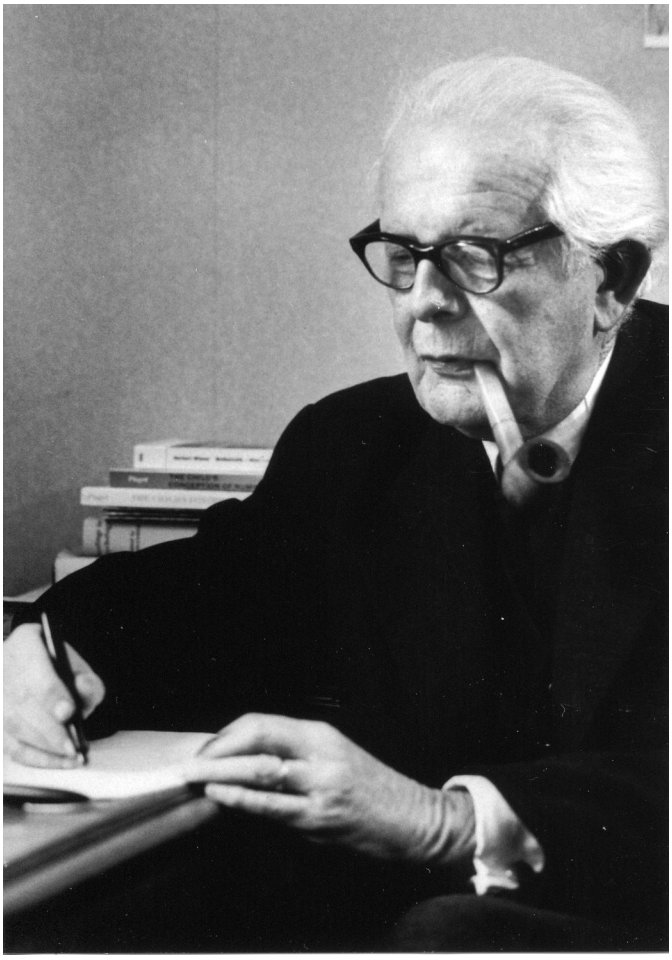
Landenberg, 1965

"La caractéristique la plus frappante de Piaget me paraît être son désir constant de découvrir des données nouvelles et d'élargir sa vision de la connaissance (…). Pour lui, la joie de découvrir a été un des moteurs puissants de sa recherche."

BÄRBEL INHELDER

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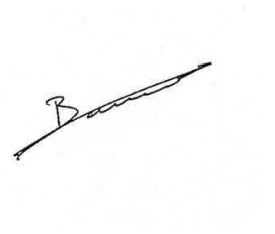
WELCOME AND SPECIALS THANKS

We warmly welcome you to the 3rd Jean Piaget Conferences. We would like to thank Daniel ANSARI, Elizabeth BRANNON, Brian BUTTERWORTH, Lisa Feigenson, Véronique IZARD and Mauro PESENTI who kindly accepted to give a lecture. We wish everyone a pleasant and fruitful conference and hope that you will enjoy your stay in Geneva.

We are indebted to the following institutions for their support: University of Geneva, Faculty of psychology and sciences of education of Geneva, Swiss National Science Foundation, Société Académique of Geneva.

Pierre Barrouillet, Director of the Archives Jean Piaget



NOTE FROM THE PRESIDENT OF THE ARCHIVES JEAN PIAGET

The Archives Jean Piaget aim at keeping Jean Piaget's work active and preserving it. Publications pertaining to the Piagetian thought or continuing it are gathered together in a documentation center. This data base is available online. In 2012, the foundation has received an important donation funds from the descendants of Jean Piaget, including all that was in his office. Aside from this documentary activity, the Jean Piaget Conferences aim to regularly update the Piagetian heritage in several psychological and epistemological domains.

Pierre-Yves Brandt

JEAN PIAGET'S LIFE

Piaget was born in 1896 in Neuchâtel in the French-speaking part of Switzerland and died in 1980. During his youth, he developed an interest in biology and the natural world, but also in philosophy, metaphysics and even theology. Piaget received a PhD in natural science from the University of Neuchâtel, and also studied briefly at the University of Zürich. He then moved to Paris to join Alfred Binet's laboratory, where he worked on his first theory of children's cognitive development. In 1921, Edouard Claparède hired him as Director of Rousseau Institute in Geneva. Since then, Jean Piaget spent most of his career in Geneva, with some time in Neuchâtel, Lausanne and Paris. Jean Piaget brought to psychology a complete change in the way we understand children's thinking. His work in genetic psychology and epistemology focused on how knowledge develops. He found evidence that children's logic develops progressively to adulthood, according to its own laws and evolving throught distinct stages.

THE ARCHIVES JEAN PIAGET

The Foundation of the Archives Jean Piaget was created in 1974 by Professor Bärbel Inhelder at the University of Geneva and from the beginning has been supported financially by the State of Geneva. Its mission is to collect the writings of the father of genetic epistemology, as well as the scientific output from research in developmental cognitive psychology conducted in Geneva. It is vital to preserve and spread this important scientific heritage. During the '60s, researchers began to establish a complete bibliography of Piaget's work. Although quite diverse, ranging fom poetry to philosophy, pedagogy, and botanics, this extensive bibliography shows the uncanny unity of Piaget's thought.

The Foundation Archives Jean Piaget organizes several scientific activities. Among others, a weekly pluridisciplinary seminar and a series of biannual conferences, the aim of which is to bring together the best specialists of a domain particularly relevant to Jean Piaget's work.

THE JEAN PIAGET CONFERENCES

The Jean Piaget Conferences are aimed at students, researchs and scholars interested in Piaget's work and theory. Althought being primarily centred on developmental and cognitive psychology, the Jean Piaget Conferences can also be of interest for a larger audience interested in child development, education, epistemology and cognitive science. The conference reunites outstanding researchers in the general domain of cognitive psychology, focusing each time on a more specific theme relevant to the oeuvre of Jean Piaget. The format of the conference is that of an advanced course, where invited speakers contribute a one-hour presentation on their own domain of competence. This biannual event affords the unique opportunity for advanced students and scholars to keep abreast with the most recent advances in the chosen domain.

The theme selected this year for the 3rd Jean Piaget Conferences is the numerical cognition. The personality and the work of Jean Piaget have long dominated this domain. However, since Piaget's death, everal different approaches and conceptions have emerged that have enriched and modified his original ideas.

The Jean Piaget Conferences **"The origins of number"** were designed to offer to students and researchers a comprehensive survey of the contemporary theories of cognitive and social development, most of which emerged in relation and sometimes in oppositions to the Piagetian approach. At the same time, we wished to provide an arena where these different lines of research can be assessed and debated.

PROGRAM

WEDNESDAY EVENING, JUNE 27, 2018

6:30 PM KEYNOTE ADDRESS

Foundational capacities and arithmetical development

BRIAN BUTTERWORTH

THURSDAY MORNING, JUNE 28, 2018

8:45-9:00 AM	INTRODUCTION TO THE 3RD JEAN PIAGET CONFERENCES
9:00-10:00 AM	**ELIZABETH BRANNON**
	Foundations for symbolic mathematics: development and evolution of the approximate number system
10:00-10:30 AM	COFFEE BREAK
10:30-12:10 AM	**SPOKEN SESSION I (1-5)**
12:10-1:30 PM	LUNCH

THURSDAY AFTERNOON, JUNE 28, 2018

1:30-2:30 PM	**MAURO PESENTI**
	Embodiment of number semantics in sensory-motorprocesses: Number-finger interactions
2:30-3:30 PM	**DANIEL ANSARI**
	Number symbols in brain and mind
3:30-3.50 PM	COFFEE BREAK
3:50-5:30 PM	**SPOKEN SESSION II (6-10)**
5:30-6:30 PM	**POSTER SESSION**
6:00-7:00 PM	COCKTAIL

FRIDAY MORNING, JUNE 29, 2018

9:00-10:00 AM	**VÉRONIQUE IZARD**
	Children's knowledge of Intergers
10:00-10:30 AM	COFFEE BREAK
10h30-12:10 PM	**SPOKEN SESSION III (11-15)**
12:10-1:30 PM	LUNCH

FRIDAY AFTERNOON, JUNE 29, 2018

1:30-3:50 PM	**SPOKEN SESSION IV (16-21)**
3h50-4:15 PM	COFFEE BREAK
4:15-5:15 PM	**LISA FEIGENSON**
	Constraints and flexibility in early quantification
5:15-5:30 PM	CLOSING SPEECH

ABSTRACT OF KEYNOTE ADDRESS

WEDNESDAY EVENING, JUNE 27, 2018

BRIAN BUTTERWORTH

University College, London

Foundational capacities and arithmetical development

Like many other species, humans, even in infancy, possess a mechanism for extracting numerosity information from the environment, which I have called a foundational capacity. This mechanism is domain-specific, is implemented in a dedicated mechanism and is innate. I argue that the efficient working of this capacity is necessary for typical arithmetical development, and if it works inefficiently, this is sufficient for atypical development – dyscalculia.

ABSTRACTS OF INVITED PRESENTATIONS

THURSDAY MORNING, JUNE 28, 2018

ELIZABETH BRANNON

University of Pennsylvania

Foundations for symbolic mathematics: development and evolution of the approximate number system

Adult humans quantify, label, and categorize almost every aspect of the world with numbers. The ability to use numbers is one of the most complex cognitive abilities that humans possess and is often held up as a defining feature of the human mind. In my talk I will present a body of data that demonstrates that there are strong developmental and evolutionary precursors to adult mathematical cognition that can be uncovered by studying human infants and nonhuman primates. Developmental data and controversies will be discussed in light of comparative research with monkeys and other animals allowing us to see both parallels and discontinuities in the evolutionary and developmental building blocks of adult human cognition. Despite the profound discontinuity between primitive number sense and uniquely human symbolic mathematics I will present evidence that primitive number sense serves as a foundation for symbolic math.

THURSDAY AFTERNOON, JUNE 28, 2018

MAURO PESENTI

Catholic University of Leuven

Embodiment of number semantic in sensory-motor processes: Number-finger interactions

In this talk, I will present and summarize the many number-finger interactions that my research group has reported in the last years: (i) how the fixed order of fingers on the hand provides human beings with unique facilities to increment numerical changes or represent a cardinal value while solving arithmetic problems; (ii) how pointing actions support object enumeration and how numerical magnitudes interact with pointing-reaching actions; and finally (iii) how number processing has been found to interact with the execution or perception of grasping movements, indicating that the adjustment of the hand grip to match object size shares processes with the computation of number magnitude estimates. From these data, I will argue that the way we express numerical concepts physically, by raising fingers while counting, pointing to objects, or using grip aperture to describe magnitudes, leads to embodied representations of numbers and calculation procedures in the adult brain.

DANIEL ANSARI

University of Western Ontario

Number symbols in brain and mind

Humans share with animals the ability to process quantities when they are presented in non-symbolic formats (e.g., collections of objects). Unlike other species, however, over cultural history, humans have developed symbolic representations (such as number words and digits) to represent numerical quantities exactly and abstractly. These symbols and their semantic referents form the foundations for higher-level numerical and mathematical skills. It is commonly assumed that symbols for number acquire their meaning by being mapped onto the pre-existing, phylogenetically ancient system for the approximate representation of non-symbolic number over the course of learning and development. In this talk I will challenge this hypothesis for how numerical symbols acquire their meanings ("the symbol grounding problem"). To do so, I will present a series of behavioral and neuroimaging studies with both children and adults that demonstrate that symbolic and non-symbolic processing of number is dissociated at both the behavioral and brain levels of analysis. I will discuss the implications of these data for theories of the origins of numerical symbol processing.

FRIDAY MORNING, JUNE 29, 2018

VÉRONIQUE IZARD

Paris Descartes University

Children's knowledge of Integers

Human infants already possess representations with numerical content: these representations are sensitive to numerical quantity while abstracting away non-numerical aspects of stimuli, and they can enter into arithmetical operations and inferences in line with the laws and theorems of mathematics. However, while core cognition captures many properties of numbers, children's early representations are not powerful enough represent our princeps concept of number, the type of numbers children first encounter in language and at school: Integers. In this talk, I will present two series of recent studies where we probed children's knowledge of fundamental properties of Integers, i.e. properties that serve as foundations for formal descriptions of Integers. First, we studied how children aged 2 ½ to 4 years understand the relation of one-one correspondence between two sets. We found that children do not initially take one-one correspondence to instantiate a relation of numerical equality (a violation of Hume's principle, at the foundation of set-theoretic descriptions of Integers); instead, they interpret one-one correspondence in terms of set extension. Second, we developed a new task to probe children's intuitions about the structure of the set of Integer, as described in Dedekind-Peano's axioms: in particular, we tested whether children understand that Integers form a list structure where all numbers can be generated by a successor function (+1), and whether they understand that this list never loops back on itself. In both sets of studies, we asked both at what age children understand essential properties of Integers, and whether numerical symbols play a role in their acquisition.

FRIDAY AFTERNOON, JUNE 29, 2018

LISA FEIGENSON

Johns Hopkins University

Constraints and flexibility in early quantification

The act of quantification (e.g., knowing how many objects are in a scene) requires selecting a relevant entity and storing it in working memory for further processing. Critically, multiple kinds of entities can be selected and stored. In this talk I offer evidence that humans can represent at least three different levels of entities in working memory. They can represent an individual object (e.g., "that bird"). They can represent a collection of items (e.g., "that flock of birds"). And they can represent a set of discrete items (e.g., "the set containing Bird A, Bird B, and Bird C"). each of these types of representations permits a different of quantificational processing. Storing individual objects in working memory permits exact but implicit representation of the number of objects present, up to a maximum of 3 objects. Storing collections of items in working memory permits explicit but inexact representation of the number of items present, with no in principle upper limit. And storing sets of individual items permits exact implicit representation of the number of items present, but is accompanied by a loss of representational precision. Hence, which quantity-relevant computations may be performed in any given situation depends on which level of representation is stored. This framework for thinking about interactions between attention, working memory, and quantification applies throughout development starting in infancy.

ABSTRACTS OF ORAL PRESENTATIONS

SPOKEN SESSION I

THURSDAY MORNING, JUNE 28, 2018

1. Counting ont to Fish: Learning Symbolic Numbers Without a Cortex

Tali Leibovich-Raveh[1] & Shai Gabay[2]

[1]Department of Mathematics Education, University of Haifa, Israel
[2]The Institute of Information Processing and Decision Making and the Department of Psychology, University of Haifa

Can an animal without a cortex learn the meaning of Arabic digits? To study the evolutionary origin of this basic numerical ability, we used the archerfish. Archerfish were selected because their brain has no analog to the human cortex and because they can be trained to respond to artificial targets presented on a computer monitor, by shooting a jet of water at it. In the learning phase, fish saw two adjacent Arabic digits (1,2 ;2,3; 3,4) and was rewarded when selected the numerically larger digit. By the end of this phase, accuracy above chance level was achieved for all pairs. In the test phase the fish saw two non- adjacent pairs (1,4; 2,4; 1,3) and was rewarded for every response. Results reveled accuracy above chance level for all pairs, suggesting that fish generalized the ordinal relationship of the digits, (i.e., that 4>3>2>1). In the third phase, we tested whether the symbolic meaning of the digits will be processed automatically. For this aim, the fish saw the same non-adjacent pairs but in two different physical sizes, and was rewarded when selecting the physically larger digit. The physical size was either congruent (1 4) or incongruent (4 1) with the symbolic meaning. For all pairs, response time to incongruent trials was significantly slower than to congruent trials, suggesting that the meaning of the symbols was processed automatically. Our pilot results put forward the possibility that learning symbols and ordinal relationship can occur even in a brain without homolog to the human cortex.

Keywords: Animal cognition - Numerical cognition - Symbolic numbers.

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

Ursina McCaskey[1,2], Michael von Aster[1,2,3,4], Ruth O'Gorman Tuura[1,2,5], & Karin Kucian[1,2,4]

[1]Center for MR-Research, University Children's Hospital Zurich, Zurich, Switzerland
[2]Children's Research Center, University Children's Hospital Zurich, Zurich, Switzerland
[3]Clinic for Child and Adolescent Psychiatry, German Red Cross Hospitals, Berlin, Germany
[4]Neuroscience Center Zurich, University of Zurich and Swiss Federal Institute of Technology Zurich, Zurich, Switzerland
[5]Zurich Center for Integrative Human Physiology, University of Zurich, Zurich, Switzerland

Developmental dyscalculia (DD) is a learning disability affecting the acquisition of numerical- arithmetical skills. Studies reveal persistent deficits in number processing, aberrant functional activation and structural differences in number-related brain areas of DD subjects. Reduced grey matter (GM) has been reported in DD for the posterior parietal cortex, intraparietal sulcus (IPS), and the frontal and occipito-temporal cortex. However, the longitudinal development of these structural differences is unknown. In the present longitudinal study, we investigate the developmental trajectory of brain structures in children with and without DD. Neuropsychological measures and structural images were collected twice with an interval of 4 years from 15 DD and 11 typically developing (TD) children. Voxel-wise estimation of GM volumes was assessed by means of voxel-based morphometry for longitudinal data. Our findings reveal that DD children show persistently reduced GM volumes over development in the left (pre)cuneus, left inferior parietal lobe, right superior occipital gyrus and IPS, anterior cingulate cortex and 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 GM volumes in the fronto-parietal regions of the numerical network for DD children. Moreover, we found a decrease in the dyscalculic's GM trajectory 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 GM volumes in number-related brain areas.

Keywords: Developmental dyscalculia - Longitudinal study - Morphometry - Grey matter volume - Children.

3. Nightmare Math: What specific anxiety can do to the developing brain

Karin Kucian[1,2], Ursina McCaskey[1,2], Michael von Aster[1,2,4,5], & Ruth O'Gorman Tuura[1,2,3]

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[2]Children's Research Center, University Children's Hospital, Zurich, Switzerland
[3]Zurich Center for Integrative Human Physiology, University of Zurich, Zurich, Switzerland
[4]Clinic for Child and Adolescent Psychiatry, German Red Cross Hospitals, Berlin, Germany
[5]Neuroscience Center Zurich, University of Zurich and ETH Zurich, Zurich, Switzerland

Adequate mathematical competences are indispensable in professional and social life. However, mathematics is often associated with stress and frustration and confrontation with mathematical tasks triggers anxiety in many children. Despite the high prevalence of math anxiety and the detrimental effects on mathematical performance, only limited attention has been devoted to the neurobiology of math anxiety. Evidence regarding brain substrates of anxiety lend support that our brain not only reacts with adapted brain activation, but also with structural changes due to detrimental experiences. However, no study has ever investigated possible structural alterations due to math anxiety. Therefore, the aim of the present study was to examine consequences of mathematical anxiety on grey matter in typically achieving children and children with developmental dyscalulia (DD). DD is a specific learning disorder of mathematical abilities and affected children are particularly prone to develop math anxiety. Behavioural and magnetic resonance imaging were acquired and findings corroborated that children with DD suffer more often from math anxiety. In general, boys and girls were equally affected and math anxiety was independent from age or general cognitive abilities like IQ. Remarkably, math anxiety affected specifically arithmetical performance negatively, probably by diminished working memory capacities based on anxiety and stress. Most importantly, present findings showed for the first time that math anxiety is related to altered brain structure. In particular, the right amygdala volume was reduced. In conclusion, math anxiety does not only hinder children in arithmetic, but it goes along with changes in brain structure of fear processing.

Keywords: Mathematical anxiety - Brain - Children - MRI.

4. Interference and problem size effect in multiplication fact solving: Individual differences in brain activations and arithmetic performance

Alice De Visscher[1], Stephan E. Vogel[2], Gernot Reishofer[3], Eva Hassler[3], Karl Koschutnig[3], Bert De Smedt[4], & Roland H. Grabner[2]

[1]Université catholique de Louvain, Belgium
[2]University of Graz, Austria
[3]Medical University of Graz, Austria
[4]University of Leuven, Belgium

A large variability of performance in simple multiplication is observed and has not found a compelling explanation yet. One robust effect in simple multiplication is the problem size effect (better performance for small problems compared to large ones). Recently, studies brought to light another effect, the interference effect, indicating that high interfering problems (receiving more proactive interference from previously learned problems) are more difficult to retrieve than low interfering problems. The behavioral sensitivity-to-the interference effect is shown to explain individual differences in multiplication, in children and adults. This study aimed at investigating the individual differences in multiplication in relation to the neural interference effect and the neural problem size effect. In a multiplication verification task, we orthogonally contrasted the level of interference and of problem size. Forty-two healthy adults, who showed high variability in an arithmetic fluency test, undertook the task during fMRI acquisition. The general reasoning level (IQ) was taken into account in the analyses. Our findings revealed a neural interference effect linked to individual differences in multiplication in the left inferior frontal gyrus, indicating a higher interference effect for low performers compared to high performers. This region is known to be involved in resolution of proactive interference. No correlation between the neural problem size effect and multiplication performance was found. This study supports the idea that the interference due to similarities/overlap of physical traits (the digits) is crucial in memorizing multiplications and in determining individual differences in arithmetic.

Keywords: Multiplication fact - Individual differences - Neuroimaging.

5. The impact of mathematical competence on brain activity during mental arithmetic

Roland H. Grabner, Lorenz Sprich, Stephan Vogel, & Clemens Brunner

Institute of Psychology, University of Graz, Austria

There is a long tradition in research showing that children and adults use different strategies to solve arithmetic problems. Neurophysiological studies have recently begun to investigate the brain correlates of these strategies. In the electroencephalogram (EEG), strong links between theta activity and fact retrieval processes, on the one hand, and between alpha band activity and the application of procedures, on the other hand, have been found. These findings converged from studies comparing problem sizes, applying arithmetic training, and using strategy self-reports. It is unclear, however, whether these activation patterns and the associated strategies depend on individual differences in mathematical competence and whether this relationship is moderated by task difficulty. To investigate these research questions, 39 adults of different mathematical competence levels worked on easy, medium, and difficult addition problems, and provided strategy self-reports after each trial. Preliminary analyses revealed the expected effects of task difficulty on performance, strategy use, and EEG activity. Interestingly, more competent participants solved problems of all difficulty levels faster but did not report having used retrieval and procedural strategies to a different extent. Nonetheless, mathematical competence was positively correlated with theta and negatively correlated with alpha activity across all difficulty levels. In theta, the correlation was moderated by task difficulty in that the largest correlation emerged for the medium problems. These findings suggest a general impact of mathematical competence on brain activation during arithmetic problem solving, which may be indicative of differences in task processing that are not evident in strategy self-reports.

Keywords: Arithmetic - EEG - Brain activation - Neurophysiology - Mathematical competence.

SPOKEN SESSION II

THURSDAY AFTERNOON, JUNE 28, 2018

6. Zero or nothing? Perceiving empty frames as null numerosity

Rut Zaks-Ohayon[1], Michal Pinhas[2], & Joseph Tzelgov[1,3]

[1]Ben-Gurion University of the Negev, Israel
[2]Ariel University, Israel
[3]Achva Academic College, Israel

The question whether humans process null numerosity as zero has received little research attention. In this study, we manipulated the context in which null numerosity was presented, using the nonsymbolic magnitude comparison task. In Experiment 1, null numerosity was presented as an empty set and other numerosities as dot arrays. We manipulated task instructions relevant to the target (i.e., "choose the target stimulus that contains more/less dots" in Experiment 1) or the given numerical range (i.e., 0-9 or 1-9 in Experiment 2). The results revealed distance effects for comparisons to null numerosity irrespective of task instructions. In Experiment 2, we manipulated the way null numerosity was presented, by varying the homogeneity of the stimuli and their background. The results demonstrated an attenuated distance effect for comparisons to an empty frame in the homogenous background groups. However, no distance effect was evident under conditions of heterogenous background, indicating that in this case null numerosity was not associated with numerical meaning. In Experiment 3, we manipulated the response mode. Two groups of participants responded to target location with a key-press or vocally, while the third group responded vocally to target color. The results revealed distance effects for comparisons to null numerosity only when responding to target location, regardless of the response mode. These findings show that perceiving null numerosity as zero or as nothing is reliant upon the context in which it is presented. The implications of our findings are discussed in light of models of number representation.

Keywords: Null numerosity - Zero - Nonsymbolic number representation - Magnitude comparison.

7. Decimal number and cognitive control in children and adults

Grégoire Borst[1,2], Margot Roell[1], & Arnaud Viarouge[1]

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While number of studies have focused on the emergence of whole number knowledge, fewer studies have investigated the development of other type of numbers such as decimal numbers. This seems to be critical in light of the fact that children and even educated adults have difficulty in comparing decimal numbers when the smallest decimal number has the greatest number of digits (3.453 vs. 3.6). Some studies have attributed this difficulty to a whole number bias, i.e., an overgeneralization of whole number properties to rational numbers. In this case, the whole number bias consists in using a property of whole number such as the "greater the number of digits the greater its magnitude" to compare decimal numbers in which the smallest one has the greatest number of digits after the decimal point. We will present a series of negative priming studies that converge in demonstrating that the comparison of the magnitude of two decimal numbers in this context relies not only on the inhibition of the property of whole numbers, but also on the inhibition of the physical lengths of the decimal numbers per se in both children and young adults. In addition, we will present evidence that the inhibition of the physical lengths of the decimal number might be needed in both children and adults because dedicated neural circuits for processing non-numerical dimensions of magnitude such as space but not luminance are co-opted during the acquisition of complex mathematical skills such as symbolic number processing.

Keywords: Decimal number - Cognitive control - Inhibition - Whole number bias - Development.

8. The role of comparison of natural numbers in proportional reasoning

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Proportional reasoning is known to be difficult for children and adults. In previous studies participants were asked to decide which of two mixtures of red and white paint drops was darker. There were two conditions: Congruent (larger number of red drops - darker), and Incongruent (larger number of red drops - not darker). There were two salience levels: Emphasized (the difference in the number of red drops between the mixtures is larger than that of the white drops) and Nonemphasized (the difference in the number of red drops between the mixtures is equal to that of the white drops). Accuracy in congruent emphasized trials was higher and reaction time of correct responses (RTC) shorter than in incongruent emphasized trials. Accuracy in congruent emphasized trials was higher and RTC shorter than in congruent nonemphasized trials. It was suggested that the automatic comparison of the differences between the natural numbers that comprise the ratios affect participants' responses. Here we explored whether explicitly displaying these differences would amplify their effects. Seventy eight computer science college students were randomly divided into two groups: Implicit presentation (e.g., 5 red : 3 white ; 3 red : 2 white) and Explicit presentation, (e.g., 3+2 red : 2+1 white ; 3 red : 2 white). In both congruent nonemphasized and incongruent emphasized trials accuracy was much lower in the Explicit presentation. RTC findings further supported the accuracy findings. Findings of the current study clearly indicate that comparison of natural numbers plays a crucial role in proportional reasoning.

Keywords: Proportional reasoning - Natural numbers - Congruity - Salience - Reaction time.

9. Tracking the cerebral correlates of numerical and continuous magnitude extraction with a frequency-based approach

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The ability to handle approximate large quantities has been identified as a building block of mathematical skills but the mechanism allowing to extract numerical magnitudes (i.e., numerosity) from environmental stimuli is still debated. Many authors agree that humans have an Approximate Number System that specifically processes numerosity. However, a set of objects is not only characterized by its numerosity but also by additional visual information related to its continuous dimensions (e.g., total area, dot size). Accordingly, the alternative theory argues that the numerosity is extracted through a weighting of the continuous dimensions. The opposite views cannot be easily tested due to the intrinsic correlations between numerosity and continuous dimensions. Our study aimed at isolating the specific cerebral responses to numerosity and to continuous dimensions by using Steady-State Visual Evoked Potentials (SSVEP). We presented dot collections that varied randomly along all dimensions but one, which entailed a systematic change at the rate of 1.25 Hz. The periodic dimension was either the numerosity or one of the continuous dimensions (size, area, convex hull or density). The EEG recording showed a neural synchronization on the numerosity as well as on total dot area and convex hull. In contrast, we did not observe such a synchronization for density and dot size. In conclusion, the numerosity and some continuous dimensions can be extracted rapidly along the visual stream but this is not the case for some other continuous dimensions, providing new insights to existing theories of numerosity extraction.

Keywords: Numerical cognition - Numerosity extraction - Fast periodic visual stimulation - Quantities - Non-symbolic - Mathematical abilities.

10. Conducting web-based experiments for numerical cognition research

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University of Amsterdam

Recent rise in availability of easy to use tools for creating web-based experiments provides an opportunity for faster and cheaper data collection that is also capable of reaching more diverse populations than a typical lab-based study (de Leeuw & Motz, 2016; Stewart, Chandler & Paolacci, 2017). Numerical cognition research is one of the areas that can potentially greatly benefit from these advancements. But how reliable is data collected in such online studies? In this project, we conduct replications of 2 classical experimental effects in numerical cognition – size-congruity effect (adopting Henik & Tzelgov 1982 protocol) and comparison and priming distance effects (adopting Van Opstal et al. 2008 protocol) with Arabic digits. We recruited participants online and measured reaction times while they completed the experiments in their web browsers. Replicating Henik & Tzelgov study, we collected data in 2 tasks – a semantic (numerical) comparison task (N=23) and a physical size comparison task (N=24) while manipulating congruence and physical and semantic distance. We obtained comparable reaction times and significant congruence and semantic distance effects parallel to the original study. The experiment aiming at replicating the comparison and priming distance effects is currently being conducted. We made all scripts and data publicly available along with their detailed descriptions. The experiments were implemented using a free JavaScript library jsPsych (de Leeuw 2015) which allows for their easy modification and re-use.

Keywords: Size congruity effect - Distance effect - Replication - Web based experiment.

SPOKEN SESSION III

FRIDAY MORNING, JUNE 29, 2018

11. Four-year olds' understanding of repeating and growing patterns in relation to their numerical ability

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Recent longitudinal studies have documented the value of young children's patterning abilities for their mathematical development. The main focus of this line of research has been on repeating patterns, whereas growing patterns have been neglected largely. Moreover, this line of research has been developing rather separately from the one on early numerical ability, a widely acknowledged precursor for later mathematical development. The aims of this study were therefore twofold: (1) to explore the impact of pattern type and activity on four-year olds patterning performance; and (2) to analyze the concurrent association between early patterning and early numerical ability. Participants were 401 Flemish four-year olds from a wide range of socio-economic backgrounds. A patterning measure that systematically assessed children's performance on three patterning activities (i.e., extending, generalizing, and identifying the unit of repeat) for two types of patterns (i.e., repeating or growing) was developed. Results indicated that activities with repeating patterns were easier than those with growing patterns and that generalizing a pattern was easier than extending it, which was easier than identifying the unit of repeat of a pattern. We also found an interaction between patterning type and activity: the difference in difficulty between the two types of patterns was the largest for extending and the smallest on generalizing. Furthermore, children's performance on both types of patterns uniquely contributed to their early numerical ability. These findings support the importance of growing patterning ability, in addition to the ability to handle repeating patterns, in the early stage of children's mathematical development.

Keywords: Patterning - Early mathematics - Numerical ability - Repeating patterns - Growing patterns.

12. Gender equality in four- to five-year-old preschoolers' early numerical competencies

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Numerical competencies acquired in preschool are foundational and predictive for children's later mathematical development. It remains to be determined whether there are gender differences in these early numerical competencies, which could explain the often-reported gender differences in later mathematics and STEM-related abilities. Using a Bayesian approach, we quantified the evidence in favor of the alternative hypothesis of gender differences versus the null hypothesis of gender equality. Participants were 402 four- to five-year-old children attending preschool in Flanders (Belgium). Children were selected via stratified cluster sampling to represent the full range of socio- economic backgrounds. All children completed eight numerical tasks (verbal counting, object counting, numeral recognition, symbolic comparison, nonsymbolic comparison, nonverbal calculation, number order, dot enumeration). Results provided more evidence for the gender equality hypothesis in all tasks, and this evidence was substantial for seven of the eight numerical tasks. In view of the observation that these early numerical competencies provide the foundation for acquiring more complex mathematics skills, the current finding of gender equality suggests that girls and boys are equally competent in acquiring more complex mathematics skills.

Keywords: Early numerical competencies - Gender differences - Preschool - STEM.

13. Computational estimation in 5-year-olds: first results of a longitudinal study

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Computational estimation is defined as providing an approximate answer to an arithmetic problem without exactly calculating it. In addition to its importance in everyday life, it is related to different mathematical competencies (e.g., number sense, arithmetic fluency, and overall mathematical competencies). Previous research has shown that school- aged children and even adults seem to be surprisingly bad at computational estimation. Since previous research mostly investigated it from age 8 onwards, very little is known about computational estimation performance at a younger age. Therefore, we conducted a large- scale study with 389 5-year-olds to investigate the computational estimation performance of young children and to explore its relationship with exact and approximate arithmetic (i.e., performing arithmetic with approximate representations). Four tasks were administered individually: computational estimation, exact arithmetic, approximate arithmetic, and working memory as a control variable. Results showed that 5-year-olds were more accurate in computational estimation when their exact arithmetic proficiency level increased and that their estimation accuracy decreased as a function of problem difficulty. We also found a positive relationship between computational estimation and approximate addition (but not approximate subtraction) performance. Moreover, working memory, exact arithmetic and approximate addition all explained a significant portion of the variance in children's computational estimation performance. Altogether, these results show that computational estimation emerges at a younger age than is usually assumed, which can open doors to its early stimulation with a view to enhance children's later mathematical abilities.

Keywords: Computational estimation - Kindergarten.

14. Promoting the Linear number representation by 4-year old children through playing number board games – which pre-knowledge is necessary?

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Recent results of the development of numerical representations show that an adult and a child playing the board game "the great race" in a one-to-one situation, strongly enhances young preschool-children's numerical knowledge. In particular, this game is fostering the shift from a logarithmic to a linear representation of numbers, where the difference in magnitude between 3 and 4 is the same as between 9 and 10. In this study we investigated, using the game "bunny race", an adapted version of the game "the great race" (i) whether younger children between 4 and 5 years are also able to make this shift toward the linear number representation and (ii) whether it is possible for children to play this enhanced board game with less adult support than the original version of the game "the great race". The sample comprised 140 children (intervention group: 75; control group: 65) between 4 and 5 years from 16 kindergarten classes in St. Gallen. The intervention was implemented in 4 sessions of 20 minutes each within 2 weeks. The tests (pretest, posttest and follow-up) included 4 diverse numerical tasks: numerical magnitude comparison, number line estimation, counting and numeral identification. The results show significantly greater learning gains for the intervention group in some numerical tasks and the necessary pre-knowledge for the acquisition of the inear number representation can be deduced. The contribution presents the research findings, discusses the role of adult support and game features in play-based-learning for early mathematics and highlights questions and consequences for further research.

Keywords : Play - Integrated learning - Board games - Early mathematical competence - Linear number representation.

15. Number Word Interpretation, Contextual Sensitivity, and Early Mathematics

Michèle M. M. Mazzocco & Sarah L. Lukowski

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Number words pose a challenge for children, despite their masterful ability to interpret novel words based on context. Yet other words – particularly forms of lexical ambiguity, such as homonymy – pose such challenges. Children's interpretation of homonyms shows more protracted development relative to rapid growth in vocabulary observed from ages 3 to 7 years. Here we argue that number words conform to some of the principles of homonyms because the numeric nature of their referents varies across contexts (e.g. 3 eggs, 3 dozen eggs, 3 Rue des Tulipe, 3-year-old). Thus, in the present study we evaluate whether contextual sensitivity (i.e., a tendency to successfully rely on contextual clues to draw correct interpretations) uniquely predicts mathematics skill. We first relied on retrospective data from 178 2nd graders who completed a battery of cognitive assessments in an earlier study. We asked if their contextual sensitivity for homonyms was related to mathematics skill beyond the contribution of other cognitive skills, including language, spatial, and executive function skills. We found that contextual sensitivity remained a significant and independent predictor of mathematics scores beyond variance accounted for by these scores. Contextual sensitivity was a significant predictor of Test of Early Mathematics Ability raw scores, and KeyMath Basic Concepts and Applied Problems factor scores, offering support for the claim that contextual sensitivity contributes to individual differences in early number knowledge and mathematics skills. Next we tested this theory in a new cohort of students who completed the TEMA and several measures of vocabulary and contextual sensitivity. Again, we found evidence that contextual sensitivity plays a role in early mathematics performance, and that this association is highly variable from ages 4 to 8 years of age, a period during which response to lexical ambiguity is also highly variable. We propose that contextual sensitivity plays a specialized role for a subset of individuals with mathematics difficulties, rather than a general role that applies to mathematics learning.

Keywords: Number words - Homonymy.

SPOKEN SESSION IV

FRIDAY AFTERNOON, JUNE 29, 2018

16. Two versions of the conservation-of-number task and their links to numerical difficulties

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Piaget's conservation-of-number task remains the subject of many debates, to the extent that it is not clear whether this task is indicative of numerical competencies. Indeed, achievement in this task is influenced by other factors such as the pragmatic aspects of the situation, verbal skills for justifying answers and the ability to inhibit intuitive perceptual responses (Fayol, 1990; Houdé et al., 2011). Interestingly, this task is included in several batteries of numerical skills in relatively different forms. Within a study on early numerical competencies (Mathplay), a test has been created to measure these skills at three times of kindergarten (N=72, mean age = 5,6 years old at time 1). Two versions of the conservation-of-number task have been incorporated for comparison purposes: an easier version in which tokens presented in line are moved in a circle, as in the TEMA-3 battery (Ginsburg & Baroody, 2003), and a classical version in which the tokens are narrowed and children have to justify their answers. Analyses show that failure at the easier task is associated to difficulties in numerical skills five months later whereas children who do not succeed the "narrowed" task have numerical performance that does not differ from the mean. Furthermore, an inter-rater agreement on the children's justifications shows that classifying them as empirical or logical, as required in the Tedi-math battery (Van Nieuwenhoven, Grégoire & Noël, 2001), is not very easy. In the middle of the school year, only 34% of the children gave responses that were based on quantity.

Keywords: Conservation of number task - Early numerical skills - Numerical difficulties - Justifications.

17. Correspondences, seriations and classifications within the development of the comprehension of human death

Tau Ramiro

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In the present work we will discuss the possibility to interpret certain aspects of the genesis of the comprehension of death in children, under the light of some processes and precursor notions of number. For this, we will build on the results of an empirical doctoral research on the development of the comprehension of human death, conducted in Argentina with 60 children from 5 to 10 years of age, belonging to atheist, agnostic and Christian families. The hypothesis we will present does not imply that the development of social knowledge, such as the understanding of death, depends or can be reduced to the development of structural or logical-mathematical knowledge. On the contrary, we will try to show how, in the production of the notions regarding the causes, the universality, the inevitability and the irreversibility of death, as well as in the type of entity in which death occurs —i.e. "person", "body", "soul", among others—, there are processes of classification, seriation and establishment of ordinal and cardinal correspondences involved. In particular, we will focus in the part-whole, interior-exterior and position-function relations of the biological knowledge implied in the comprehension of life and death. We will also refer to the children's beliefs on "the beyond" and the afterlife. Furthermore, we will address the gradual transformation of the complex and nonsymmetrical relations between life and death.

Keywords: Comprehension of human death - Correspondences - Classification - Seriation.

18. Neurocognitive correlates of arithmetic complexity in adults and children

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In arithmetic, difficulties are particularly prevalent when complexity increases. In particular, the carry operation in addition (carrying a decade when the sum of the units exceeds 9) and the borrow operation in subtraction (borrowing a decade when the unit of the minuend is smaller than the unit of the subtrahend) reflect major obstacles in math education. Therefore, in four studies we aimed at understanding the neurocognitive foundations of arithmetic complexity in the mature brain of adults as well as in the developing brain of school children as concerns the carry and borrow effects and their relation. By investigating the neural in addition to the behavioral correlates of arithmetic complexity, it is possible to identify the underlying mechanisms of increased task demands. The results showed that the carry and borrow operations increase the difficulty of addition and subtraction because of increased domain-general processing demands, but the borrow operation was more difficult than the carry operation indicating an inverse relation. Regarding arithmetic development, children improved in subtraction in general by relying less on frontal domain-general processing, but not in place-value manipulation in terms of the borrow effect in particular. Furthermore, in individuals with high math ability, arithmetic complexity lead to increased frontal activation, while individuals with low math ability need these resources even for simple arithmetic. In conclusion, this project contributes to educational neuroscience by investigating the neurocognitive foundations of arithmetic complexity and development in a natural setting.

Keywords: Arithmetic complexity - Carry effect - Borrow effect - Neurocognitive correlates - Longitudinal development - Math ability.

19. Contributions of executive functions and visual-spatial skills to mathematical achievement across development: Evidence from a large, representative sample

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Children's mathematical achievement depends on their domain-specific abilities and domain-general skills such as executive functions and visual-spatial skills. Even though research has repeatedly indicated that these two skills predict mathematical proficiency, it is yet unclear whether their contributions on mathematics change across development. The current study used a large sample of 1777 participants aged 5-20 years to answer this question. Executive functions, visual-spatial skills, and mathematical achievement were assessed using the Intelligence and Development Scales–2 (Grob & Hagmann-von Arx, 2018). Hierarchical regression analyses were computed with age, sex, SES, and verbal reasoning skills as control variables, and executive functions and visual-spatial skills as predictor variables. Interaction terms with age and quadratic terms were also entered into the model. Results indicated that executive functions and visual-spatial skills both contributed to mathematical achievement (with controls, all $\beta s > .26$, all $ps < .001$, total $R2 = 86\%$). Whereas effects of executive functions did not interact with age and were not quadratic (all $\beta s < -.01$, all $ps > .67$), effects of visual-spatial skills depended on age and were quadratic (all $\beta s > .13$, all $ps < .001$). Simple slope analyses revealed that associations between visual-spatial skills and mathematical achievement were stronger in adolescents than in children and followed a non-linear pattern. Our findings highlight stable relations between executive functions and mathematics across development. However, it seems that contributions of visual-spatial skills for mathematical proficiency increase across childhood and adolescence, indicating the rising importance of visual-spatial skills for mathematics with higher age.

Keywords: Mathematical achievement - Spatial skills - Executive functions.

20. Does arithmetic knowledge put aside informal problem solving strategies?

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University of Geneva

Transforming numbers with elementary arithmetic operations is considered to be a rather intuitive cognitive ability (Dehaene, 2009). Studies have shown that – before receiving any kind of instruction regarding arithmetic – kindergarten children can solve a problem such as "Paco had 13 cookies. He ate 6 of them. How many cookies does Paco have left?" by mentally simulating the actions described in the problem (Carpenter et al., 1993). The semantic relations described in the problem lead the solver to construct a representation of the situation (Thevenot & Barrouillet, 2015). Yet, it is unclear if even after math instruction, solving such problems reflects the actual use of arithmetic knowledge or rather mere language comprehension skills followed by a mental simulation of the actions depicted in the problem, just as it occurs in preschool children. We conducted three experiments among second grade students: two regarding performances and one focusing on strategy use during verbal interviews. Word problems from various semantic categories were presented in two versions, one that could be easily solved by mental simulation, and one that was not simulatable and could only be solved if relevant arithmetic knowledge was used. Our studies revealed that students do indeed perform better on the former kind of problem and use informal simulation strategies when possible. Calculations that involve arithmetic knowledge were only performed when informal strategies fail to provide a solution. Our studies suggest that the informal strategies evidenced among preschool children remain influent after instruction. Educational stakes of this phenomenon will be discussed.

Keywords: Arithmetic problem solving - Informal knowledge - Solving strategies.

21. Daily world knowledge at the origins of number representations

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Recent evidence suggests that differences in the representations of arithmetic word problems originate in seemingly irrelevant non-mathematical pieces of world knowledge involved in problem statements (Gamo, Sander & Richard, 2010; Gros, Thibaut & Sander, 2017). The daily knowledge one has about the elements described in a problem statement appears to make different mathematical relations salient, and thus emphasize either the ordinal or the cardinal nature (Frege, 1980) of the numerical values featured. Thus, problems involving entities that are usually grouped together (for example, turtles and iguanas being kept in a vivarium or red and blue marbles being stored in a bag) tend to emphasize cardinality of the numerical values. On the other hand, problems involving elements that have an ontological order, usually represented along axes (for example piano lessons occurring over time, or people using an elevator to go from one floor to another), emphasize ordinality of the numerical values instead. We used isomorphic problems that were embodied either in a cardinal or in an ordinal context to investigate this issue. We performed 5 experiments illustrating how tasks such as problem classification, analogical transfer, problem solving, solvability assessment and solution evaluation are significantly influenced by the distinction hypothesized between the cardinal and ordinal aspects of numbers. Results in each experiment showed that from this distinction originated crucial differences in participants' answers. This highlights the decisive role of non-mathematical world knowledge in arithmetic reasoning and the importance of integrating this issue in the design of educational curriculum in mathematics.

Keywords: Arithmetic word problems - Semantic representations - Problem solving - Numerical representations.

POSTER ABSTRACTS

1. Visual and tactile ANS acuity: development from kindergartners to adults and relationships with mathematics achievement

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To represent and process numerical magnitude, humans rely on an approximate number system (ANS). This system can process numerosities in different sensorial modalities (i.e. visual, auditory, tactile). However, its acuity is usually measured with visual stimuli. Two main results have been shown about ANS acuity: improvement with age and weak correlation with mathematics achievement, especially beyond 6 years of age. The present research aimed to investigate if these two results are specific to the visual modality or if they can be generalized to another sensorial modality: the haptic modality. Four different age groups were recruited: 5- (n=49), 10- (n=61), 14-year-old children (n=46) and adults (n=56). Participants were asked to perform two nonsymbolic number comparison tasks, one involving the visual sensorial modality (Panamath) and the other one the haptic sensorial modality, two tasks measuring mathematics achievement (addition problems and numerical verbal problems), and Raven's Matrices used to control for general cognitive ability. Results from the two nonsymbolic number comparison tasks showed that ANS acuity improved with age, especially between 5 and 10 years of age. Simple correlations were significant in 5-year-olds between haptic ANS acuity and addition problems and between visual ANS acuity and numerical verbal problem, and in adults between visual ANS acuity and addition problems. No significant relationship was observed in 10- and 14-year-olds. When controlling for general cognitive ability, significant relationships only remained in 5-year-olds between haptic ANS acuity and addition problems. Our findings suggest that the two ANS tasks do not involve exactly the same processes.

Keywords: ANS - Numerical cognition - Development - Haptic modality.

2. Developmental trajectories of children's symbolic numerical magnitude processing skills and associated cognitive competencies

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While symbolic numerical magnitude processing skills are key for learning arithmetic, its developmental trajectories remain unknown. We therefore delineated in the first three years of primary education (ages 5-8) groups with distinguishable developmental trajectories of symbolic numerical magnitude processing skills, using a model-based clustering approach. Three clusters or groups of children were identified and were labeled as: inaccurate, accurate but slow and accurate and fast. The clusters did not differ in age, sex, socioeconomic status and IQ. We additionally tested whether these clusters differed in domain-specific (non-symbolic magnitude processing; digit identification) and domain-general (visuospatial short-term memory; verbal working memory; processing speed) cognitive competencies that might contribute to children's ability to (efficiently) process the numerical meaning of Arabic numerical symbols. We observed minor differences between clusters in these cognitive competencies, except for verbal working memory for which no differences were observed. Follow-up analyses further revealed that the abovementioned cognitive competencies not merely accounted for the cluster differences in children's development of symbolic numerical magnitude processing skills, suggesting that other factors account for these individual differences. On the other hand, the three trajectories of symbolic numerical magnitude processing revealed remarkable and stable differences in children's arithmetic fact retrieval, stressing the importance of symbolic numerical magnitude processing for learning arithmetic, but also raising the question whether this association might be bidirectional.

Keywords: Symbolic numerical magnitude development - Developmental trajectories - Arithmetic development - Longitudinal design.

3. Finger calculation precedes finger counting during the course of development

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In this study, 5 to-6-year old children were followed longitudinally over two years. They were presented sequentially with a series of pictures and were asked to count the number of pictures while naming them. Because the phonological loop is blocked during the task, it is hardly possible to count the pictures without keeping track of the number of pictures on fingers. In the first year and out of 82 children, 31 used their fingers in order to perform the task. The same children were also asked to solve simple additions and we

observed whether or not they calculated on their fingers. Almost all children who used their fingers in the picture naming task also used them in the addition task (i.e., 28 out of 31). In contrast and interestingly, about half of the 51 children (i.e., 24) who did not count on their fingers in the picture naming task, used them to calculate in the addition task. In the second year, 30 children instead of 51 still did not use their fingers in the counting task whereas almost all of them used them to calculate. Therefore, children can implement a finger counting strategy to calculate but do not think of using the finger strategy in a counting task when it is nonetheless a condition of success. We conclude that children can be inflexible in their use of finger counting because they cannot transfer their clever strategy from one numerical task to another.

Keywords: Finger calculation - Finger counting - Development.

4. The longitudinal influence of fingers on the acquisition of discrete cardinal number knowledge

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Fingers are widely and systematically used for counting and representing numbers in early stages of numerical development. Due to these embodied experiences of numbers it was argued that fingers are important tools for the acquisition of numerical representations, including discrete cardinal number knowledge. Accordingly, children who are more successful at using their fingers to convey numerical quantities should also perform better in understanding the cardinality principle. To evaluate this assumption, we assessed 55 children (25 boys, mean age 46 months at first assessment time point, SD 2.88 months) longitudinally on measures of i) finger numeral pattern display and ii) recognition as well as on their knowledge of iii) discrete cardinality (i.e., give-N task) and iv) approximate quantifiers (e.g., “some”, “none”, “a couple”). Participants were reassessed around 12 and 18 months later. When controlling for gender and vocabulary (as a measure of general cognitive ability), higher scores on actively displaying quantities with fingers at age 3.5 were associated with better cardinality knowledge 12 months later ($r = .38$ $p < .01$), and better passive finger pattern recognition assessed at the same age was associated with better cardinality knowledge 18 months later ($r = .31$ $p < .05$). On the other hand, knowledge of quantifiers was not associated with any of the finger-based numerical measures. These results corroborate the importance of finger-based numerical strategies for the acquisition of early numerical abilities such as cardinal knowledge of discrete quantities.

Keywords: Finger counting - Numerical development - Give-N task - Cardinality knowledge.

5. Difficulties to develop sense of fractions

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Developing the sense of fraction is tough at primary school. The intuitive conception amounts to understand fractions as bipartite structures (Bonato et al., 2007) linked to division (a/b is a divided by b). This conception is reinforced due to examples that align a/b form with examples of part/whole (DeWolf et al., 2013), and therefore fraction is seen as a division of two numbers and not as a number (Sophian, 2007). We analyze difficulties in understanding fraction as a quantity in sentences through two problems: one with a unit used in daily-life « how many quarters of an hour are in 3⁄4 of hour? » and one with a non-usual unit "... third of... in 2/3 of hour?". We hypothesize that despite the answer is mentioned in the question, pupils fail to answer and formalize it (a/b= ax1/b or a/b=1/b+1/b+...). 157 students (4th& 5th Grade) have to solve one of the above-mentioned problems. The success rate is 46%, - 54% for "usual" problems and 37% for "non-usual"- and the rate of mathematical formalization is 7% for both problems. As predicted the success rate is low, given the answer is in the statement. Indeed, understanding that a unit can be a fraction - "quarter of hour"- should overcome the intuitive conception of the bipartite structure. Even though language habits suggest the answer, they do not foster the mathematical formalization, namely understanding that a fraction can be decomposed as a value multiplied by a number "3 quarters is like 3 multiplied by 1 quarter."

Keywords: Preconceptions - Fractions - Conceptual development.

6. The impact of Montessori education for the development of early numerical abilities: A longitudinal randomized controlled study on disadvantaged preschoolers

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In the early 20th century, Maria Montessori developed an educational method based on individualized learning, multisensory materials and free choice of activities. This method – which has gained popularity in recent years -- includes a complete math curriculum for preschoolers, with a precise progression and specific manipulative materials. Although several aspects of this curriculum are supported by cognitive science, few studies have evaluated its impact on math learning. Moreover, prior studies have methodological issues (e.g., cross-sectional design, limited range of math skills studied).

The goal of this longitudinal study was to measure the impact of Montessori education on the development of early numerical abilities in children from a disadvantaged neighborhood in France. Specifically, we compared math skills of children who were randomly assigned to either Montessori (n=32) or conventional classrooms (n=40). We tested them at the beginning of their first year of preschool and 1.5 years later with two tasks: the Applied Problems task of the Woodcock-Johnson-III battery and a set of tasks designed to assess a variety of math skills (i.e., the "math didactical diagnosis" battery, or MDD). Our results showed that children in Montessori classrooms made progress at a higher rate than children in conventional classrooms in the Applied Problems task ($F(1, 68)= 9.71$, $p= 0.003$, $BF10= 11.56$) and in the MDD ($F(1, 70)= 3.83$, $p= 0.054$, $BF10= 1.34$). Increased rates of learning were particularly salient in tasks involving number symbols' recognition ($F(1, 70)= 8.81$, $p=0.004$, $BF10= 20.65$) and simple non-symbolic arithmetic ($F(1, 70)= 6.67$, $p=0.01$, $BF10= 7.03$).

Keywords: Montessori - Preschool - Early numerical abilities - Low socioeconomic status.

7. Development of numerical skills in children aged from 5 to 12 using touch-enabled computerized tasks

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Numerical skills are of daily use and thus crucial for children's intellectual development. Because of this crucial role, numerous studies have investigated numerical skills in children throughout the years. However, some computerized tasks that are implemented to study such skills may seem unintuitive to some children of early age as they require the use of a keyboard. In this study, we measured reaction times in children from age 5 to 12 through computerized tasks using touch as a more natural way to provide responses. For each age group, 22 children (a total of 176 participants) performed four numerical tasks (symbolic number comparison, number line estimation, numerosity estimation, and subitizing task). We analyzed reaction times for subitizing, numerosity estimation, and symbolic number comparison within and between each age group. In addition, we investigated to what extent number line estimation was able to predict reaction time performance on the three aforementioned tasks. As expected, reaction time decreases with age as children gain more proficiency in numerical skills for all tasks although significant gain in reaction time did not benefit from age similarly throughout the different tasks. Number line estimation was a significant predictor of reaction time for subitizing, but not for symbolic number comparison after controlling for age. Our results provide evidence that touch-enabled interfaces can be used in children tasks for numerical skills and may provide further insight on results and inconsistencies found in previous literature.

Keywords: Numerical cognition - Children - Development.

8. Effects of the home learning environment on math skills in elementary school

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Math knowledge in children is characterized by inter-individual differences that persist through most school years. Because some of these differences can be observed even before children start formal schooling, they may (at least in part) come from children's social environment. In line with this hypothesis, a growing number of studies have shown that home environments in which parents exhibit positive attitudes towards math and expose their children to number- related activities promote math learning in children. However, prior studies have exclusively focused on the math home learning environment (MHLE) of preschoolers. Therefore, it remains unclear to what extent the MHLE influences math learning later on, i.e., when children formally learn math in elementary school. Here we measured the MHLE of 8-year-olds by asking parents to complete an extensive questionnaire assessing their beliefs, expectations and behaviors towards math. Math knowledge in children was assessed using an arithmetic test (i.e., the Math Fluency task of the Woodcock-Johnson-III battery) and a battery measuring a range of numeracy skills (i.e., the Zareki-R). Our preliminary results show a relation between children's math skills and maternal reports of home math activities, both for the Math Fluency ($r=0.62$; $p=0.01$) and the Zareki-R ($r=0.50$; $p=0.06$). Interestingly, this relation held even when only implicit math-related activities were considered (e.g., playing board games). Thus, our results suggest that the impact of the math home learning environment on children's math knowledge may not be restricted to the preschool period but may also affect math learning later on.

Keywords: Home Learning Environment - Math skills - Elementary school.

9. Arithmetic Word Problems Describing Discrete Quantities: E.E.G Evidence for the Construction of a Situation Model

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In this research, university students were asked to solve arithmetic word problems constructed either with discrete quantities, such as apples or marbles, or continuous quantities such as meters of rope or grams of sand. An analysis of the brain activity showed different alpha levels between the two types of problems with, noticeably, a lower alpha power in the parieto- occipital area for problems describing discrete quantities. This

suggests that processing discrete quantities during problem solving prompts more mental imagery than processing continuous quantities. These results are difficult to reconcile with the schema theory according to which arithmetic problem solving depends on the activation of ready-made mental frames stored in long-term memory and triggered by the mathematical expression used in the texts. Within the schema framework, the nature of the objects described in the text should be quickly abstracted during problem solving because it cannot impact the semantic structure of the problem. On the contrary, our results support the situation model theory, which places greater emphasis on the problem context in order to account for individuals' behaviour.

Keywords: Numerical cognition - Mental Arithmetic - Compare problems - Situation Models - Text Comprehension.

10. Automatic visual discrimination of digits and letters in first graders and adults: an EEG Fast Periodic Visual Stimulation study

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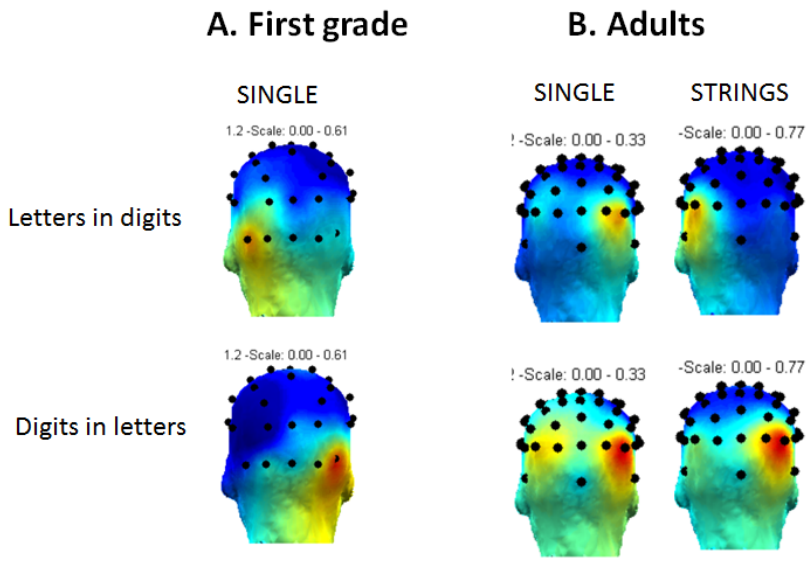
Both letters and digits are arbitrary visual shapes that are distinguished into categories only after cultural acquisition. The observation that digits are easier to identify than letters has been repeatedly reported in the literature (Shubert, 2017). In the present study, we used a Fast Periodic Visual Stimulation approach with EEG recordings to assess the automatic discrimination of letters and digits from each other in 1st grade children (N=17) and in adults (N=18). Participants viewed 40 sec sequences (3 repetitions per condition) of frequent stimuli (letters or digits) at a fast periodic rate (adults: 10Hz, children: 6Hz), in which rare stimuli (the other category of alphanumeric symbols) were periodically inserted (every five items, e.g., adults: at 2Hz, children: at 1.2Hz). Results showed discrimination responses in both groups in posterior occipito-temporal regions with clear changes in lateralization patterns. In children, stimuli contained only single elements. Responses were right-lateralized for digits among letters, and revealed a trend for left-lateralization for letters among digits. In adults, when stimuli contained only 1 character, both letters and digits gave rise to responses in the RH. However, when strings of characters were presented, then letters were discriminated from digits in the LH. These findings show a developmental pattern where single elements in children seem to be processed like strings of elements in adults.



Supplementary Figure. Topographical maps for **A.** children and **B.** adults for the discrimination response in Fast Periodic Visual Stimulation for letters among digits (first row) and digits among letters (second row). Children viewed only single elements at 6Hz, and adults viewed both single and strings of elements at 10Hz.

Keywords: Visual recognition - Numbers - Letters - EEG - Children - Adults.

11. The neural correlates associated with numerical and non-numerical as well as symbolic and non-symbolic ordinal processing

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Investigations that explore the cognitive mechanisms of numerical ordinal processing (i.e., verifying the order of elements in a set) have significantly increased over the past years. Findings from this research have indicated that the ordinal processing of number symbols (i.e., digits) relies on specific cognitive mechanisms that constitute unique and reliable predictors of arithmetic abilities. The cognitive architecture associated with this processing remains, however, poorly understood. As a consequence, the present study aimed to further explore the neural correlates associated with numerical, non-numerical, symbolic and non- symbolic ordinal processing. Functional magnetic resonance imaging data from 24 adults were collected while participants performed a symbolic-numerical (digits), a symbolic-non- numerical (letters of the alphabet), a non-symbolic-numerical (dot-arrays), and a non- symbolic-non-numerical ordinal (patches of lines) verification task. In each condition, three stimuli were presented on a computer

screen and participants had to indicate as fast and as accurate as possible whether the stimuli were displayed in a correct order (e.g., 2 3 4) or an incorrect order (e.g., 3 6 4). The performed analysis of variance revealed brain activation differences between the numerical and non-numerical conditions in the anterior cingulate and the middle temporal gyrus. Activation differences between the symbolic and non-symbolic conditions were found in the middle frontal, angular and parahippocampal gyrus. An overlap in brain activation across all conditions was found in the angular gyrus and the posterior parietal cortex. Together, these findings indicate that both format-specific as well as format-general processing mechanisms are associated with the verification of ordinal sequences.

Keywords: Numerical order - Numerical cognition - Functional magnetic resonance imaging.

12. Neurofunctional changes in fraction learning: results of a training study

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To evaluate 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 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 items. Additionally, we observed significant changes in activation patterns of 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.

Keywords: Fraction learning - Magnitude representation - Neurofunctional plasticity.

13. Screening early for math learning difficulties with a nonverbal cross-modal addition task

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Although numerical skills are essential in modern societies, a considerable part of the population suffers from mathematical learning disabilities. Due to the hierarchical nature of mathematical knowledge, screening during the earliest stages of learning is essential to intervene efficiently. While different screening tools exist, they rely on verbal instructions and/or task content, hampering their usefulness in linguistically heterogeneous school populations. We developed a 3-minute computerized task that requires participants to encode both auditory and visual numerical information to respond to the task's demands. For task instruction, participants were presented a video showing a person correctly solving three easy items of the task, before moving on to a practice session of three different items. If any item was solved incorrectly, the entire practice session was repeated. We administered the task to a sample of first grade students (N=71) and collected participant's performance in standardized addition, subtraction (De Vos, 1992) and number comparison (1 and 2-digit) tasks (Brankaer, Ghesquière, & De Smedt, 2017). A multivariate analysis with practice repetition as between-subject factor on the four standardized control measures revealed that participants who repeated the practice session scored significantly lower in three out of four dependent measures. These results suggest that the immediate understanding (i.e. practice items solved correctly on the first try) of the cross-modal addition task, requiring deductive reasoning and an abstract, format-independent representation of quantity, can rapidly and nonverbally differentiate between high (65%) and low (35%) performers on standardized measures of basic math competence. Implications and limitations will be discussed.

Keywords: Nonverbal - Mathematics - Screener - Dyscalculia - Multilingual - Diagnostics.

14. Does a dyscalculic child use the inversion principle to solve a 3-term arithmetic problem: the impact of the presentation condition

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Numerical inversion is an important conceptual principle in arithmetic. It is the ability to understand that addition is the opposite of subtraction and vice versa. Thus, adding a particular number *b* to a set *a* can be cancelled by subtracting the same number *b (*a+b-b=a). Complex arithmetic sums can then be solved without calculating thanks to this conceptual shortcut. To verify the implicitly use of this principle it is possible to compare inverse problems with standard three-term problems (a+b-c). If it is used, then the performances in the inverse problems will be higher than in the standard problems since no calculation is necessary. Although many studies have taken interest in this principle in children, to our knowledge this was never studied in children with dyscalculia (DYS). Our aim is 1/ to study if 9/10-year-olds with DYS are able to use this principle in 3-term arithmetic problems and 2/ to assess the importance of the presentation condition. To this end, 64 children with or without dyscalculia solved problems allowing (inverse problem) or not (standard problem) the use of the inversion principle into two presentation conditions (symbolic or picture). The results showed that even if the DYS children have difficulties in solving arithmetic problems, they are able when the problem is presented with pictures to identify and use efficiently the conceptual inversion shortcut and by so doing equal the performances of the control children. These results provide us interesting perspectives for helping DYS children.

Keywords: Dyscalculia - Inversion principle - Arithmetic.

15. Non-adaptive strategy selection in adults with high mathematical anxiety

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Participants with mathematical anxiety (MA) tend to show particular difficulty in mathematical operations with high working memory (WM) demands compared to operations with lower WM demands. Accordingly, we examined strategy selection to test the cognitive mechanism underlying the observed weakness of high MA participants in

mathematical operations with high WM demands. We compared two groups of college students with high or low MA, in the solution of simple non-carry addition problems (e.g., 54+63) and complex carryover addition problems (e.g., 59+63). The results indicated that high MA participants showed particular difficulty in the harder carry condition. Testing the strategy selection mechanism among high MA participants, we found in the carry condition 1) they used the common strategy less often compared to low MA participants and 2) employed unusual strategies more often compared to low MA participants. Therefore, high MA participants were less efficient in their strategy selection, which may be due to weaker spatial representations, numerical difficulties, or less experience solving complex problems. These primitive representations are not adaptive, and can negatively impact performance in math tasks with high WM demands.

Keywords: Strategy choice - Arithmetic - Spatial representation - Mathematical anxiety - Quantities.

16. Arithmetic Skills in Older Adults: Evidence for the Use of Automatized Procedures

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In contrast with other cognitive abilities, arithmetic skills are known to be preserved in healthy elderly adults. In fact, they would even outperform young adults because they retrieve more often the results of arithmetic facts from long-term memory. However, a new conception of arithmetic-skill development suggests that the results of very simple additions such as 2 + 3 are not retrieved from memory by young expert adults but rather solved through the use of automatized and unconscious counting procedures. In order to determine whether the application of such procedures can also be revealed in older adults, we tested 18 expert participants aged from 60 to 77 using the sign priming paradigm. As already observed in young adults, we showed that presenting the "+" sign 150 ms before the operands speeds up the solving process compared with a situation wherein the problem is classically presented in its whole on the screen. This result is interpreted as the indicator of the pre-activation of an abstract procedure as soon as the arithmetic sign is presented. These results challenge previous conclusions in literature by suggesting that the superiority of older adults in mental addition does not stem from more frequent reliance on retrieval strategy but, rather, on the more efficient implementation of automatized procedures. This might give new insight for the conception of training programs aiming at preserving numerical skills and, in a longer term perspective, at maintaining older adults' financial autonomy, which is decisive for keeping them in charge of their daily life.

Keywords: Additions - Procedure - Older adults.

17. Retrieval or counting procedures for simple addition problems?

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For years, it has been assumed that addition problems involving two one-digit operands, such as 2 + 3, are solved through retrieval of the result from long-term memory. However, this assumption has been recently challenged and several recent studies suggest that, for such simple problems, adults could in fact resort to very fast and unconscious counting procedures. In one of previous studies, we asked adults to solve additions from 1 + 1 to 9 + 9 and we examined the distribution of solution times as a function of the sums of the problems. For non-tie problems, solution times clearly increased for additions with a sum equal or inferior to 7 or with a sum above 10, which is compatible with the view that individuals use one by one counting procedures. However and strikingly, no increase was observed for non-tie additions with a sum ranging from 8 to 10, suggesting that adults could solve these problems by retrieval strategies. Nevertheless, in the present study, we show that this plateau in solution times is already observable in 6-to-7-year-old children at the beginning of the school year. Because these children are obviously too young and too inexperienced to retrieve the results of such addition problems we conclude that the plateau does not reflect retrieval strategy.

Keywords: Arithmetic - Strategy.

18. Performing mental arithmetic tasks affects spatial attention: Evidence from temporal order judgments

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Previous research has shown that the concepts of numbers and space are linked. In the context of arithmetic processing, it has been demonstrated that solving addition and subtraction problems shifts attention to the right and left side of space, respectively. However, it remains unclear at what point during arithmetic processing these attentional shifts occur. On top of that, so far it has not been investigated whether the auditory presentation of two-digit arithmetic problems has an impact on the visuo-spatial domain which would indicate that the observed bias is due to a central processing stage. The present study addresses these issues by using a temporal order judgment task (TOJ) where participants need to decide which of two lateralized stimuli was presented first in the context of solving two-digit addition and subtraction problems presented auditorily via headphones. In a dual-task set-up, participants were first presented with the arithmetic problems and performed the TOJ task after a varying delay (250, 750 & 1500 ms) before responding to the arithmetic task. We found that addition tasks induced attentional shifts

to the right and that these shifts appear to be more likely after shorter delays. This suggests that visuospatial attention mechanisms are recruited during mental (symbolic) calculation. The observation that an auditory input can affect performance in a visuo-spatial task provides evidence for a magnitude representation that is inherently spatially oriented. Further research is needed to clarify whether general attentional resources have an impact on these effects.

Keywords: Numerical cognition - Mental arithmetic - Visuospatial attention - Attentional shifts - Operational momentum.

19. Irrelevant numerosity and visual cues influence time reproduction

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Numerosity judgments are affected by the non-numeric visual features of the stimuli (e.g., aggregate area, convex hull). Typically, dot sets with larger convex hulls are overestimated. Whether these influences occur at the perceptual level or emerge from the strategic use of visual features remains uncertain. To tackle this issue and prevent the strategic use of visual cues, we used a paradigm in which stimulus (perceived) numerosity was not the target of the task, but could still influence the performance. Participants had to reproduce the display duration of visual stimuli consisting of dot sets by the duration of their button press. Beyond duration, we manipulated orthogonally the numerosity, as well as the size of the convex hull of the stimulus. Based on previous results in time estimation (Chang et al, 2011), we predicted that more numerous sets would be associated with longer presses. Furthermore, given the link between convex hulls and estimated numerosities, we expected that, at equal durations and (physical) numerosities, arrays with larger convex hulls would lead to longer button presses. The results confirmed our hypotheses, indicating that convex hull and numerosity are automatically extracted even when they are not strategically useful. These findings also support the notion that closely linked magnitude representations underlie numerical and temporal processing. Whether visual cues interfere directly on time judgment or indirectly through their influence on perceived numerosity remains however an open question that would need further investigation.

Keywords: Numerical cognition - Time Reproduction - Magnitude representation.

20. The temporal dynamics of numerosity comparison : insights from response trajectories

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Our ability to estimate the number of items in a set is often ascribed to the Approximate Number System (ANS). In a comparison task, however, performance is not only driven by the numerosities of the arrays but also by their visual properties (e.g., convex hull). To account for these effects, authors have recently modeled the numerosity comparison as a weighting process, teasing apart the effects of ANS acuity from those of the non-numeric stimulus features. The major drawback of this model is that it is static: It predicts well the final choice (i.e. the set selected) but does not allow to make inferences about how processing evolves over time. This is particularly annoying considering that recent data suggest that numerical representation precision and influence of visual properties are time- dependent. To overcome this limitation and provide insights on the dynamics of the process, we tracked continuous hand movements during a comparison task, in which we orthogonally manipulated numerosity, size, and convex hull ratios. Analyzing the evolution of the trajectory over time allowed us to map out a timeline of the relative weights of numerosity and visual properties during the comparison process.

Keywords: Numerical cognition - Numerosity comparison - Visual cues - Temporal dynamics.

21. Are numerosity, size and spacing processed independently?

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Université Libre de Bruxelles (CRCN)

Dewind et al (2015) proposed a method to orthogonally manipulate numerosity and two dimensions, labeled Size and Spacing, mathematically derived from the continuous visual properties of dot collections. They showed that both dimensions influences numerosity judgments. Nevertheless, they did not examine the impact of numerosity on the non- numerical features. In the present study we studied the three dimensions by asking participants to detect changes in either one. The experiment consisted of a Go/No-Go task with collections of dots (ranging from 13 to 44) created following Dewind et al (2015). Participants had to press a button whenever they detected a change in numerosity, a change in Size or a change in both. Changes either deviated by a small or a larger ratio. Our results showed reciprocal influences of Size (Spacing) on numerosity as well as numerosity on Size (Spacing). It suggests thus an influence of the non-numerical features on numerosity judgements, as found by Dewind et al (2015), but also an impact of numerosity on the judgements of non-numerical features. Thus, even if we can make stimulus properties mathematically orthogonal it doesn't mean that they are treated independently.

Keywords: Numerical cognition - Numerosity extraction.

22. Two-digit number transcoding in bilingual and monolingual adults: does the order of tens and units matter?

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The German number word system inverts units and tens compared to the symbolic Arabic notation. At the opposite, the French number words are more transparent with respect to the Arabic number code. The linguistic structure of number words can facilitate or impede numerical development and performances in number transcoding tasks. Here, we investigate the influence of inverted (i.e. German) and non-inverted (i.e. French) number-words in transcoding task in a group of monolingual and a group of bilingual adults. We used an original transcoding paradigm in both monolingual and bilingual university students who listened to two-digit numbers and had to identify the heard number amongst four visually presented Arabic numbers. Our paradigm manipulated the order of appearance of the units and tens of two-digit numbers on the screen to mimic the German vs. the French number word systems. More precisely, Units-first appearance for German, Tens-first appearance for French, and finally Simultaneous appearance similarly as in a classical transcoding task. Monolinguals were significantly faster than bilinguals (in their respective language) during the Simultaneous condition. In contrast, bilinguals did not systematically differ from monolinguals during the decomposed conditions. This suggests that similar strategies (e.g. decomposition) are used by bilinguals and monolinguals when processing sequentially presented two-digit numbers. We conclude that speaking two languages has a cost even in a simple cognitive task such as transcoding. In other words, bilingual minds do not simply correspond to the sum of two monolingual minds. Taken together, the results provide new insights on how language structure qualitatively influences basic numerical processing, even in adulthood.

Keywords: Bilingual - Transcoding - Two - Digit number - Numerical cognition.

23. Two-digit number transcoding in bilingual and monolingual adults: does the order of tens and units matter?

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It has been repeatedly shown that finger sensitivity, or finger gnosia, is a good predictor of children mathematical achievement. Two different explanations can account for this surprising result. First, this relationship can be due to a mere neuroanatomical overlap of the brain areas specialized in finger sense and number sense. Second, this

relationship could result from a functional link between fingers and numbers, through finger counting for example. Therefore, if finger gnosia is damaged, the neuroanatomical explanation leads to the prediction that all numerical abilities, including non-symbolic ones, will be impaired whereas the functional hypothesis leads to the prediction that only numerical skills involving finger use will be impaired. Our results show that, compared with a control group, children suffering from finger sensori-motor impairments without cognitive deficits also present non-symbolic numerical processing deficits. Nevertheless, at a more individual level of analysis, the majority of children in our sample presents preserved non-symbolic abilities. We can conclude that the overlap of the brain areas devoted to number and finger processing does not prevent number and finger abilities from developing independently from each other. Therefore, a mere neuroanatomical explanation of the relationship between finger gnosia and mathematical abilities is not sufficient and more functionalist explanations will have to be favored.

Keywords: Finger gnosia - Number sense - Neuroanatomic explanation - Functional hypothesis - Finger sensori - Motor impairments.

24. Cardinal understanding of the hierarchical structure of number words

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Theories of numerical cognition has identified the successor principle as the critical ingredient to children's understanding of natural numbers. However, there is no agreed-upon account about how successor principle is acquired or even methods to assess children's understanding of it. Based on the proposition that the hierarchical and recursive linguistic structure of numerals allows the discrete infinite property of natural numbers (Hurford, 1975, 1987), we posit that children's cardinal understanding of the hierarchical structure of number words is key to their understanding of the natural number system. In this study, we developed a task to assess this knowledge, examined the age at which children understand the hierarchical structure of numerals, and tested how this understanding relates to other types of numerical knowledge. We found that children's ability to infer the successors of numbers is necessary but not sufficient to understand the hierarchical structure of number words. In particular, 5-year-old children who correctly infer the next number of a cardinal value fail to understand the meaning of the hierarchical structure of number words, which is not acquired until 6 years of age. Furthermore, we found that this hierarchical understanding is associated with children's counting ability and syntactic comprehension of number words. These results bolster the idea that the linguistic structure of numerals is key to understanding the principles of the natural number system, and further indicate that acquisition of the successor principle (indirectly assessed by the cardinal understanding of the hierarchical structure of number words) is much protracted than previously thought.

25. Influences of grammatical number on numerical processing in educated adults

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The presence of grammatical distinction between singular and plural increases saliency of "one" versus "more than one" differentiation. Children, speaking languages with such a distinction, acquire numbers faster. However, there are some languages with an opaque relationship between grammatical form and the number of elements. In Polish, in number- indicating sentences 1 is preceded by the singular form of the verb "to be", 2-4 are preceded by the plural form of the verb, and followed by plural-nominative form of noun (like in English), but 5-9 again by the singular form of the verb and followed by the plural, genitive form of the quantified noun. The same syntax is used in the second decade, and with multi- digit numbers above 20, numbers ending with 0,1,5,6,7,8,9 whereas to those ending with 2,3,4 standard plural-nominative syntax applies. We investigated whether inconsistencies in grammatical number influence numerical processing in adults. We tested 98 Polish, German, and English native speakers. Participants were presented with short sentences, e.g., "There is/are 23/36" [number corresponding either with singular or plural in Polish]. They were cued whether they are to classify the grammatical number of the verb or number parity. No language differences were observed in the grammatical judgement. For parity judgment, Polish, but not English or German speakers, responded faster when the verb form corresponded to the grammatical number of the presented number. This result suggests that when grammatical number is made salient, it influences numerical processing in adults providing another instance of linguistic influence on numerical cognition.

Keywords: Grammatical number - Linguistic influences – Adults.

26. Strategic adaptations to dual tasking and concurrent articulation in working memory

Clément Belletier, J. Doherty, A. Jaroslawska, S. Rhodes, Nelson Cowan, M. Naveh-Benjamin, Robert Logie, Pierre Barrouillet, & Valérie Camos

In experimental studies, whereas working memory is often pushed to the limits of its capacity, recall performance rarely falls to zero, regardless of memory or processing load. A key question is thus to understand the cognitive functions supporting this residual performance. Here, investigators associated with three different theoretical frameworks (Barrouillet & Camos, 2012; Cowan, 2010; Logie, 2011) collaborated to address this question. In four experiments, participants were first assessed on a serial recall of letter

sequences and a processing task (arithmetic verification). They then performed the same tasks at their individual span, alone and in combination, with or without a concurrent articulation. Finally, they reported the strategies they used in each condition. Results revealed that strategy choices were task-dependent. Participants reported using less rehearsal and more meaning-related strategies under concurrent articulation. Moreover, they sometimes gave up on maintaining the letters (in the memory task) and used more intuitive rather than step by step calculations in the arithmetic task under dual tasking. These findings argue for more research on strategic adaptation in working memory.

27. Does attentional refreshing allow a long-term memory implication in a working memory span task?

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Long-term memory (LTM) is known to affect recall during working memory (WM) tasks. However, the way LTM intervene in WM remains unknown. To address this issue, the implication of LTM representations in a WM span task was manipulated through variations of the associative relatedness of the memory items. Moreover, the concurrent cognitive load was varied to manipulate refreshing opportunities. Different WM models were compared (Barrouillet, Bernardin, & Camos, 2004; Cowan, 1999; Unsworth & Engle, 2007) on the variation of associative relatedness effect according to the cogntive load. Children and adults were also contrasted, children using refreshing and relatedness cues less efficiently. Despite the impact of both manipulated factors on recall, associative relatedness and cognitive load did not interact neither in children nor in adults. This suggests that refreshing might not rely on LTM representations' retrieval, supporting the latest view on refreshing in the Embedded-Processes model (Vergauwe & Cowan, 2015).

Keywords: Working memory - Long-term memory - Associative relatedness effect - Attentional refreshing.

28. A game-like context helps 5-year-olds' working memory performance when presented first

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Goal maintenance has been shown to be crucial in preschoolers' executive functions (Chevalier, 2015). Accordingly, the presentation of goal cues during a task improves their performance in flexibility and inhibition tasks (Blaye & Chevalier, 2011). In another executive function, namely working memory (WM), it has been shown that a

game context can improve their performance when testing memory in recognition tasks (Bertrand & Camos, 2015; Istomina, 1948). The aim of the present study was to examine whether such a game context provides some goal cues that enhance preschoolers' WM performance. In Experiment 1, 5-year-olds had to maintain verbal information in either a game-like or an exercise context for further recall or recognition of memory items. Despite the fact that neither the context nor the type of task (recall or recognition) impacted WM performance, preschoolers who did the game-like context condition first had better performance than those who did the exercise condition first. This result suggests that preschoolers would be able to take advantage of the game-like condition to integrate some task requirements, which are beneficial for performing the second condition, the reverse order of the two context conditions being unhelpful. In a second on-going experiment, we test how the goal cueing provided by the game-like context is at the root of this beneficial effect.

Keywords: Goal setting - Working memory – Preschoolers - Playing.

29. Verbal working memory maintenance strategies in aging: a trial by trial report study

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Maintenance of information in working memory is well-known to decline during aging. Still unclear are the sources of such aging effects. In particular, we ignore whether older adults exhibit poorer performance than young adults to maintain information in working memory because they use different, less efficient sets of maintenance mechanisms than young adults, or because both populations use the same mechanisms but older adults are less able than young adults to execute them efficiently. To address this issue, we collected trial-by-trial verbal reports of which strategy young and older adults use while accomplishing a verbal complex span task. Overall, results document age-related differences and invariance in strategic aspects of working memory. Our findings suggest than an important source of age-related changes in working memory stems from older adults' using different maintenance mechanisms. The implications of our findings on our understanding of age-related changes in working memory during adulthood are discussed in the framework of the Time-Based Resource Sharing model of working memory (Barrouillet & Camos, 2004, 2015) and of a strategy perspective on cognitive aging (Lemaire, 2016).

Keywords: Verbal working memory - Cognitive aging - Strategy use.

30. Evidence for refreshing in working memory in 8 to 12 years old children?

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Refreshing in working memory (WM) refers to the attentional mechanism of briefly bringing back information into the focus of attention, preventing short-term forgetting. Refreshing has often been investigated by means of the cognitive load (CL) effect. This effect refers to the observation that WM performance decreases as the CL of a concurrent task increases. The rationale behind the CL effect is that the more attention is taken by the concurrent task, the less attention is available for refreshing, resulting in poorer memory performance. The CL effect has been shown for adults, making use of different types of memory materials (verbal, spatial, visual) as well as different types of materials used in the concurrent task (verbal, spatial, visual, neutral). The CL effect has also been demonstrated for children, starting at the age of about seven years old. However, the effect has mainly been shown using verbal memory material and verbal concurrent task material. The aim of the present study was to further investigate the CL effect in children between eight and twelve years old, using different kinds of materials. We present two experiments in which the nature of the memory material was varied systematically: verbal, spatial or verbal-spatial associations. The nature of the concurrent task was verbal in the first experiment and domain-neutral in the second experiment. Overall, we observed a CL effect, although not all combinations of memory and concurrent task material followed this same pattern. The boundary conditions of the CL effect in children will be discussed.

Keywords: Working memory - Refreshing - Cognitive load.

31. Consolidation and/or Refreshing: What do people typically do between list items?

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It is commonly assumed that attention-demanding post-encoding processes take place during the free time immediately following encoding of each memory item in a list. These processes are thought to prevent loss of information from working memory (WM). We tested whether inter-item pauses during presentation of a list are used to focus attention (1) on the last- presented memory item or (2) on all items currently in WM, and (3) whether this changes over time. Here, we presented black probe letters between to-be-remembered red letters. Participants judged whether each probe letter corresponded to the last-presented memory item (last-item match group) or to any of the memory items

presented up to that point in the list (any-item match group). To examine mnemonic processing as a function of time, the delay between the to-be-remembered letter and the following probe was manipulated in three experiments. When pre-probe delays and inter-item intervals were relatively short (Experiment 1), recall performance was observed to be better in the last-item match group and this did not change as a function of the duration of the delay before the probe. When pre- probe delays and inter-item intervals were longer however (Experiment 2), this disruptive effect of Any-item match instructions was no longer observed. This pattern was found again in Experiment 3 and suggests that the nature of the attention-demanding post-encoding processes taking place in between memory items depends on task context in a systematic manner. The results are discussed in terms of previously proposed attention-demanding processes; specifically, consolidation and refreshing.

Keywords: Working memory - Short term memory - Attention - Consolidation - Refreshing.

32. Sternberg memory scanning 50 years later: A new comparison between item and order retrieval rate

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In the laboratory setting, different paradigms can be used to assess WM performance. Often, probe recognition is used as a proxy to WM performance and broadly compared to data from studies using serial recall. However, contrary to item recognition, serial recall, a traditional retention test, requires memory for items, as well as their respective position of occurrence (Nairne & Kelley, 2004). Fifty years ago, Sternberg (1969) established important differences between the retrieval of item and order information. The present results obtained with a classic Sternberg paradigm (i.e, memory lists of varying length followed by single probe recognition) confirm that item and order information are differently accessed during a recognition task. First, it seems that recognition time of order information is more sensitive to list length than item information, with a pattern suggestive of serial search processes. Second, serial position curves are different for item and order recognition with the former showing clear recency effects, and the latter showing both primacy and recency effects. Our results have implications for recent theories about memory search, with regards to different aspects of the information maintained.

Keywords: Short term memory - Retrieval rate - Sternberg - Item and order.

33. Is temporal grouping beneficial for musical short-term memory for serial order?

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In the verbal short-term memory (STM) domain, the nature of serial order processes has been extensively studied and it has been shown that temporal grouping manipulations positively impact serial recall accuracy and modify the pattern of serial order errors. These effects are important for theoretical accounts of serial order since only models relying on positional markers are able to account for the effects that temporal grouping has on both recall accuracy and errors. However, we do not know much about the nature of serial order mechanisms in musical STM. The aim of the present study is therefore to better understand the nature of the ordering mechanisms at work in the musical domain by studying the impact of temporal grouping on order STM tasks involving musical stimuli. We are interested in whether temporal grouping manipulations lead to the same pattern of results as observed in the verbal domain. To test this, we will expose musically untrained participants to a STM task requiring serial order reconstruction of temporally grouped and ungrouped tone sequences. If the same effects as those reported in the verbal domain are observed in our musical STM task, this would indicate that common ordering mechanisms are responsible for processing serial order information in the musical and verbal domains of STM.

Keywords: Short term memory - Serial order - Rhythm - Music.

34. Impact of face processing strategy on facial emotion recognition in school-age children

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Abilities to identify faces and decode facial emotional cues are essential for social development [1]. The relations between these abilities have been little studied during childhood. We hypothesize that the use of a specific face processing strategy in children could be linked to their emotional recognition performance. We assessed 225 children (age 4 to 12) with six subtests from face processing tasks developed by Bruce and al., (2000). For identity matching, two subtests were presented with whole faces which were of similar appearance (Face-Sim) or dissimilar (Face-Dis); 2 subtests were presented with faces were hair and ears were masked of similar (Masked-Sim) or dissimilar (Masked-Dis) appearance. In each task children were asked to choose from two faces the picture of the same child as the target face (16 trials). For identification of emotion expression, children had to point to the face corresponding to the right emotion (happiness, sadness, anger, surprise) named orally by the experimenter or to match two faces with the same expression. ANOVA were performed with the age group as a between- subjects factor.

Results revealed a significant effect of the age group for face identity and for happiness, sadness and surprise identification. Moderate correlations (.25 to .30) were found between scores of Face-Dis, Masked-Dis, sadness and surprise. Young children exhibited more difficulty in tasks with similar and/or masked faces but also for the recognition of emotions. They favor a featural over a configural strategy when processing faces but this preference seems to reverse during the childhood [2]. These results suggest a prominent role of configural processing strategy for improvement of emotion expression recognition later in childhood.

Keywords: Face Processing - Children - Development - Emotion Identification - Configural strategy - Featural Strategy.

35. Is there an amodal recognition of emotion from voice to face? Evidence in 6-month old infants and adults

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The present study investigated the nature and the development of the ability to recognize emotions in 6-month old infants and in adults. In particular, how does the ability to transfer amodal (i.e. independently of sensory modalities) information from auditory emotional voices to emotional faces develop? We hypothesized that listening to an emotional (happy or angry) prosody would influence the visual looking for emotional facial expressions. To test this hypothesis, we examined whether infants could transfer amodal information from emotional voice to emotional face. Each sequence presented an emotional voice (angry or happy) followed by the simultaneous presentation of a pair of static emotional faces (angry or happy, congruent or not with the emotional voice). The recording of eye movements on these visual stimuli was carried out using an eye-tracker. Real faces were presented in experiment 1 and virtual faces in experiment 2. Results for the looking time preference after hearing the emotional voice indicated that adults look longer at the congruent face (happy or angry). Results for 6-month-old infants showed that with virtual face condition there is no preference for one of the two emotional faces, independently of the voice condition, while, with real face condition, it is only after listening to the happy voice that the angry face is preferred. These results suggest that an emotional cross-modal transfer (from audio to visual modalities) is present in adults and in infants in some specific conditions depending on the propriety of the visual stimuli.

Keywords: Emotions – Amodal – Development.

36. Playing to improve spatial organization in the Williams syndrome population

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Numerous games or applications on tablets were developed these last ten years, to fill in the difficulties for special needs children. From a very young age, Williams syndrome (WS) persons encounter learning difficulties with drawing, writing, geometry and calculus. Indeed, their cognitive functioning is marked by an important dissociation between relatively well-developed language abilities and severe deficits in visuospatial abilities. To help them train and improve the specific spatial skills associated with drawing and graphic motor activities, we developed the serious game "Playing with Space". This game allows the player to train precise visuospatial geometric forms by hand drawing, with increasing levels of complexity, based on the VMI-Beery Test (Visual Motor Integration tests). Developed with Clickteam Fusion 2.5 authoring tool, for a touch screen interface, this platform game requires the player to hand draw precise and correct forms in order to allow his/her character to move around, perform actions and progress through various levels. The game is currently being tested with school age children in order to investigate its ergonomics qualities. The next step of this project will be to evaluate its effectiveness in terms of spatial performance gain or skill transfer on VMI tasks for people with WS. This poster will illustrate the general approach taken in the development of "Playing with Space", and present preliminary results of ergonomics tests conducted on school age children.

Keywords: Williams syndrome - Serious game - Visuospatial abilities - VMI Beery.

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