## Title
Body movements affect Counting



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# Body movements affect Counting

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**Abstract**

Aim of the present study is to investigate whether and to what extent movements performed with the whole body can influence calculation processes. Participants were asked to perform additions or subtractions while executing an ascending or descending movement in a passive (i.e., by taking the elevator) or active (i.e., by taking the stairs) mode. Results revealed a congruency effect between the type of calculation made and the direction of the movement performed, but only when participants experienced it through a passive mode. Our data are in line with studies providing evidence of a strict link between numerical and spatial representations, and between motor actions and number magnitude processing (motor-to-semantic effect). Implications of the results for the embodied and grounded nature of numerical cognition will be considered and discussed.

**Keywords:** numerical cognition; body movement; embodied cognition

## Introduction

One of the main challenges of embodied and grounded cognition views (e.g., Barsalou, 2008) is to account for the representation of abstract concepts, such as numbers. The present study focuses on numerical cognition, an important area in which this challenge can be addressed. The mental representation of quantity (i.e., number magnitude) is the main focus of an increasing number of researches. In a well known study, Deahene and colleagues (Dehaene, Bossini, & Giraux, 1993) demonstrated that numbers ranging from 0 to 4 and from 6 to 9 facilitate left and right responses, respectively, even if number magnitude was a task-irrelevant feature. These results led the authors to claim that number magnitude is visuo-spatially represented along an horizontal mental number line (MNL) with small numbers on the left and large numbers on the right of a continuum (for a review, see Hubbard, Pinel, Piazza, & Dehaene, 2005). In a recent study, Holmes and Lourenco (2012) investigated the strength of this Spatial Numerical Association of Response Codes (SNARC effect), on both the horizontal (i.e., small - left; large - right) and vertical (i.e., small - bottom; large - up) MNL and found that the horizontal organization is rather dominant. Their data also showed, though, that the vertical organization depends on how number are conceptualized. In other words, the vertical organization emerged only when numbers are conceptualized as magnitudes that elicit an orientation (e.g., 1$^{st}$ floor from surface, 2$^{nd}$ floor from surface, etc.).

To our knowledge, all the studies so far were aimed at investigating whether and how the numerical magnitude, that is the representation of the number as a small or large quantity, impacts two processes. First, recent studies analyzed the influence of the numerical magnitude on the spatial representation of the horizontal/vertical axis, that is left/low and right/high spatial position (Fisher, Castel, Dodd, & Pratt, 2003; Nicholls, Loftus, & Gevers, 2008; Pecher & Boot, 2011). Second, several researches focused on the impact of the magnitude on the action related processes investigating the bi-directional interaction between the magnitude code and the action plans of grasping objects with precision or power grip (Andres, Ostry, Nicol, & Paus, 2008; Badets, Andres, Di Luca, & Pesenti, 2007; Badets, Bouquet, Ric, & Pesenti, 2012; Badets & Pesenti, 2010, 2011; Chiou, Chang, Tzeng, & Wu, 2009; Ranzini et al., 2012).

Starting from this evidence, the current study aims at investigating whether and to what extent processes leading to numerical magnitudes, such as arithmetical calculations of addition and subtraction, can be influenced by real upward and downward movements experienced with the whole body. In a study by Knops, Viarouge, and Dehaene (2009) participants tended to select the numerosity displayed in the upper right location for additions, and in the upper left location for subtractions (Space-Operation Association of Responses: SOAR). Differently from Knops and colleagues, our task required participants to: (a) keep adding or subtracting the same quantity from a starting number in a given period of time; (b) repeat the result of each calculation aloud, so that participants had to focus on the on-line and progressive calculation process; (c) experience an ascending or descending movement with the whole body in a passive (i.e., taking the elevator) or active (i.e., taking the stairs) mode.

In a recent research, Hartmann, Grabherr, and Mast (2011) demonstrated that the passive displacement of the body was sufficient to influence the magnitude of self-generated numbers. In their Experiment 1, participants were positioned on a motion platform and were asked to generate numbers at random while the platform was moving (leftward, rightward, downward, upward, forward, and backward) or when it was stationary. Results indicated a bias for small numbers, which were generated more easily during leftward and downward motions as compared to rightward and upward motions, respectively. Differently from Hartman et al. (2011), we asked participants to experience the movements through an active and a passive mode, and to make additions and subtractions rather than generating random numbers.

To summarize, our experimental procedure is new with respect to current literature in two aspects: first, we focused on the processes leading to a numerical magnitude, rather than focusing on the number magnitude per se. Second, we asked participants to experience real movements engaging their whole body through passive and active modes. We hypothesized a congruency effect between the direction of the experienced ascending or descending movement and the spatial orientation inferred by the type of calculation made, that is additions-upward orientation vs. subtractions-downward orientation. More precisely, we predicted that participants would be facilitated when asked to make additions while experiencing an upward movement and subtractions while experiencing a downward movement (congruent conditions) as compared to the opposite instructions (incongruent conditions). Finally, we also assessed whether this congruency effect was modulated by the passive or active mode through which the movements were experienced. It is crucial to say that the type of movements and the sense of their direction were different in these two modes. In fact, when taking the elevator participants passively perceived themselves moving in a given direction. Conversely, when the stairs were taken, participants performed an overt and real motor action with a full physical body involvement. Moreover, the sense of the movement was fast and clearly vertical when using the elevator, while it was more progressive and less vertical when using the stairs, since that the awareness of going up or down changed progressively step by step. Hence, these two modes can modulate results differently: if the congruency effect requires an active motor process, we hypothesize to find the effect only in the stairs mode. Conversely, if the fast and vertical passive displacement of the body is sufficient to obtain the congruency effect, we expect the effect even when participants take the elevator.

## Method

**Participants** Twenty-eight undergraduate students from the University of Bologna (15 females, age range 19-24 years) took part in the experiment in exchange of 5 Euros. The majority of them had a background in humanities. All were naïve as to the purpose of the experiment and gave informed consent.

**Apparatus and Stimuli** Participants were asked to add or subtract 3 to a starting number (e.g., 342) for 22 seconds and to say the result of each calculation aloud (e.g., 345, 348, 351 or 339, 336, 333 and so on, for additions and subtractions, respectively, until 22 seconds were elapsed). In order not to make the calculation process too easy, the starting numbers: a) were composed by three digits; b) started with two different digits (i.e., 3 or 5, such as 378 or 516).

**Procedure** The task required participants to make the additions or subtractions while taking the elevator or taking the stairs. In order not to mix these modes, the task was divided in two blocks, whose order was balanced between subjects. In one block, participants performed the calculations while taking the elevator, whereas in the other block calculations were performed while taking the stairs. Within each block, four trials were performed, resulting from the combination of the two types of calculation, additions and subtractions, and movement, ascending and descending. We designed each block in order to make additions and subtractions always alternate: an addition was always followed by a subtraction and vice versa. At the beginning of each trial, the experimenter explicitly informed the participant about the type of calculation that had to be performed and about the type of movement that was going to be experienced. For each trial, the experimenter spoke the starting number aloud and then a go signal followed. Immediately after the go signal, the passive or active movement began and, at the same time, participants were required to repeat the starting number and then to keep saying the result of each calculation aloud for 22 seconds consecutively, until the experimenter gave the stop signal. If a calculation error was made, the trial was stopped and a new trial began with a different starting number. No feedback was given during the task and the importance of accuracy over speed was stressed at the beginning of each trial. The experimenter was present during the whole experiment. For the passive mode, she went up/down using the elevator together with the participant. For the active mode, she walked close to the participant while going up/down the stairs and asked the participant to keep her pace throughout the whole movement. In other words, each participant and the experimenter went up/down the stairs together so that the number of steps taken was held constant across participants. Overall, the experiment lasted about 15/20 minutes.

## Results

We considered the correct number of calculations made within the 22 seconds time window as our dependent variable. Since we predicted a congruency effect between the direction of the movement and the type of calculation, we divided the trials in congruent (ascending movements – additions; descending movements – subtractions) and incongruent (ascending movements – subtractions; descending movements – additions), and then we averaged the number of calculations separately for each group of pairings.

The correct calculations were entered into a repeated-measures ANOVA with *Congruency* (congruent vs. incongruent) and *Mode* (elevator-passive movement mode vs. stairs-active movement mode) as within-subjects factors. The *Congruency* [$F$ (1, 27) = 10.20, MSE = 7.51, $n^2_p$ = 0.27, $p$< .01] and *Mode* [$F$ (1, 27) = 32.50, MSE = 3.96, $n^2_p$ = 0.55, $p$< .001] factors were significant. We found a higher number of calculations: a) for congruent pairings (M = 11.2) with respect to incongruent ones (M = 10.7); b) when the movement was experienced with a passive (M = 12) with respect to an active (M = 9.8) mode. Crucially, the *Congruency* x *Mode* interaction was significant [$F$ (1, 27) = 5.16, MSE = 1.36, $n^2_p$ = 0.16, $p$ = .03]. Fisher's LSD post-hoc test showed that, in the passive mode, participants performed a higher number of calculations for congruent pairings than for incongruent ones (Ms = 12.5 vs. 11.5, respectively, $p$< .01). Conversely, this pattern failed to emerge for the active mode (Ms = 9.9 vs. 9.8, for congruent and incongruent pairings, $p$ = 0.95, see Figure 1).

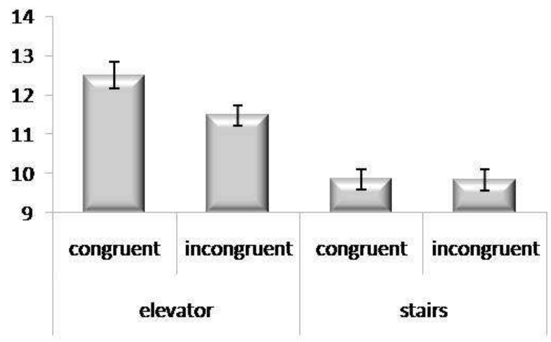


Figure 1: Number of calculations for congruent and incongruent pairings performed through a passive (i.e., elevator, leftmost panel) or active (i.e., stairs, rightmost panel) mode. Bars are standard error of the mean.

## Discussion

We investigated whether calculation processes, such as additions and subtractions, are influenced by real movements experienced with the whole body. Our findings showed a facilitation, in terms of correct number of calculations made, for the congruent condition, that is when additions and subtractions were performed while experiencing an ascending and descending movement, respectively, with respect to the opposite mapping. This result is in line with recent behavioral findings showing the influence of the motor process over the semantic one (i.e., motor-to-semantic effect, see Badets et al., 2012; Badets & Pesenti, 2010, 2011; Ranzini et al., 2012).

The fact that we did not find the congruency effect for the active mode could be due to different factors. First, climbing the stairs required an overt movement and a full physical body involvement. Second, the sense of the movement direction was more progressive and less vertical, with respect to when the elevator was used, since the awareness of going up or down changed step by step. Hence, the lack of a congruency effect could be due to the higher amount of resources required by the dual-task of climbing the stairs and counting at the same time, as also suggested by the lower amount of calculations yielded for this mode compared to the passive one. In addition, the fact that the movement was probably perceived as faster and more vertical when taking the elevator, could have yielded a significant effect for this mode only.

In a recent study Hartmann and colleagues (2011, Experiment 1; see also Hartmann, Farkas, & Mast, 2012) found that the number generation process was influenced by experiencing a passive whole body movement. Our results are in line with these findings, but we also obtained a congruency effect between the body movements and the calculation processes, instead of a given set of numbers. Moreover, participants in our study also experienced real movements with their whole body instead of passive movements while seated in a chair. We claim, indeed, that experiencing ascending and descending movements with the whole body can influence the processes responsible for numbers representations as magnitude with an upward and downward orientation, that is addition and subtraction calculations.

Our results can have intriguing implications for the embodied and grounded cognition view, which claims a close link between perception and action, due to the influence of both our sensory-motor system and previous experiences on the cognitive processes (e.g., Barsalou, 2008). Of particular relevance to our work is the debate concerning the claim that both concrete and abstract concepts, such as numbers, are grounded in perception-action systems (e.g., Borghi & Pecher, 2011; Fischer, 2012; Gianelli, Ranzini, Marzocchi, Rettore Micheli, & Borghi, 2012; Pecher & Boot, 2011). So far few studies demonstrated the grounding of abstract concepts on sensory-motor experiences (for reviews, see Borghi & Cimatti, 2012; Pecher, Boot, & van Dantzig, 2011) and thus our study, by focusing on an interesting example of abstract concepts such as numbers, can be relevant for this issue. In fact, the influence of whole body movements on numbers representation can be interpreted as a proof that also number processing can be embodied. Interestingly, our findings are in line with a recent proposal, advanced by Fischer and Brugger (2011) on the origin of the Spatial-numerical associations (SNAs), that recognizes the grounded and embodied nature of numerical cognition, which would origin from finger counting.

To summarize, our study contributes to highlight the close link and interaction between our everyday activities, as movements in real-life situations, and higher-order cognitive processes, as spatial representation and number processing.

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