Finger-Montring Configurations Affect Arabic-Number Processing in Left Hemisphere

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Abstract

The influence of finger-strategies on number processing is documented by several findings which suggest that finger-based embodied representations could constitute a potential bridge between the innate number sense and the development of symbolic numerical abilities. Recent studies show evidence of hand muscle activation during passive observation of Arabic digits, as well as priming on the processing of Arabic stimuli if preceded by pictures of culturally-appropriate canonical finger-numeral configurations. However, little is known about how the sensory-motor and visual systems interact in the adulthood cognition and about the particulars of numerical processing grounding in the brain hemispheres. To fill this gap, a cross-modal priming study was designed, in which participants had to identify lateralized Arabic digits (2-3-4) while performing covert canonical or non-canonical finger-numeral configurations with their hemisphere-matching or hemisphere-mismatching hand. Results showed that responses to a visual target (e.g., 3) were faster when participants' hand was fixed in canonical configuration compared to arbitrary finger position, particularly when bodily-hand information and visual stimuli were projected simultaneously into the left hemisphere. This cross-modal priming effect can be taken as evidence of the numerical cognitive-facilitation supported by integrative processing of multiple sensorial information, and as an indication of specialized hemispheric involvement in the semantic processing of number information.

Keywords: Embodied cognition; canonical finger numeral; symbolic number; semantic priming.

Introduction

Cognitive theories of embodied cognition generally assume that sensory-motor systems are central for human cognition. This double use of the sensory-motor cortex, when we interact with the environment, may imply a greater functional economy for the brain, compared to the use of new cortical areas to process the meaning of visual, auditory and motor information. It seems reasonable that sensory-motor areas are partially reused to process the meaning of visual, auditory or motor contents expressed through symbolic language (Anderson, 2010; De Vega, 2005; Gallese & Lakoff, 2005). This new approach has recently received strong evidence in the field of neuroscience and behavioural research (Barsalou, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003; Glenberg, 2010). Supporters of this view claim that systematic sensory-motor activities present during the acquisition of numbers remain as part of our numerical knowledge also later in adulthood (Lakoff & Núñez, 2000) and that, consequently, finger related strategies could represent a bridge between the innate number sense and the development of a more mature abstract counting system (Andres, Di Luca, & Pesenti, 2008; Dehaene, 1997). In childhood, it is claimed, this "embodied" strategy develops spontaneously and supports the use of more abstract numerical codes, such as the oral and written codes (Butterworth, 2005).

The idea that "number concepts" are embodied fits well with current integrative views in cognitive neuroscience, and has enriched the field with new specific neurobehavioral predictions and findings. Indeed, several studies have experimentally verified a significant association between finger habits and numerical skills in adults (Andres, Seron, & Olivier, 2007; Badets & Pesenti, 2010; Di Luca, Granà, Semenza, Seron, & Pesenti, 2006; Sato, Cattaneo, Rizzolatti, & Gallese, 2007). Focusing on behavioural measures, Di Luca and Pesenti (2008, 2010) and Di Luca, Lefèvre and Pesenti (2010) showed that adult subjects exhibited faster judgment and naming of Arabic digits preceded by masked hand pictures with *canonical* finger positions (that is, positions used in a culture to indicate a number using fingers), compared to arbitrary or non-canonical positions. Also, mental sums between numbers are faster when the results are represented by compatible canonical finger-numeral representations, compared to functionally-equivalent representations using no fingers but rods, which provides direct evidence of the close relationship between mental computation of arithmetic results and finger representations (Badets, Pesenti, & Olivier, 2010). Nevertheless, to date few studies have directly examined the potentially facilitatory (or priming) effect of the finger *embodied-simulation* on visual Arabic number processing during the adulthood, a strategy that could provide an additional direct test about the relation between fingers and semantic number processing. Precedent studies focus only on visual channel presenting pictures of hands (cf. Di Luca & Pesenti, 2008). In an attempt to fill this gap, an experiment was designed in which the participants' hands were positioned in different finger configurations during the execution of an Arabic-identification task.

Method

Subjects

The sample consisted of 30 neurologically healthy students at the University of Salamanca, Spain, (27 women and 3 men; *M* = 20.3 years, *SD* = 1.72 years). All participants received academic credit for their contribution and all signed an informed consent form. Before the beginning of the computerized experimental test, each subject filled the Edinburgh Handedness Inventory (Oldfield, 1971). Overall, a positive score (*M* = + 0.56; *SD* =

0.29) was obtained, reflecting a global sample preference for the right hand and thus a greater left-hemisphere dominance for language.

Stimuli

The Divided Visual Field (DVF) paradigm was used as the methodology for the lateralization of visual stimuli. When used with care, this paradigm is an effective neuropsychological experimental tool for analyzing each hemisphere independently (Marzi, 1999; Gazzaniga, 2000; Bourne, 2006). The subject's face was placed at a standard distance of 57 cm from the screen using an ergonomic fixed chinrest. The stimuli were a set of Arabic digits (2 - 3 - 4) typed in black Arial® font (36 pt), projected on a white background, and flashed randomly an equal number of times per condition (see Figure 1).

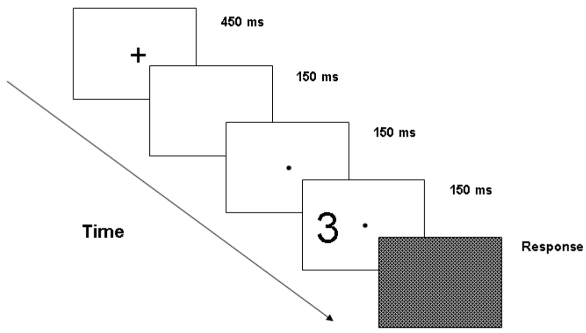

Figure 1: Stimuli. A set of Arabic digit (2-3-4) was flashed randomly to left or to right of a central fixation point.

Procedure

The experimental task was a simple Arabic-identification task. The subjects had to press with finger a key corresponding to the number displayed on the screen as quickly and accurately as possible. To also lateralize body information, the hand not used for responding was placed through a little door inside one of two boxes (50 × 80 × 80 cm) placed on the desk at the left and right of the screen, and kept well out of the participant's view to eliminate possible unintended interferences in the visual pathways. Inside each box there was a fixed square support (24 × 24 × 4 cm), with a central cavity and with edges covered with Velcro®. The participant was required to wear a highly adherent glove, and without giving him further information, his non-responding hand was placed by the experimenter on the square support, with fingers naturally fixed in the corresponding experimental positions (see Figure 2, for "3 canonical" or "3 non-canonical" finger positions). The true target was the Arabic numeral "3", whereas the numerals "2" and "4" represented mere distractors inserted in the trials to keep the participant's attention and to make the task more challenging.

The measures of interest were the participant's reaction time/accuracy when responding to the target (the Arabic numeral "3") in the identification task. In addition, at the end of the task, participants were asked to see themselves in an imaginary situation and to show how they could use their fingers to order three beers from a waiter in a noisy pub (Pika, Nicoladis, & Marentette, 2009), with the experimenter recording which fingers were raised and which hand was used to show the numeral. As expected in Spanish culture, 80% of the sample used the canonical position reported in Figure 2, and 83.3% used the right hand for finger-montring.

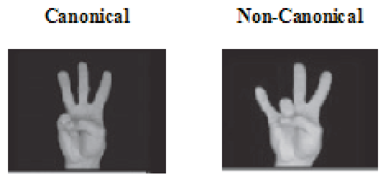

Figure 2: Finger-Numeral Configurations. Only canonical configuration matches with cultural habits of subjects.

Results:

For the RT's analysis a mixed ANOVA 2 × (2 × 2) was run, with "Finger-Numeral lateralization" (in left vs. right hemisphere) as between-subjects factor, and with "Finger pattern" (canonical vs. non-canonical configuration) and hemispheric Arabic "Target-3 lateralization" (in left vs. right hemisphere) as within-subjects factors. The main effect of the between-subjects variable, showed no statistical significance (p > .05), whereas the main effect of the first within-subjects "Target-3 lateralization" was statistically significant ($F_{1,\ 28}$ = 42.919, p < .001, partial-η2 = .605), confirming that symbolic "3" Arabic target was processed overall significantly faster when it was lateralized in the left hemisphere (*M* = 333.739 ms; *SD* = 54.64 ms) compared to when it was lateralized in the right hemisphere (*M* = 358.18 ms; *SD* = 59.61 ms). No statistical significance was found for the second main effect, "Finger pattern", and for none of the two-way interactions (all $p > .05$). More importantly, the 3-way interaction was statistically significant ($F_{1,28}$ = 5.538, p = .026, partial-η^2 = .165), revealing a combined effect of the three independent variables on reaction times. As can be seen in the Figure 3, when both types of information (visual and finger-postural) are lateralized directly to the left hemisphere, the canonical position condition led to significant lower latencies compared to the non-canonical one (*M* = 332.60 ms; *SD* = 35.22 ms vs. *M* = 347.64 ms; *SD* = 34.34 ms), whereas in the mismatch condition, that is with the numerical target projected to the left hemisphere and with the finger information transmitted principally to the right hemisphere, a reverse pattern was observed with higher latencies in the canonical position compared to the other condition (*M* = 336.08 ms; *SD* = 83.27 ms vs. *M* = 318.61 ms; *SD* = 64.30 ms). Moreover, when the numeric target was flashed to the right hemisphere, this pattern of interaction seems to disappear and the difference between the means of the other two variables are tiny, with higher overall latencies in all conditions compared to the left hemisphere. In the discussion below we explore a possible explanation for the 3-way interaction.

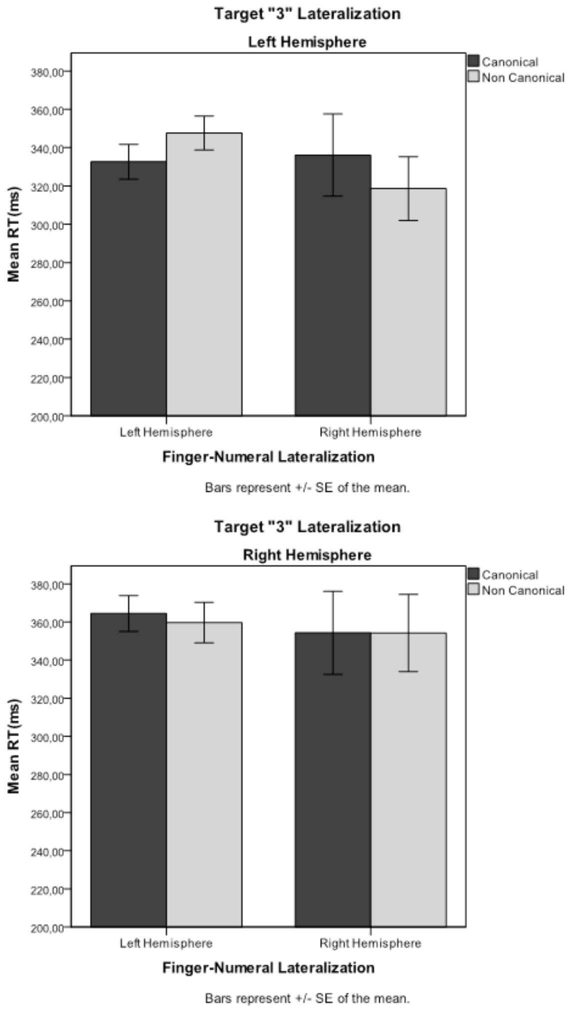

Figure 3: Results. A significant 3-way interaction was found, revealing a different effect of the type of finger-configuration within and outside the left hemisphere.

Discussion

In line with our predictions, the effect of target lateralization was significant, confirming that participants that are left-lateralized for language exhibit a speed advantage in processing a small symbolic Arabic (such as the digit 3) if the digit was lateralized directly to the left hemisphere. However this result should be interpreted in light of the three-way interaction that provides more precise information about the theorized priming effect and the semantic linkage of the finger canonical position with visual information. As evidenced in the results (Figure 3, at the top), when the numerical target was lateralized in the left hemisphere and bodily information was lateralized in the same side, the reaction times are faster if the contralateral hand (right) simulates the canonical position compared to the non-canonical. The priming effect of the finger canonical configuration produced by the right hand would be positive because the specific semantic numerical representation activated by the finger configuration and the visual target stimulus representation are matched in the same left side. In this case a reasonable explanation is that the information conveyed from the canonical right hand would prime the processing of the visual target by pre-activating the target's semantic code in left parietal areas of the cortex which directly receive information from the fingers of the right hand (cf. Glenberg, 1997). These different types of information (visual and sensory-motor/bodily information), as suggested in the literature, could be integrated in the left angular gyrus (cf. Roux, Boetto, Sacko, Chollet, & Trémoulet, 2003; Rusconi, Walsh, & Butterworth, 2005) and then sent to the left motor areas for planning the output response.

In summary, the results indicate that when the bodily numeric information activated by a canonical finger position is moved from the right to the left hemisphere, this visuo-body integration affects reaction times in a negative fashion for the cost of time spent during the intercallosal information transmission between hemispheres. Conversely, when bodily information of canonical hand is directly projected to left hemisphere with visual information, this may speed up the target digit processing by means of a theorized positive semantic priming effect, that is a genuine cross-modal priming and that could be conceptualized as a specific case of semantic interaction between iconic gestures and words (cf. Bernardis, Salillas, & Caramelli, 2008). Finally, canonical finger numeral representation is directly linked with the semantic representation of the target number whereas non-canonical configuration is not.

Taken together, these results suggest that bodily information can be conceived as a kind of implicit sensorial memory representation that, through the interaction between cultural habits, language development and natural hand preference, eventually develops semantic characteristics, helping in the deployment of our symbolic numerical abilities and in the understanding and use of abstract numerical concepts.

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