strongly related to arithmetic performance. However, only few studies, have examined whether WM uniquely and genuinely explains variance in arithmetic performance when other WM-related domain-general factors are taken into account. Here, we examined whether WM explains unique variance in arithmetic performance when planning, self-regulation and self-control are considered. We used the Tower of London task as a measure of planning, self-rated reports as a measure of self-regulation and self-control, and WM measures, to test which of these domain-general functions predicts complex multiplication performance. Results showed that only planning predicted multiplication accuracy, while self-control predicted response time in a complex multiplication task. WM did not predict any variance in multiplication performance when other domain-general factors were considered. We suggest that complex multiplication is not predicted by WM per se, but rather by WM-related general cognitive and behavioral factors, namely the planning component of executive functions and self-control.

10 Preregistered Participants

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11 Notes