Influence of numerical magnitudes on the free choice of an object position

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Abstract

The link between numerical magnitude and mechanisms of spatial orienting has been underlined in an increasing number of studies. Similarly, the relationship between numerical magnitude and grasping actions has started to be investigated. The present study focuses on the influence of numerical magnitude processing in the free choice of the position of an object. Participants were presented with a digit (1-9 without 5) and were required to decide whether it was smaller or larger than 5. Then, they had to grasp a small cube and change its position before vocally responding “higher” or “lower”. Results showed that in the initial phase of the grasp movement the grip aperture was modulated by the numerical magnitude. Moreover, participants shifted the position of the cube more leftward with smaller digits compared to larger ones, and they tended to position the object closer to themselves with smaller digits compared to larger ones. These results extend previous findings indicating that the processing of magnitude is tightly related to the mechanisms of spatial orienting that subserve action execution.

Keywords: spatial-numerical associations, magnitude processing, hand kinematics, embodied cognition

Introduction

The way we represent and process numbers constitutes a challenge for embodied and grounded theories of cognition stating that concrete and abstract concepts are grounded on previous sensorimotor experiences (Borghi and Pecher 2012; Pecher et al. 2011). Several studies have underlined the importance of specific cultural habits, such as counting or reading/writing directions, on the development of a spatially defined mental representation for numbers (Fischer and Brugger 2011).

For instance, many studies have found that in the Western societies small and large numbers are associated to the left and right hemispace, respectively, during numerical tasks, while this association is reversed in cultures with an opposite writing direction (Dehaene et al. 1993). Spatial-numerical associations are present also when the task is not numerical but spatial (e.g., numerical cueing detection tasks), suggesting a fundamental role of visuo-spatial attentional orienting mechanisms in number processing (Fisher et al. 2003).

Moreover, recent accounts have underlined the importance of finger-counting in number processing, as it leaves its mark in adulthood (Di Luca et al. 2006; Fischer 2008), and it contributes to develop associations between numbers and hand actions. For example, the speed in initiating a closure or opening movement is modulated by digit magnitude (Andres et al. 2004). Again, associations between small/large digits and precision/power grip respectively have been observed (Lindemann et al. 2007; Moretto and Di Pellegrino 2008). Number-action associations have been observed even in absence of hand movements (e.g., Badets and Pesenti 2010), and when action-related processes were mediated by object affordances (Badets et al. 2007; Chiou et al. 2009; Ranzini et al. 2011).

The representation of numerical magnitude can thus be considered *embodied*, as it might develop through sensorimotor experiences, relying on cognitive mechanisms devoted to action execution. Lindemann et al. (2007) and Andres et al. (2008) investigated the influence of numerical magnitude on the execution of a grasping action, by analyzing its kinematic parameters. Specifically, participants were required to grasp an object, and to select the kind of grip (precision or power grip: Lindemann et al. 2007) or the object displacement (forward or backward: Andres et al. 2008) in function of the parity of a presented digit. Results of both studies showed that the grip aperture was modulated by the digit magnitude, as a larger grip aperture was observed in the larger digit condition compared to the smaller digit one.

The present study aimed at investigating in detail the influence of number processing on the action of grasping and placing: participants were presented with a digit, then they had to grasp and freely change the position of a small cube, before orally indicating whether the digit was higher or lower than 5. We expected to replicate the magnitude effect on the grip aperture and, additionally, to observe a bias in the cube position choice, compatible with spatial-numerical associations.

Methods

Participants

Twelve volunteers (mean age = 22, SD = 4; 5 males; all right handed by self report) participated in this study. All reported normal or corrected-to-normal vision, and were naive as to the purpose of the experiment.

Apparatus and stimuli

The participants sat in front of a 17” cathode-ray tube screen at a viewing distance of 92 cm, and were required to hold their right hand in pinch position before the beginning of each trial (Fig.1). A digit (ranging from 1-9, except 5) or an asterisk (control condition) appeared on the screen: participants were required to leave the starting hand position to grasp a small cube (size 4 cm) in front of them (distance 28 cm) and to freely change its position with any direction or distance in their reaching space. Once the desired position was reached, they had to leave the cube and judge whether the digit was higher or lower than 5 by saying “lower” or “higher” (or “asterisk”). Responses were collected by a microphone. At the end of each trial the experimenter re-positioned the cube.

Each digit was repeated five times, while the asterisk was repeated ten times, for a total of 50 trials. The stimuli were randomly presented at the center of the screen by means of Eprime 2 (Psychology Software Tools, Inc.).

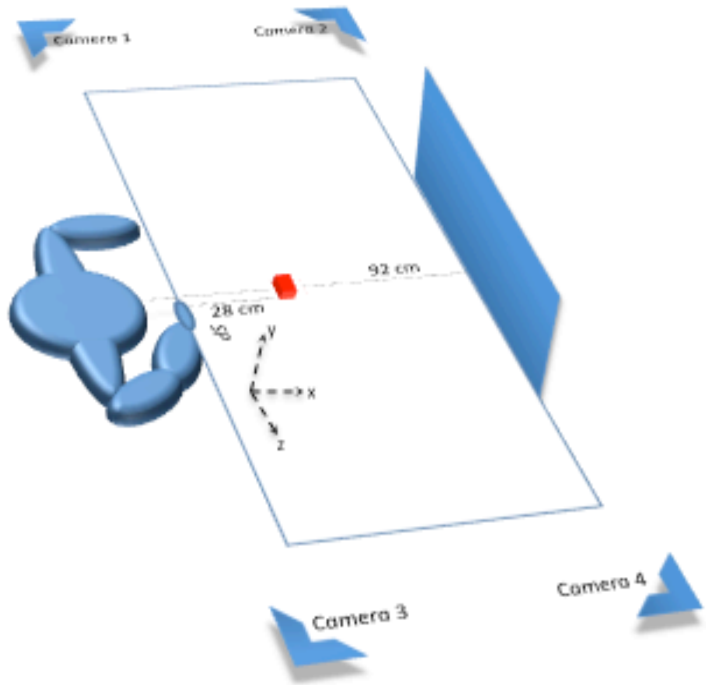

Fig.1 Graphical representation of the experimental set-up

Data recording and analysis

Participants' movements were recorded using a 3D-optoelectronic SMART system (BTS Bioengineering), consisting of four infrared cameras (sampling rate: 120 Hz). Three reflecting markers were applied on the participant's wrist, index and thumb fingers. A marker was applied on the top of the cube to keep track of its displacement.

Kinematics recording was used to analyze the movement from its beginning to the moment where the fingers touched the cube, and afterwards to check for cube displacement. Two sensors (controlled by an Arduino device, see http://www.arduino.cc/) were applied on the cube to detect when the fingers grasped it.

We analyzed:

- the temporal evolution of Finger Aperture (FA: the distance between index and thumb) until the Maximal Finger Aperture (MFA: maximal index-thumb distance during reaching). Specifically, we calculated and analyzed the mean FA for each of 5 temporal windows (each interval corresponding to 20% of time from the movement begin – i.e., when the hand left the starting position - to the MFA).

- The final-initial cube position difference along the horizontal (z) and the depth (x) axes (horizontal cube displacement: HCD; depth cube displacement: DCD). Negative/positive values corresponded to a leftward/rightward (or nearer/faraway from the body) displacements, respectively. The amplitude of the displacement (ACD) was also analyzed.

All measures were analyzed with repeated measures ANOVA with Numerical Magnitude (small: 1-4; large: 6-9) and Numerical Distance (close: 3-4-6-7; far: 1-2-8-9) as within-subjects factors.

Results

Trials with incorrect responses (1%) or deficient kinematics recording (10%), and from the control condition were not analyzed. From the FA analyses we excluded one participant whose MFA time (at 47.5% of the movement time) and MFA (103.4mm) were anomalous.

FA was affected by Numerical Magnitude only at the first temporal interval ($F(1,10) = 5.285$, $p < .05$), increasing at larger Numerical Magnitude (M= 30.3 vs. 30.6 mm). On the contrary, an opposite, although not significant, trend was observed in the following temporal windows preceding the MFA ($p_s > .08$). The main effect of Numerical Distance was never significant, nor its interaction with Numerical Magnitude ($p_s > .1$). MFA was neither affected by Numerical Magnitude nor by Numerical Distance, nor by their interaction ($p_s > .05$).

Interesting results came from the HCD and DCD analyses (Fig. 2). Indeed, Numerical Magnitude significantly affected the HCD ($F(1,11) = 6.031$, $p < .05$). Participants placed the cube more on the left with small than large numbers (M = -26.93mm vs. 32.65mm). HCD was not affected by Numerical Distance or by the interaction of the two factors. Similarly Numerical Magnitude marginally affected the DCD ($F(1,11) = 4.173$, $p < .07$). Participants tended to place the cube closer to themselves with small numbers and more faraway with large numbers (M= -23.33mm vs 14.02mm). No significant effects nor interactions were found on the ACD ($p_s > .5$).

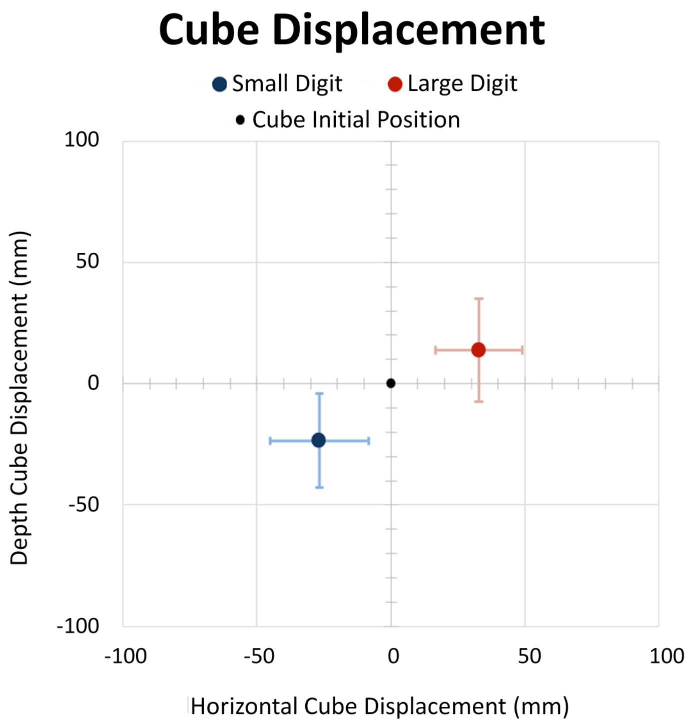

Fig.2 Results of HCD and DCD mean. SEM are reported

Conclusions

The present study aimed at investigating in detail the interactions between number processing and the execution of hand actions. Our results replicate but also widely extend previous findings. First, the effect of a modulation of finger aperture in function of the digit magnitude is in line with the literature, but it also adds interesting insights about the timing of this effect. Indeed, the effect was quite precocious when compared to previous studies, albeit rather small (large-small digits difference in FA: 0.3mm in the present study at the first temporal window; 1.5mm at the 40% of the movement time in Andres et al. 2008; 0.6mm at the MFA time in Lindemann et al. 2007). These variations across studies can be explained as consequences of the differences between the adopted paradigms. For instance, we did not manipulate cube dimension (differently from Andres et al. 2008), and the cube was visible to participants during grasping (differently from Lindemann et al. 2007), thus possibly minimizing the numerical magnitude effect on FA. Indeed, Andres et al. (2008) observed that the effect decreased at decreasing object sizes, disappearing with smaller objects.

Second, we observed a systematic dislocation of the cube in function of the magnitude. The cube was placed more leftward when processing a smaller digit. This finding is in line with the idea of a left-to-right oriented mental representation for numbers. The effect is similar to what observed by Daar and Pratt (2008) with a free key-press selection task (participant selected more often the left than the right key-press when they were presented with a small digit compared to a large one), and by Fernandez et al. (2011) who found that after a numerical priming participants' gaze attraction toward a left or right stimulus was modulated by the prime magnitude (Fernandez et al. 2011). However, differently from those studies, our paradigm did not require an explicit spatially-defined response mapping, as participants freely displaced the cube from trial to trial along all possible directions, thus minimizing a possible strategic account for this effect, but suggesting the involvement of mechanisms of visuo-spatial attentional orienting (e.g., Ranzini et al. 2009).

Results also suggest that the cube was placed closer to the participant's body when processing a small digit than a large one. A study by Conson et al. (2009) found that the numerical representation is oriented with egocentric rather than allocentric coordinates, which suggests that a vertical mental representation for numbers (Schwarz and Keus 2004) might correspond to the close/far space (with respect to the body) in an egocentric 3D coordinates system. This idea is also consistent with case reports of number-form synaesthesia, perceiving smaller numbers closer to the body compared to larger ones (e.g., Hubbard et al. 2009).

Albeit a dichotomic representation of the categories "small" and "large" over than a fine-grained numerical magnitude representation might account for both the observed effects, these findings are nonetheless interesting in the contest of embodied and grounded cognition theories. Indeed, by confirming that number processing interacts with action, our data suggest that the abstract concept of magnitude is linked to action, in line with previous studies reporting for instance that words referring to object size (Gentilucci et al. 2000) prime grasping actions as actual object size does. Similarly to words, numbers affected the representation of object size and position during grasping planning and execution. This speaks in favor of the idea that not only concrete but also abstract concepts rely on our previous sensorimotor experiences (Borghi and Pecher 2012).

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