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Numerical Representation are Influenced by Spatial Relation or Finger Counting? An Eye Tracking Study

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Abstract

Background: Fingers are employed to represent numerosities before symbolic representations are used meaning that finger use might be the fundamental basis of numerical knowledge. Fingers are a support during the recitation of the numerical chain and they might also help children to understand the cardinal meaning of number words. Fingers are used to point at each object when counting a set, which is important in establishing the one-to-one correspondence principle. Finally fingers can help to keep track of the counted items in mental calculations which alleviates the burden on working memory and increases accuracy. In our study we attempted to investigate the relationship between the embodiment effect and mathematical and spatial representation (SNARC effect).

Methods: we presented to adult subjects (N=35) between 19 and 27 years of age, a coupling finger-number task that involves three different conditions. Each condition depicted a hands in which the numbers from one to five were placed above each finger in a random condition (random), in a inverted condition (number one on the little finger ending with the number five on the thumb) or in an orderly condition (number one on the thumb ending with the number five on the little finger). Parameter taking into account were: Accuracy; response times; number of fixations; difference in the number of fixations; saccades difference.

Results: The orderly and inverted configuration resulted the more efficient in order to elicits a decrease of response time and a decrease of saccades and fixation. The random condition resulted in the poorer performance on all parameter analyzed with the higher response times, higher number of fixations and major saccades difference.

Conclusions: We observed a facilitation effect in orderly and inverted condition due, in the orderly condition, to embodied effect, and, in the inverted one, to spatial numerical representation.

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Introduction

The concept of embodiment offers a new vision of the human mind which is related to the characteristics and shape of the body. Ideas, concepts, thoughts are the result of the influence of the body on human mind. In this way all the abilities becomes the outcome of a complex communication between body and brain. Every new learning involves the accumulation of a new conceptual and motor knowledge producing an integration between body and mind [1]. Therefore, the hand-brain combination cannot be reduced to a manipulation of techniques and instruments; hand in its essence is a precious way to build, maintain, and enhance social relationships (grooming), learn math skills and language; our body is able to highlights the social and culturally mediated cognitive activity [2].

An important aspect of the reading writing and math learning is just the space-time organization; in fact children whose psychomotor development took place normally, develops a perceptual space of Euclidean intuitive nature, product of a sensory-motor activity that is based on all the physical activities of child. For this reason in primary school there is an important link between concrete manipulations of objects and arithmetic operations. In effect fingers are employed to represent numerosities before symbolic representations are used [3,4], meaning that finger use might be the fundamental basis of numerical knowledge. Fingers are a support during the recitation of the numerical chain [5] and they might also help children to understand the cardinal meaning of number words [6]. Fingers are used to point at each object when counting a set, which is important in establishing the one-to-one correspondence principle [7,8]. Finally fingers can help to keep track of the counted items in mental calculations [9] which alleviates the burden on working memory [10] and increases accuracy [9].

The hypothesis that knowledge of numbers is based on the representation of the fingers even in adulthood are also supported by data from neuroimaging techniques that show how this activation is in numerical tasks at the level of the pre-central parietal circuits classically associated with the finger movements [11]. Besides in 1930 Gerstmann described a syndrome in which neuropsychological dyscalculia, and finger agnosia represented two of the cardinal symptoms of the disorder; so finger counting is able to mediate and critically accompany the transition from one type of symbolic to a not symbolic type of number processing. Some research has suggested that the spatial awareness of one's fingers, known as finger gnosis, is an important associate of early math performance [12], as well as adult math performance [13], and may indicate a common representational format for mathematics and finger gnosis [14,15]. Finger gnosia for 5-7 year olds has been found to predict math performance a year later, and may be a better predictor than IQ, reading ability, or other performance indicators.

In addition Conson, Mazzarella and Trojano [12] in several studies in which subjects were required to judge the laterality of stimuli, observed a phenomenon called SNARC effect (spatial numerical

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association of response codes), such that the smaller numbers would be mentally represented on the left side of the space and larger numbers on the right side of the space. In our study we attempted to investigate the relationship between the embodiment effect and mathematical and spatial representation that in our research they are partly overlying.

In our case we presented to adult subjects between 19 and 27 years of age, a coupling finger-number task that involves three different conditions. Each condition depicted a hands in which the numbers from one to five were placed above each finger in a random condition (random), in a inverted condition (number one on the little finger ending with the number five on the thumb) or in an orderly condition (number one on the thumb ending with the number five on the little finger). According to the hypothesis of research, the participants in the task would have to have the best performance to respond to a specific question that was about the order of presentation of the numbers on the fingers, in the event that it had been observed a certain numerical configuration that subjects had unconsciously linked to the way they count digitally numbers from one to five and to their own mental representation of the fingers. Therefore, the intent was to identify a certain embodiment effect in the adult characterized by lower performance in the case of a random condition and better performance for the inverted condition but especially for the orderly condition that would follow the classic pattern of digital configuration which typically individuals start to count; from the thumb to which is assigned the number 1 to the little finger which is assigned the number 5. However, we must emphasize that exists within the same Western culture a individual variability in the way in which the finger counting can be explained; although the majority of people is prone to start the digital computing with the left hand, starting from the thumb and the palm facing inward, not all follow this specific pattern, thus preferring other digital configurations that contribute to make it even more clear the flexible and dynamic nature of finger counting the peculiarity of which is precisely to adapt to the inclinations and preferences of the person who uses it.

In conclusion a last aim of the research was to detect the presence of an embodiment effect in a sample of young adults to test the hypothesis that supports how the incorporated mind influences the processing of stimuli and cooperates to processing of information of high level not only during childhood but during the whole life of the individual, not surprisingly, the participants were chosen in a range between 19 and 27 years of age in order to be able to find out how the body experiences faced in childhood are able to modulate the neural substrates and cognitive mechanisms in adulthood.

Method

Participants

The experiment was carried out in the laboratory of the Department of Psychology of Developmental and Social Psychology of "Sapienza" University of Rome and saw the participation of 35 able-bodied subjects aged between 19 and 27 years (M = 22, 8, SD = 2.17), including 22 females (M = 23.31, SD = 2.16) and 13 males (M = 22.15, SD = 2.07), recruited directly within the Faculty of Medicine and Psychology, "Sapienza" University of Rome.

Materials

The experiment was carried out in the laboratory using two computers, one reserved to the experimenters, containing the software of the experiment, and used to start each time the task monitoring the correct position of the participant relative to the screen and the other to allow to the participant to perform the task assigned.

The experiment with randomized trials and conditions in such a way to control any effects of order and sequence, has been done to the computer and in a totally anonymous, taking care to mark out an appropriate table for each item in the sample gender, age, birth date and version of the experiment carried out by the person in question (A / B / C).

Finally, thanks to the eye-tracking tool, located under the screen of the computer assigned to the participant for the execution of the task, it was possible to track and analyze the salient features of the eye movements of the subject on the screen during the entire course of the test.

We collected the data of the eye tracking software Sensomotoric Instrument 60Hz image "simple hand" and on the "hand condition".
For this study the physiological parameters considered were the number of fixations and number of saccades.

Procedure

Each participant was asked to sit in front of the computer holding a stable position, back and head straight as still as possible throughout the course of the experiment, taking care to keep silent during the test in order to ensure the best possible concentration. From our location directly connected to the Eye tracking was possible to evaluate the accuracy of the posture of the subject through a small window on desktop that indicated the location of eyes on the screen and possibly correct it if inaccurate or inadequate for a good reading by the machine ; also before starting the experiment it was necessary to calibrate the eye tracking inviting the participant to observe a small point that moved on its screen. Following were provided to the subject of the basic directions on how to carry out the task by asking finally fill a screen by entering age and sex; Once reading the experiment was started. A first slide informing the subject on how to perform the task and once understood the instructions was enough to push the spacebar to continue. The experiment, consisted of 50 trials, of which the first five of practice. The trial started with the appearance on the screen of a number ranged from 1 to 5 (2 sec.), followed by the shape of a hand (2 sec.) that was replaced by the shape of a second hand similar to the first, which, however, presented on each finger a number from one to five according to 3 different and variable configurations during the experiment (Figure 1). The subject was asked to observe the pattern represented and when ready click the spacebar and to answer the question asking about which finger that contained the number presented at the beginning of the task.

Data analysis

Parameter taking into account for each participant were: 1) Accuracy (percentage of corrected response; 2) response times; 3) number of fixations; 4) difference in the number of fixations (obtained by subtracting the sum of fixations on the picture of the hand with numbers from the sum of fixations on the picture of the simple hand); 5) saccades difference (obtained by subtracting the sum of saccades on the picture of the hand with numbers from the sum of saccades on the picture of the simple hand).The data analysis was performed using the SPSS statistical software, applying univariate analysis (ANOVA) to 2 factors (condition x trials) within the subject (within the same group to which is subjected to different experimental conditions) taking as index reference Wilks' lambda.

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Results

The analysis of variance condition x trial conducted on the accuracy parameter showed a non-significant effect of the factor condition ($F_{2.33}$ = 1:47 , p = ns; η^2= 0.082) , a significant effect of the factor trial ($F_{12.23}$ = 3.07 , $p < 0.05$; η^2= 0.10) and a non-significant interaction effect ($F_{19.16}$ = 1:43 , p = ns; η^2=0.615) .

The analysis of variance condition x trial conducted on the parameter response times showed a significant effect of condition factor ($F_{2.33}$ = 4.57 , $p < 0.05$; η^2=0.217) , a significant effect of the factor trial ($F_{12.23}$ = 3.09 , p <0.05; η^2= 0.618) and a non-significant interaction effect ($F^{24.11}$ = 2.18 and p = ns; η^2=0.826) . Pairwise comparisons conducted on the parameter condition showed a significant decrease in response time in the inverted condition than the other two (ordered vs inverted $p < 0.05$; random vs inverted p <0.01 ; ordered vs random p = ns) .The analysis of variance condition x trial conducted on the parameter number of fixations showed a significant effect of condition factor ($F_{2.33}$ = 8.41 , $p < 0.005$; η^2=0.338) , a significant effect of the factor trial ($F_{12.23}$ = 2.27 , $p < 0.05$; η^2=0.543) and a non-significant interaction effect ($F_{24.11}$ = 1.7 , p = ns; η^2=0.701) . Pairwise comparisons conducted on the parameter condition showed a significant decrease in the number of fixation in the opposite condition than the other two (ordered vs inverted $p < 0.005$; random vs inverted $p < 0.005$; ordered vs random p = ns).The analysis of variance condition x trial conducted on the parameter saccades difference showed a significant condition factor effect ($F_{2.33}$=6.247), a significant of trial factor effect ($F_{12.23}$= 1.557) and a significant interaction effect ($F_{24.11}$= 0.543). Pairwise comparisons conducted on the parameter condition showed a significant reduction of saccades difference on inverted condition (orderly vs inverted p<0.005; random vs inverted p<0.005; orderly vs random p=n.s.) (Fig ure 2).

Discussion

Our experiment has set itself the objective to verify the influence of mathematical embodiment processing on finger counting and math skills of a higher order, referring to a wide and fruitful scientific and experimental framework for which, through the passage of millennia and between different cultures, the numbers have been frequently and widely represented using parts of the body, particularly the hands and fingers, and this representation is able to contribute to a rapid and automatic processing of mathematical and arithmetic competence [6]. Therefore we tried to track down a specific relationship that young adults show between mental representation and bodily representation of the numbers and to evaluate how the learning of the classical counting with the fingers contributes in varying degrees to a recognition perceptive, quick and fast with all those numerical symbols that are represented from infancy through specific configurations of the fingers; just a testament to the fact that higher cognitive processes such as mathematical processing are mediated by the body and its sensory and motor activity in space. On the basis of data from neuroimaging techniques implemented by Pesenti and coworkers [11] it shows that in numerical tasks is present an activation at the level of pre-central parietal circuits classically associated with the movement of the fingers. The results of our experiment seem partially demonstrate this hypothesis; the fact that the random condition has gotten poor performance on all parameters analyzed in the study with the higher response times, higher number of fixations and major saccades difference, confirms the 'hypothesis that a non-linear representation of the numbers on the fingers of the hand is not active in the observation and cognition of handily stimuli that is direct, rapid and automatic, contrary to what would happen with a inverted configuration or ordered. In this way we had confirmed the thesis of Galton, Fischer and Brugger [14], for which the numbers

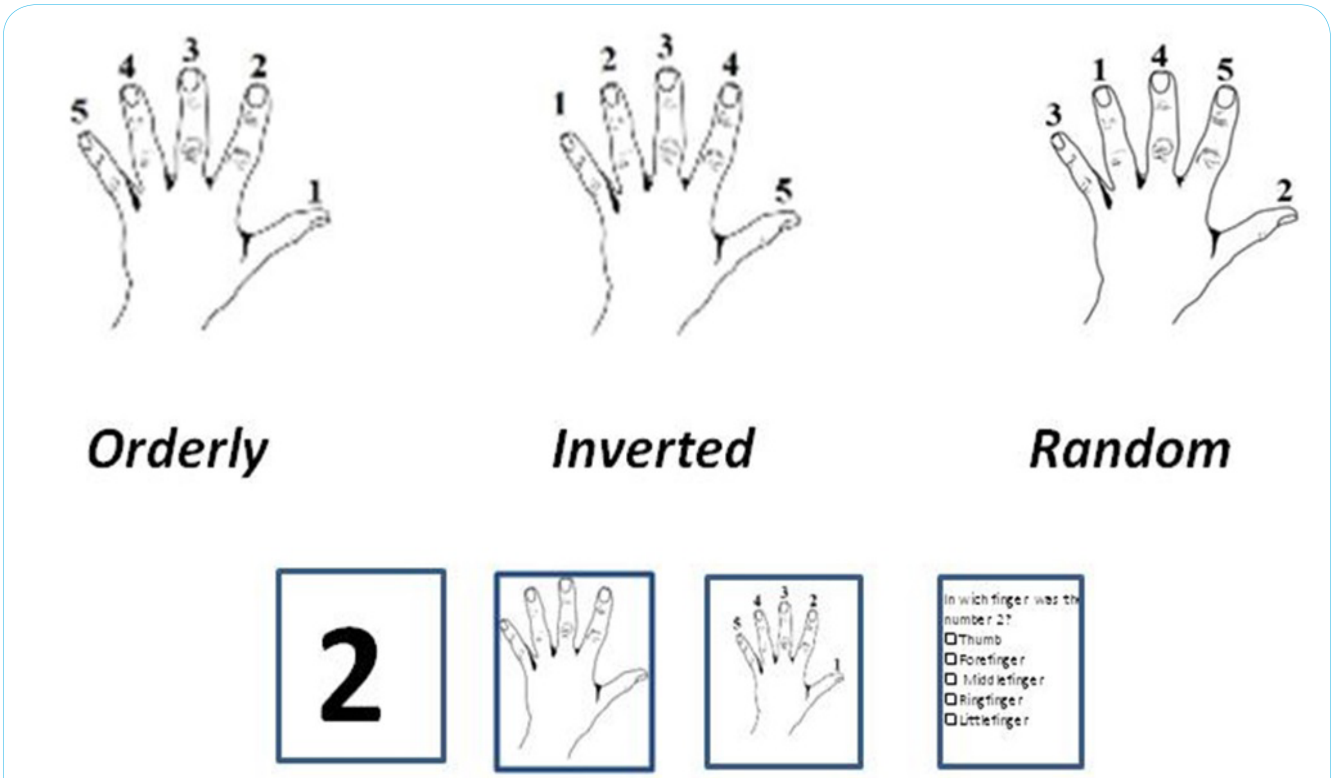

Figure 1: number-finger association task. All partecipant performed 50 trial bilance between the three conditions, orderly, inverted and random.

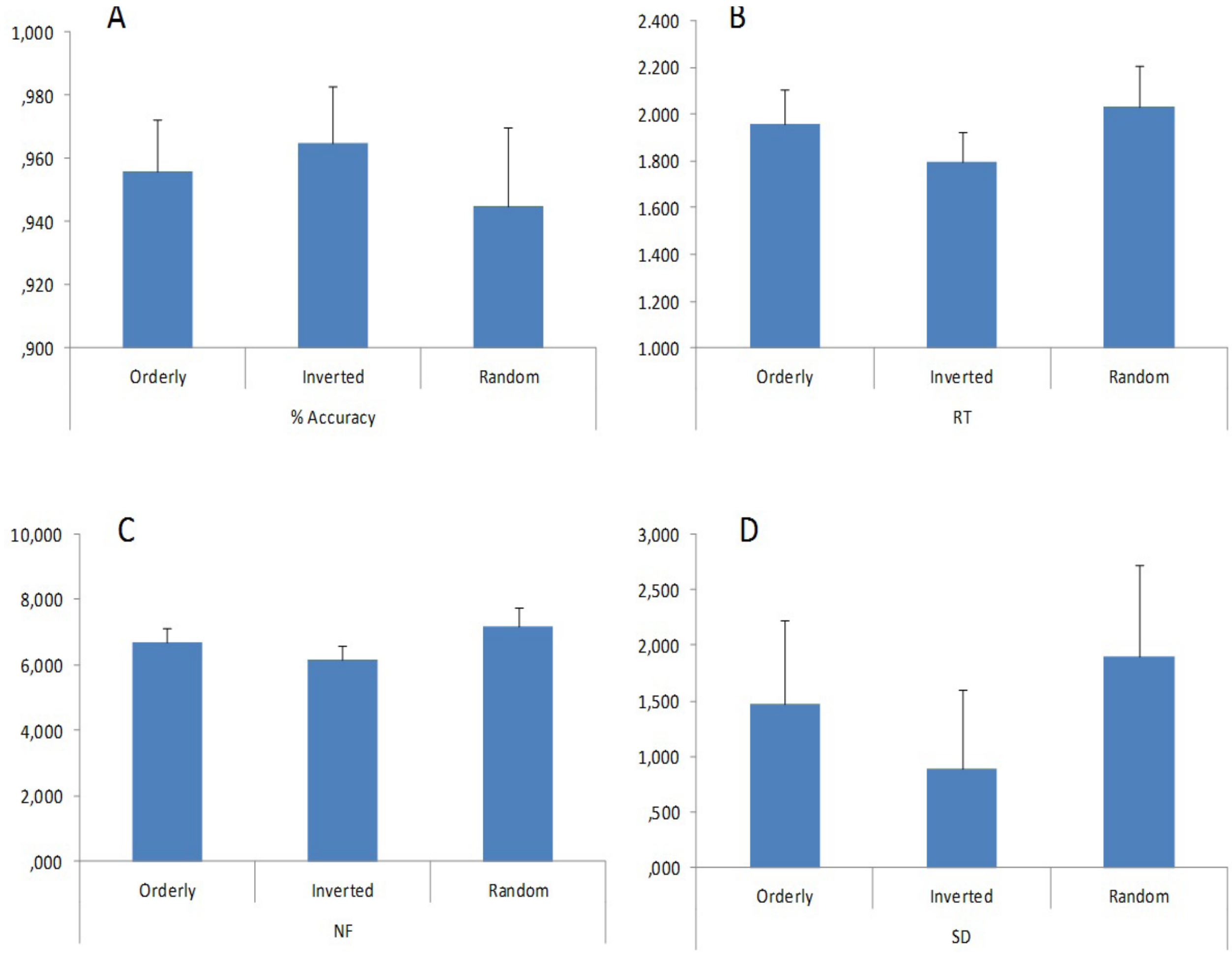

Figure 2: Participant's performance in all parameters taken into account: A) accuracy; B)Response time; C) numbers of fixation; D) saccades difference.

would retain a spatial representation orderly and coherent attributed to the different fingers depending on the cultural context. At the beginning of our research, however, we would expect the best performance of the sample in orderly condition because as noted previously, people tends to count the numbers from one to five starting with the thumb and ending with the little finger and the palm of the hand placed in front of observer (the same pattern represented by its orderly condition); in reality the fact that the inverted condition is that in which the subjects have the best performance is not a real surprise. As is clear from the studies of Conson, Mazzarella and Trojano [11] in which subjects had to judge the laterality of some stimulus, occurred the phenomenon called SNARC effect (spatial numerical association of response codes), so the smaller numbers were mentally represented in the left side of space and larger numbers to the contrary in the right side of the space. On the basis of these reflections Fischer [13] inferred that the association of numbers with space seems to be related to the hand with which people begin to count, in fact, the participants in his experiments were starting the calculation with the left hand and ended with the right showed a stronger orientation from left to right in their line numbers. A salient point is that in our experiment the hand is not placed spatially with the palm facing toward the subject, therefore, the typical configuration of the finger counting in Western countries, on the contrary, in the case of the inverted condition, the shape of the hand shows the numbers from 1 to five in sequence, starting with the little finger with one (left) until you get to the thumb with the five (right) invoking precisely the so-called line of numbers and consequently the SNARC effect but with the back of his hand placed in front. The subjects, therefore, tend to use in the processing of perceptual and numerical shape of the hand a spatial pattern in which numbers are represented from left to right and proceeding in order; same sequence depicted in orderly condition but is weakened by the fact that the back is represented frontally to the observer, the thumb on the right and the little finger on the left of the image. So it would seem that the SNARC effect has played a very strong impact on the performance of the sample which failed to have this effect on the basis of the bond finger-number. In our view, this fact does not prove the absence of mathematician embodiment rather confirms the hypothesis for which the ability to finger counting and mathematical embodiment would establish associations between number and space since childhood and even before the acquisition of skills reading and writing significantly contributing to the genesis SNARC effect. The origin of numerical skills derived from finger counting in fact represent a clear example of embodied cognition which is then basically determined by the interactions of the human body with its environment. This idea of "cognition manumerica" explain precisely why the finger agnosia, right-left disorientation and dyscalculia often coexist within certain disorders such as Gerstmann syndrome and how then SNARC effect embodiment and mathematical phenomena are not at all disjoint. Finally, on the basis of this reflection and the data obtained, we can state, as expected from the hypothesis of the

the research, the sample in the presence of an embodiment mathematical effect, supported by the expression SNARC effect that involved significantly the entire experimental sample but in the future it would be interesting to implement small changes in experimental introducing the shape of the hand with the palm (rather than the back), in front, so that the thumb appears to the observer on the left and the little finger on the right side of the space; in this case we would have an even more faithful representation of the typical mode of finger counting present in the Western population for which it would be possible to hypothesize an embodiment effect even stronger since in this case it is obvious not only the influence of the SNARC effect on the sample but also the relation between a specific finger to a specific number; in our case, 1 thoumb, 2 index, 3 medium, 4 ring finger, 5 little finger.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

Both authors contributed substantially to conception and design, acquisition and analysis of data and interpretation of results.

References

1. Varela FJ, Thompson E, and Rosch E (1991) The Embodied Mind: Cognitive Science and Human Experience. MIT Press, Cambridge, MA.
2. Vygotsky LS (1986) Thought and language. Cambridge, MA: MIT Press.
3. Fuson KC (1988). Children's Counting and Concepts of Number. New York: Springer-Verlag
4. Rusconi E, Walsh V, Butterworth B (2005) Dexterity with numbers: rTMS over left angular gyrus disrupts finger gnosis and number processing. Neuropsychologia 43: 1609-1624.
5. Sato M, Lalain M (2008) On the relationship between handedness and hand-digit mapping in finger counting. Cortex 44: 393-399.
6. Butterworth B (1999) The mathematical brain. London: Macmillan.
7. Gelman R, Gallistel CR (1978) The child's understanding of number (1986 edn). Cambridge, MA: Harvard University Press.
8. Gallistel CR, Gelman R (1992) Preverbal and verbal counting and computation. Cognition 44: 43-74.
9. Geary DC, Hoard M (2005) Learning disabilities in arithmetic and mathematics: theoretical and empirical perspectives, in Handbook of Mathematical Cognition, Campbell, Jamie I. D. (Ed). Handbook of mathematical cognition , (pp. 253-267). New York, NY, US: Psychology Press, xvii, 508 pp.
10. Alibali MW, DiRusso AA (1999) The function of gesture in learning to count: More than keeping track. Cognitive Development 14: 37-56.
11. Pesenti M, Thioux M, Seron X, De Volder A (2000) Neuroanatomical substrates of arabic number processing, numerical comparison, and simple addition: A PET study. J Cogn Neurosci 12: 461-479.
12. Noël MP (2005) Finger gnosia: a predictor of numerical abilities in children? Child Neuropsychol 11: 413-430.
13. Penner-Wilger M, Waring RJ, Newton AT (2014) Subitizing and finger gnosis predict calculation fluency in adults. In Bello P, Guarini M, McShane M, Scassellati B (Eds.), Proceedings of the 36th Annual Conference of the Cognitive Science Society (pp. 1150-1155). Austin, TX: Cognitive Science Society.
14. Anderson ML, Penner-Wilger M (2013) Neural reuse in the evolution and development of the brain: Evidence for developmental homology? Dev Psychobiol 55: 42-51.
15. Penner-Wilger M, Anderson ML (2013) The relation between finger gnosis and mathematical ability: Why redeployment of neural circuits best explains the finding. Front Psychol 4: 877.
16. Conson M, Mazzarella E, Trojano L (2009) Numbers are represented in egocentric space: effects of numerical cues and spatial reference frames on hand laterality judgements. Neurosci Lett 452: 176-80.
17. Fischer MH (2008) Finger counting habits modulate spatial-numerical associations. Cortex 44: 386-392.
18. Fischer MH, Brugger P (2011) When digits help digits: Spatial-numerical associations point to finger counting as prime example of embodied cognition. Front Psychol 2: 260.
19. Opfer JE, Furlong EE (2011) How numbers bias preschoolers' spatial search. J Cross Cult Psychol 42: 682-695.
20. Tversky B, Kugelmass S, Winter A (1991) Cross-cultural and developmental trends in graphic productions. Cogn Psychol 23: 515-557.