Methods in Numerical Cognition Workshop - Program

Website https://www.thenumberworks.org/numerical_cognition_methods_workshop

Slides We will ask the presenters to upload their slides to the OSF Meetings page of the workshop.

Presentations

Open peer-review database of methods for numerical cognition
Attila Krajcsi 1, Bert Reynvoet 2
1 ELTE, Department of Cognitive Psychology, Hungary
2 KU Leuven, Brain and Cognition, Belgium

Development

Psycholinguistic methods in testing children's interpretation of quantification
Katalin É. Kiss 1, Tamás Zétényi 2
1 MTA Linguistics Institute
2 BME Ergonomics

The development of quantification in propositional attitude contexts: false belief and number in kindergarteners and grade schoolers
Zoltán Jakab 1, Szabolcs Kiss 2
1 Eötvös Loránd University
2 University of Pécs

Enumerating objects

New method for calculating individual subitizing range
Tali Leibovich-Raveh 1, Daniel Jacob Lewis 2, Saja Al-Rubaiey Kadhim 2, Daniel Ansari 2, Shai Gabay 1, Orly Rubinsten 1
1 University of Haifa
2 University of Western Ontario

Chicks spontaneously represent the absence of objects
Eszter Szabó 1, Cinzia Chiandetti 2, Elisabetta Versace 3, Ernő Téglás 1, Gergely Csibra 1, Ágnes Melinda Kovács 1, Giorgio Vallortigara 4
1 Central European University
2 University of Trieste
3 Queen Mary University of London
4 University of Trento

Visual features of nonsymbolic stimuli

Numerical Perception biased by saliency
Naama Katzin, Avishai Henik, Moti Salti
Ben Gurion University of the Negev

Designing non-symbolic stimuli: An extent to Dehaene's (2005) method to control for non-numerical visual cues
Mathieu Guillaume 1, Christine Schiltz 2, Amandine Van Rinsveld 1
1 Université Libre de Bruxelles
2 University of Luxembourg

Introducing CUSTOM: a Customized Ultraprecise Standardization Oriented Multipurpose algorithm for generating non-symbolic number stimuli
Damiano De Marco, Simone Cutini
Department of Developmental Psychology, University of Padova

Measuring congruence effects in nonsymbolic number comparison: the importance of the degree of congruence
Nicholas K. DeWind, Elizabeth M. Brannon
University of Pennsylvania, Department of Psychology

Symbolic and nonsymbolic processing

Using the full stimulus space in numerical cognition
Petia Kojouharova 1, 2, 3, Gábor Lengyel 4, Attila Krajcsi 3
1 Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences
2 Doctoral School of Psychology, Eötvös Loránd University
3 Department of Cognitive Psychology, Institute of Psychology, Eötvös Loránd University
4 Central European University

Audiovisual approach for measuring symbolic and non-symbolic number processing
Mila Marinova 1, 2, Delphine Sasanguie 1, 2, Bert Reynvoet 1, 2
1 Brain and Cognition, Faculty of Psychology and Educational Sciences, KU Leuven, 3000 Leuven, Belgium
2 Faculty of Psychology and Educational Sciences, KU Leuven @Kulak, 8500 Kortrijk, Belgium

Same or different? The ERP signatures of uni- and crossmodal integration of number words and Arabic digits.
Ferenc Kemény 1, Sabrina Finke 1, Anna Steiner 1, Chiara Banfi 1, Corinna M. Perchtold 1, Silke M. Göbel 2, Karin Landerl 1
1 Institute of Psychology, University of Graz
2 Department of Psychology, University of York

Understanding the role of language in multiple magnitude representation mechanisms: An fMRI investigation

Sarit Ashkenazi 1, Yarden Gliksman 2, Avishai Henik 2
1 The Seymour Fox School of Education, The Hebrew University of Jerusalem, Jerusalem, Israel
2 Department of Psychology and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Israel

What do numerical estimation tasks measure? Insights from calibration paradigms

Darren J. Yeo 1, 2 and Gavin R. Price 1
1 Department of Psychology & Human Development, Peabody College, Vanderbilt University, United States
2 Division of Psychology, School of Social Sciences, Nanyang Technological University, Singapore

Interferences and associations

Prevalence of spatial-numerical associations: Psychometric approach

Carrie Georges
University of Luxembourg

Prevalence of spatial-numerical associations: Bootstrapping approaches

Krzysztof Cipora
Department of Psychology, University of Tuebingen, Germany; LEAD Graduate School & Research Network, University of Tuebingen, Germany

Measuring interference effects in numerical cognition

Gábor Lengyel 1, Attila Krajcsi 2
1 Central European University
2 Eötvös Loránd University

A novel number-space mapping task: The direction, order and space (DOS) task

Francesco Sella 1, Daniela Lucangeli 2, Marco Zorzi 2
1 University of Sheffield
2 University of Padova

The SNARC effect is not a unitary phenomenon

Simone Cutini 1, Sara Basso Moro 2, Roberto Dell'Acqua 1
1 Department of Developmental Psychology, University of Padova
2 Cognitive Psychology Unit, Institute of Psychology, Leiden University

Abstracts

Open peer-review database of methods for numerical cognition

Attila Krajcsi 1, Bert Reynvoet 2
1 ELTE, Department of Cognitive Psychology, Hungary
2 KU Leuven, Brain and Cognition, Belgium

Research on numerical cognition utilizes various methods. Many times it is not straightforward what methods are recommended to use, because for example, some advanced methods are not easy to find, and sometimes different approaches are not contrasted. All classic dissemination methods have their shortcomings: Peer review papers are evaluated only by a few experts, papers in journals or in handbooks are not updated, conference talks and discussions may not be appropriate to cite, just to name a few problems. Here, we propose an online, open peer-review database that can be edited by any experts. Any methods that are relevant in numerical cognition can be added by any experts. Any expert can evaluate the listed methods or can share her or his experience about that method, which evaluations will be partly automatically summarized and listed. The database can be updated continuously, incorporating new findings and considerations. Finally, and most importantly, anyone can use the database to support a decision about methodological issues, either in developing an experiment or data analysis strategy or in reviewing other's works.

Development

Psycholinguistic methods in testing children's interpretation of quantification

Katalin É. Kiss 1, Tamás Zétényi 2
1 MTA Linguistics Institute
2 BME Ergonomics

In the project „The psycholinguistics of quantification", we aimed to test among children the relation between linguistic quantification and mathematical cognition. We examined how children interpret sentences containing a universal quantifier (Every girl is riding a bicycle), a numerical quantifier (If you have collected (at least) three red stars, you can get a candy), and two numerical quantifiers (Two boys (each) are playing with three matchboxes). The methods we employed included the truth value judgement of sentences matched with a picture. Children were also shown pairs of pictures, and had to choose the picture that the given sentence matched. In a third type of experiment children were asked to act out with props the sentences they heard. Whereas the truth value judgement and the forced choice tasks showed whether children could access the different readings of the – often ambiguous – quantified sentence types, the act-out task helped us identify children's primary or default interpretation. In an experiment testing the multiplicative reading of distributive sentences (Two boys each are playing with two matchboxes), the act-out task showed whether children could actively carry out the algorithm of multiplication. We demonstrated that certain non-adult-like interpretations attested in previous experiments are due the ostensive presentation of a misleading detail in the icon-like visual stimulus – by comparing children's interpretations of the same stimuli embedded in more natural contexts, e.g., in photos, or in stories acted out with props.

The development of quantification in propositional attitude contexts: false belief and number in kindergarteners and grade schoolers

Zoltán Jakab 1, Szabolcs Kiss 2
1 Eötvös Loránd University
2 University of Pécs

We examined how kindergarteners (5-6- yrs) and grade schoolers (8-9 yrs) combine concepts of integer numbers with those of false belief and perspective taking. We assumed that as soon as children succeed on tests of false belief attribution, perspective taking, and counting separately they are able to combine both physical and mental perspective taking with number concepts. In the perspective taking plus number task subjects saw a given number of toy mushrooms on a table, and a Papa Smurf character on the opposite side of the table who was only able to see a subset of the mushrooms because the rest was, visibly to the subject, blocked from his point of view. We used two numerosities: 2+1 (two visible to Papa Smurf; one blocked); and 5+3 (one within subitization range; one outside it). In another experiment we introduced both object control (a dog and a cat), and consistent perspectives control (all objects in the scene visible to both S and Papa Smurf). In the FB plus number task subjects saw videos of two actors leaving balls in a box either both being present or one absent. We varied the transparency of the box toward the subject (transparent vs. not), the numerosity of the balls (within/outside subitization range), the second actor's adding vs. removing balls, and the color of the balls dropped by the two actors (same or different). Our hypothesis was not upheld as many children who passed the constituent tests failed on the combination tasks, and a few who failed false belief attribution were able to subsequently combine false belief and number concepts. Number plus physical percpective was notably easier to combine than number plus FB. There was a very tight correlation between performance within and outside subitization range. Minimizing performance load seems crucial in examining the development of quantification.

Enumerating objects

New method for calculating individual subitizing range

Tali Leibovich-Raveh 1, Daniel Jacob Lewis 2, Saja Al-Rubaiey Kadhim 2, Daniel Ansari 2, Shai Gabay 1, Orly Rubinsten 1
1 University of Haifa
2 University of Western Ontario

Subitizing is the ability to perceive the quantity of up to 3-5 items in a quick and accurate manner. The two most common methods for calculating subitizing range today – bilinear fit and sigmoid fit – have their strengths and weaknesses. By combining these two methods, we overcome their biggest limitations and come up with a novel way for calculating Individual Subitizing Range (ISR). I will introduce this new method as well as empirical studies designed to test it. In addition, I will present a study that used this method to investigate whether early-visual and sub-cortical areas are involved in subitizing; Subcortical and early visual brain areas are involved in basic pattern recognition, a mechanism that assume to support subitizing. Therefore, it is plausible that these areas are involved in the pattern-recognition aspect underlying subitizing. Typically developed adults enumerated canonically or randomly arranged dot sets. The sets were presented to one eye (i.e., ‘one eye’ condition), or segregated between the eyes (i.e., ‘different eyes’ condition). For each condition, we calculated ISR. We found that ISR for canonical patterns was significantly lower in the ‘different eyes’ condition than in the ‘same eye’ condition. In the ‘different eyes’ condition, early visual areas, that receive input only from one eye, cannot take part in processing the complete set. Therefore, any benefit that comes from the activity of early visual areas diminishes. This pattern was specific to canonical patterns but not to random patterns. Results support the involvement of early-visual and sub-cortical areas in pattern recognition.

Chicks spontaneously represent the absence of objects

Eszter Szabó 1, Cinzia Chiandetti 2, Elisabetta Versace 3, Ernő Téglás 1, Gergely Csibra 1, Ágnes Melinda Kovács 1, Giorgio Vallortigara 4
1 Central European University
2 University of Trieste
3 Queen Mary University of London
4 University of Trento

In four experiments, 8-day-old domestic chicks were placed into an arena, in which a screen rotating up/down could occlude or reveal the presence or absence of a target object that they were imprinted to. The chicks observed the target object either going behind the screen or leaving the scene entirely, and could thus infer that the target did or did not remain behind the screen. At the end of a trial the screen fell, revealing an outcome that was either consistent or inconsistent with their expectation about the presence or absence of the object. We measured how long the chicks looked at these outcomes and which eye they used to inspect the scene. Chicks' looking pattern was different in response to consistent and inconsistent outcomes about the presence of the object compared to similar scenes involving absence. Importantly, we found evidence for encoding the absence of an object and forming expectations about having nothing at a particular location. We observed a systematic left eye bias when inspecting an object at a location where nothing should have been. Crucially, this difference was present only when we added sex as a factor to the analysis. There was a left eye bias at females, while males did not show any consistent pattern. Left eye bias reflects the dominance of the contralateral right brain structures in processing the appearance of the object, and was previously associated with response to novel, unfamiliar stimuli. As the appearing item was used for imprinting, the novelty reaction of females reflects that, despite visual similarities, they identified this item as a new object based on their anticipation of the absence of any object at a particular place. This is strong evidence that absence representations can guide complex inferences in 8-day-old chicks.

Visual features of nonsymbolic stimuli

Numerical Perception biased by saliency

Naama Katzin, Avishai Henik, Moti Salti
Ben Gurion University of the Negev

How do people process numerosity? Do they rely on general magnitude processing (e.g. area, density etc.)? Or do they depend on a designated module underlying numerosity judgements? A recent paper by Cicchini and colleagues (Cicchini, Anobile & Burr, 2016) show results that strongly support the latter. They demonstrated that humans automatically perceive and spontaneously use numerosity, rather than other physical magnitudes (area of convex hull or density), when asked to make a judgment in an "odd-one-out" task. Here we present an alternative account for their findings. We suggest that saliency of the different attributes of the stimuli (i.e. numerosity, area of convex hull and density) can bias participant's strategy. Using Cicchini et al's published data and an experiment we conducted, we show that indeed in their study, numerosity was more salient than the other stimuli dimensions. This casts doubt on Cicchini et al.'s conclusion that numerosity is processed automatically.

Designing non-symbolic stimuli: An extent to Dehaene's (2005) method to control for non-numerical visual cues

Mathieu Guillaume 1, Christine Schiltz 2, Amandine Van Rinsveld 1
1 Université Libre de Bruxelles
2 University of Luxembourg

Since nearly two decades, researchers have expressed their interest in evaluating non-symbolic numerical abilities and their potential influence on cognitive processes that involve number, such as mathematic skills. However, the method by which visual stimuli are created was shown to substantially impact participant behaviour. Some authors tackled this issue by providing various procedures to generate non-symbolic stimuli while controlling for non-numerical visual cues. Most of recent procedures are sophisticated but tend to be difficult to replicate or to implement outside the laboratory. In this study, we suggest an easy dot generation algorithm based on the procedure popularized by Dehaene, Izard, & Piazza (2005). Their procedure originally controlled for two visual cues that are mediated by the Number, the Total Area and the Item Size (i.e., N = TA/IS). In our extended paradigm, we control for an additional twofold dimension related to the array extent, which is also mediated by the Number, comprising the Convex Hull Area and the Spatial Frequency (i.e., N = TA/IS = CH/SF). The dimensions that we additionally manipulate are independent of the visual properties from the initial procedure. We show that the introduction of this twofold dimension substantially affected adult performance. We further did not replicate the relation between non-symbolic number abilities and arithmetic skills, as the former rather correlated with executive functions, such as inhibitory control and visual working memory. We discuss these worrying findings about the reliability of previous studies that did not control for Convex Hull and Spatial Frequency.

Introducing CUSTOM: a Customized Ultraprecise Standardization Oriented Multipurpose algorithm for generating non-symbolic number stimuli

Damiano De Marco, Simone Cutini
Department of Developmental Psychology, University of Padova

When evaluating the properties of a set of elements in a natural environment, an increase in numerosity unavoidably corresponds to an increase in the physical properties of the set: five apples differ from ten apples not only in numerosity, but also in visual features such as volume, density, occupied space. In order to properly investigate non-symbolic number processing, it is therefore mandatory to rule out that performance might be driven by visual features, since participants might use them instead of numerosity as a strategical shortcut to enumerate the stimuli. Although several methods attempted to dissociate numerosity and visual features, users approaching this research field still suffer from three main limitations: i) there is no standard agreement about how to measure or control visual features; ii) current methods do not allow to readily recreate sets of stimuli with specific properties for comparative purposes; iii) no algorithm is able to produce stimuli suitable for more than one paradigm (e.g., estimation and comparison).

Here we present a Customized Ultraprecise Standardization-Oriented Multipurpose (CUSTOM), algorithm for generating non-symbolic number stimuli, characterized by several core features: there are no fixed parameters or rules (aside from geometrical constraints), thereby letting the user to freely manipulate the visual features of the stimuli; the control over the visual features of the stimuli is extremely high; no modification is required to perform different types of manipulation; it is possible to recreate any set of stimuli described in previous experiments on numerical cognition conducted so far, for a wide variety of task, such as comparison, estimation, habituation and match-to-sample.

The CUSTOM algorithm could represent an asset in the field of numerical cognition, because it is a neutral platform (with no a-priori theoretical assumptions) that can be used to generate stimuli for different paradigms with an excellent level of precision.

Measuring congruence effects in nonsymbolic number comparison: the importance of the degree of congruence

Nicholas K. DeWind, Elizabeth M. Brannon
University of Pennsylvania, Department of Psychology

Many studies have found that visual features, such as convex hull, affect the perception of numerosity in a nonsymbolic number comparison task. Depending on the stimuli used, performance on a number comparison task may be consistently below chance level when other visual features are incongruent to number. This finding has been cited as evidence that numerosity perception is derived from the perception of other visual features. Here we argue that an important piece of empirical evidence is largely overlooked in these studies: the degree of congruence and incongruence. Without simultaneously considering the ratio of the nonnumerical feature as well as its effect on accuracy, we are left with an incomplete picture. We show that the finding that performance is below chance depends on using a larger ratio of the incongruent feature than the ratio of number. When ratio is equated, number has a larger effect on accuracy than convex hull or any other visual feature. In this sense, the true number of items in a set drives the perception of number more than other visual features. Nevertheless, convex hull does have an important secondary effect on numerosity perception, which should not be ignored. As in other aspects of vision, the imperfections in numerosity perception may tell us something important about its mechanism.

Symbolic and nonsymbolic processing

Using the full stimulus space in numerical cognition

Petia Kojouharova 1,2,3, Gábor Lengyel 4, Attila Krajcsi 3

1 Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences
2 Doctoral School of Psychology, Eötvös Loránd University
3 Department of Cognitive Psychology, Institute of Psychology, Eötvös Loránd University
4 Central European University

The properties of symbolic and non-symbolic numbers are often investigated through effects relying on the values and other properties of the numerical stimuli. Two of the most widely studied phenomena, the distance effect and the size effect in the number comparison paradigm, behaviourally describe such an effect - performance depends on how close and how large the values of the two numbers are. The interpretation of the two effects underlie the majority of the literature about the number concept.

The classical method of calculation relies on aggregation, i.e., number pairs with the same numerical distance are grouped together for analysis, and information about possible existing patterns is lost. Alternatively, considering the performance for the full stimulus space allows for a richer and more informative analysis. This method allows for 1) a data-driven approach as opposed to the theory-driven approach of the classical method, which helps to look for other effects or for deviations in the expected effects, including when using nonconventional stimuli such as artificial

numbers, 2) more specific predictions about performance for each stimulus, 3) displaying systematic patterns whose presence could be convincing even without the statistical hypotheses tests because of the relatively large number of cells, 4) better communication of the results without loss of information, 5) application in any paradigm that uses number pairs besides number comparison, e.g., prime-target in a number priming task.

I will present studies in which the use of the full stimulus space allowed us to investigate how the change in the relations between the numbers as a result of the manipulation of their properties distorts the space in different ways. In all cases the stimulus space revealed performance patterns that better differentiated between predictions and made the interpretation of the results more straightforward.

Audiovisual approach for measuring symbolic and non-symbolic number processing

Mila Marinova 1, 2, Delphine Sasanguie 1, 2, Bert Reynvoet 1, 2
1 Brain and Cognition, Faculty of Psychology and Educational Sciences, KU Leuven, 3000 Leuven, Belgium
2 Faculty of Psychology and Educational Sciences, KU Leuven @Kulak, 8500 Kortrijk, Belgium

Previous studies examining the relation between symbolic numbers (e.g., Arabic numerals, number words) and non-symbolic numerosities (e.g., dot arrays) provided us with inconsistent results and contradictory interpretations. In this contribution, we evaluate the different approaches these studies have used to create their numerical tasks, and propose a new audiovisual paradigm as an alternative for measuring number processing. In a first study we show that the numerical tasks that make use of a purely visual presentation suffer from serious hidden drawbacks. The latter, however, can be elegantly overcome by using an audiovisual paradigm, in which participants have to compare/match purely symbolic number pairs (e.g., auditory presented number word and visually presented digit), purely non-symbolic pairs (e.g., auditory tone sequence and visually presented dots), or mixed pairs (e.g., tones and digits). In a second study we validate this paradigm more thoroughly by using more extensive stimulus sets, and varying the order of presentation modality (i.e. visual vs auditory). Results showed that the findings obtained with the audiovisual paradigm are robust, making this paradigm a reliable alternative for the purely visual numerical tasks. Finally, a cross-modal approach has three main advantages compared to the typical visual methods: (1) In a sequential presentation, participants' responses are not influenced by possible processing differences between the first and second stimulus; (2) Participants cannot base their decisions on visual cues or on the visual similarity between the stimuli; and (3) It is very suitable for testing small children, as reading is not a prerequisite here.

Same or different? The ERP signatures of uni- and crossmodal integration of number words and Arabic digits.

Ferenc Kemény 1, Sabrina Finke 1, Anna Steiner 1, Chiara Banfi 1, Corinna M. Perchtold 1, Silke M. Göbel 2, Karin Landerl 1
1 Institute of Psychology, University of Graz
2 Department of Psychology, University of York

Although the strength of the association between spoken number words and Arabic digits has been identified as a longitudinal predictor of arithmetic performance (Göbel et al., 2014), little is known about the underlying neural mechanisms. The present series of ERP experiments tried to grasp the nature of crossmodal digit-number word associations with as low of an involvement of semantic content as possible.

In the first study, a group of adult participants were exposed to sequentially presented number pairs (SOA of 500 ms), and had to decide whether the second number is bigger or smaller than 5. The first number could be a visually presented digit or an auditorily presented number word, whereas the second number was a visually presented digit. Congruent numbers elicited a higher central N300 as well as lower left parietal P3 amplitudes both unimodally and crossmodally. The active task demand, however, might elicit semantic activation of the first number as well.
The task was revised to avoid semantic activation. In experiment 2, participants saw three types of stimuli: moving numbers, non-moving number or moving letters. They were instructed to indicate the moving direction of moving numbers, but not respond to non-moving numbers or moving letters. Non-moving numbers were organized into sequentially presented pairs with an SOA of 900-1100 ms. Number pairs were presented unimodally (visual-visual) and crossmodally (auditory-visual). Pairs consisted of the same number or different numbers. An occipital P2 component was sensitive to both unimodal and crossmodal congruence. Meanwhile, the lack of SNARC effect suggests no activation of the semantic content.
Results suggest that crossmodal association of number words and digits is highly automatized in adults, however, this effect is much weaker than those appearing for unimodal congruence. Future studies should aim to investigate the developmental trajectory of this integration process.

References:
Göbel, S. M., Watson, S. E., Lervag, A., & Hulme, C. (2014). Children's arithmetic development: It is number knowledge, not the approximate number sense, that counts. Psychological Science, 25(3), 789–798.

Understanding the role of language in multiple magnitude representation mechanisms: An fMRI investigation

Sarit Ashkenazi 1, Yarden Gliksman 2, Avishai Henik 2
1 The Seymour Fox School of Education, The Hebrew University of Jerusalem, Jerusalem, Israel
2 Department of Psychology and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Israel

The current study examined whether discrete numerical estimation is based on the same cognitive process as estimation of continuous magnitudes such as weight and time. We target verbally mediated estimations. While estimation of numerical quantities is contingent on the unit of measure, estimation of time and weight does not. We innovatively designed a new method to test estimations during a functional magnetic resonance imaging scan. Twenty two students performed estimations with three estimation categories: number, time and weight. Estimations elicited activity in multiple brain regions. The loci of activity could be categorized into three major brain systems–the dorsal visual stream (bilateral lingual gyrus), the ventral visual stream (left angular gyrus and right supramarginal gyrus), and the frontal regions (cingulate gyrus and the inferior frontal cortex). Numerical estimation elicited a different brain region from those for time and weight estimations, demonstrating dissociations between discrete numerical estimations and estimations of continuous magnitudes.

What do numerical estimation tasks measure? Insights from calibration paradigms

Darren J. Yeo 1, 2 and Gavin R. Price 1
1 Department of Psychology & Human Development, Peabody College, Vanderbilt University, United States
2 Division of Psychology, School of Social Sciences, Nanyang Technological University, Singapore

Numerosity estimation tasks are commonly used to measure the acuity of the mental representations of number or the quality of mapping between numerals and numerosities. However, studies have shown that calibration (e.g., providing an initial reference quantity or feedback) can influence participants to modify their estimates, suggesting that the numerosity-numeral mappings may be malleable. This calls into question whether performance on estimation tasks reflects the action of cognitive mechanisms beyond mental representations of number. Across two studies involving adults performing a numerical estimation task under uncalibrated and calibrated conditions, we examined the hypothesis that a malleable "response grid" (e.g., a certain segment of the mental number line corresponds to "20's") serves as an interface between the so-called analog "mental number line" and the symbolic number system, and the relation of calculation skills and strategies to the putative response grid. In Study 1 (N = 71), consistent with the response-grid (RG) hypothesis, we found that higher calculation skills predicted an increase in linearity of participants' estimates upon calibration, over and above uncalibrated estimation performance measures. In Study 2 (N = 57), inconsistent with RG hypothesis, we found that whether an individual possessed a higher continuous range of associative numeral-numerosity mappings (i.e., resistant to calibration) among small numbers was neither related to estimation performance nor with calculation skills. Moreover, in both studies, the effect of calibration was not continuous across numerosities in most participants, and offline strategy reports (Study 2) indicated that a direct retrieval of numerosity-numeral mappings from memory was not part of the strategy repertoire in half of our participants. Taken together, our results suggest the RG hypothesis is insufficient in explaining estimation performance, and estimation tasks likely index other cognitive (e.g., strategic) mechanisms beyond representation of numbers.

Interferences and associations

Prevalence of spatial-numerical associations: Psychometric approach

Carrie Georges
University of Luxembourg

In numerical cognition, one of the most replicated group-level phenomena is the SNARC effect. It reflects the observation that Western participants respond faster to small/large numbers with the left/right side respectively. When the regression slope between number magnitude and right-left RT difference is taken as an index of the effect, c.a. 75% of participants exhibit negative slopes and are therefore considered as revealing the effect. Individual slopes are, however, only estimates of true slope parameters with measurement error, and only if the task was perfectly reliable, they would reflect true effects. In psychometrics, confidence intervals (CIs) are built around observed scores to account for non-perfect reliability. In case of the SNARC effect, individuals could be considered as revealing the effect, if the CI around the observed negative slope does not contain zero. We calculated CIs around individual SNARC slopes from 18 different and uniformly-analysed data-sets using the traditional psychometric approach: measurement reliability and sample variance (SD) were used to determine the standard error of measurement (SEM), based upon which CIs were determined. When 90% CIs were considered, only 37% of participants revealed the consistent effect. Consequently, with only 3% revealing a consistent reverse mapping, 60% of individuals did not feature a consistent SNARC effect. This suggests that despite its group-level robustness, the SNARC effect only occurs in a minority of people. The SNARC effect might thus not be a good proxy of universal spatial-numerical associations (SNAs). Alternatively, SNAs might be present in only a part of the population. In this case, theories of numerical cognition should be reconsidered. To disentangle these alternatives, future studies should determine the prevalence of other SNAs by applying the current method.

Prevalence of spatial-numerical associations: Bootstrapping approaches

Krzysztof Cipora
Department of Psychology, University of Tuebingen, Germany; LEAD Graduate School & Research Network, University of Tuebingen, Germany

We know that considering individual confidence intervals can bring some new insights into prevalence of Spatial-Numerical Associations. However, the psychometric method described in the previous talk has some shortcomings. Most importantly, to estimate individual confidence intervals it considers not only individual's performance but also sample characteristics. It means that given participant can be classified as either revealing or not revealing the SNARC depending on which sample he or she belongs to. To challenge this problem, we developed two bootstrapping techniques. First of them allows checking whether the SNARC slope is consistently negative irrespective of which particular trials are used for averaging. The second allows checking whether the empirically observed SNARC slope differs considerably from slopes one could observe if there was no association between number magnitude and response side. Both methods allow estimating confidence intervals for the SNARC slopes.

As it was in case of the psychometric approach, these analyses were applied to 18 different, uniformly analyzed SNARC datasets. When 90% confidence intervals are considered, it turns out that about 40% of participants reveal consistent SNARC effect. Again, the proportion of individuals revealing consistent reverse mapping is very low. In general, the agreement between psychometric and both bootstrapping methods is about 80%.

Methods we develop or its logic in general can be applied to other phenomena investigated within numerical cognition. It can help answering the question whether these phenomena are robustly present in virtually all participants, or it is rather that some individuals reveal certain phenomenon, while majority does not reveal any effect, and almost no one reveals reversed one. As we see in the case of the SNARC, the latter is sufficient to observe robust and highly replicable group level effect. Nevertheless, theoretical implications of these two cases differ considerably.

Measuring interference effects in numerical cognition

Gábor Lengyel 1, Attila Krajcsi 2
1 Central European University
2 Eötvös Loránd University

A large number of studies use interference effects to investigate the underlying mechanisms of numerical cognition. One of the most studied interference is called the SNARC effect which reveals the association between response side and numerosity. The classical method to measure interference effects implicitly assumes that most participants have the same associations between the interfering attributes. As an example, in SNARC effect, most of the people from the western culture associate LARGE numbers with RIGHT responses and SMALL numbers with LEFT responses producing a homogenous interference effect. However, previous studies showed that interferences are not necessarily homogeneous across participants. Iranian people, for example, have opposite associations than western people, namely associating LARGE numbers with LEFT responses and SMALL numbers with RIGHT responses. Here, we present a new method for detecting interferences in a population with heterogeneous associations. Considering the SNARC effect, the classical method calculates the linear regression slope for the difference of the right and left response side performance (number as independent and performance as dependent variable in the linear regression). In contrast, the new method computes two separate slopes for the performance on the right and the left sides and measures the correlation between them. We show that the classical method measures homogenous but not heterogenous, while the new method assesses heterogeneous but not homogenous interferences. Therefore, the classic and the new methods are complementary measurement of interferences. Finally, we demonstrate the importance of using the new method by revealing a new type of interference between parity and numerosity which, being heterogeneous across participants, would have been impossible to find with the classical method alone. Our work suggests that the usage of both the single and the dual indices is inevitable when investigating interference effects.

A novel number-space mapping task: The direction, order and space (DOS) task

Francesco Sella 1, Daniela Lucangeli 2, Marco Zorzi 2
1 University of Sheffield
2 University of Padova

The ability to map numbers to space is usually assessed by asking individuals to place target numbers on a horizontal line entailing a numerical interval (e.g., 0-100), as in the number line (NL) task. Children's performance in the NL task is characterised by a shift from a compressed (log-like) to an accurate (linear) mapping. Despite its extensive use, the NL task presents some limitations to obtain a detailed analysis of the development of number-space association. Placing numbers on a horizontal line entails three distinct components: (a) direction (left to right or right to left), (b) order (the ordering of numerical magnitudes, e.g., n1 > n2 > n3), and (c) spacing (the distances between numbers reflect systematic changes in numerical magnitude). In the classic version of the NL task, the direction is fixed from left-to-right, even though the direction of the mapping might still be flexible, especially in young children. After placing a target number, a new line is presented with the request to place another target number. Therefore, it is difficult to disentangle whether spatial order is respected, especially in the case of a compressed mapping, whereby target numbers are placed close to each other. Finally, the spacing between numbers becomes meaningful when order is respected. Here, we present a novel computerised task to assess direction, order, and spacing—the Direction, Order, and Space task (DOS)—of numbers on the visual line. We found that children with a logarithmic mapping in the NL task have reduced ordinal knowledge of large numbers in the DOS task. Once the ordinal component is taken into account, we found no evidence of a compressed mapping of numbers.

The SNARC effect is not a unitary phenomenon

Simone Cutini 1, Sara Basso Moro 2, Roberto Dell'Acqua 1
1 Department of Developmental Psychology, University of Padova
2 Cognitive Psychology Unit, Institute of Psychology, Leiden University

Models of the spatial–numerical association of response codes (SNARC) effect—faster responses to small numbers using left effectors, and the converse for large numbers—diverge substantially in localizing the root cause of this effect along the numbers' processing chain. One class of models ascribes the cause of the SNARC effect to the inherently spatial nature of the semantic representation of numerical magnitude. A different class of models ascribes the effect's cause to the processing dynamics taking place during response selection. To disentangle these opposing views, we devised a paradigm combining magnitude comparison and stimulus–response switching in order to monitor modulations of the SNARC effect while concurrently tapping both semantic and response-related processing stages. We observed that the SNARC effect varied nonlinearly as a function of both manipulated factors, a result that can hardly be reconciled with a unitary cause of the SNARC effect.