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Research report

Perceiving numbers does not cause automatic shifts of spatial attention

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ABSTRACT

It is frequently assumed that the brain codes number magnitudes according to an inherent left-to-right spatial organization. In support of this hypothesis it has been reported that in humans, perceiving small numbers induces automatic shifts of attention toward the left side of space whereas perceiving large numbers automatically shifts attention to the right side of space (i.e., Attentional SNARC: Att-SNARC; Fischer, Castel, Dodd, & Pratt, 2003). Nonetheless, the Att-SNARC has been often not replicated and its reliability never tested. To ascertain whether the mere perception of numbers causes shifts of spatial attention or whether number–space interaction takes place at a different stage of cognitive processing, we re-assessed the consistency and reliability of the Att-SNARC and investigated its role in the production of SNARC effects in Parity Judgement (PJ) and Magnitude Comparison (MC) tasks. In a first study in 60 participants, we found no Att-SNARC, despite finding strong PJ- and MC-SNARC effects. No correlation was present between the Att-SNARC and the SNARC. Split-half tests showed no reliability of the Att-SNARC and high reliability of the PJ- and MC-SNARC. In a second study, we re-assessed the Att-SNARC and tested its direct influence on a MC-SNARC task with laterally presented targets. No Att-SNARC and no influence of the Att-SNARC on the MC-SNARC were found. Also in this case, the SNARC was reliable whereas the Att-SNARC task was not. Finally, in a third study we observed a significant Att-SNARC when participants were asked to recall the position occupied on a ruler by the numbers presented in each trial: however the Att-SNARC task was not reliable. These results show that perceiving numbers does not cause automatic shifts of spatial attention and that whenever present, these shifts do not modulate the SNARC. The same results suggest that numbers have no inherent mental left-to-right organization and that, whenever present, this organization can have both response-related and strategically driven memory-related origins. Nonetheless, response-related factors generate more reliable and stable spatial representations of numbers.

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1. Introduction

One of the most valid and reliable examples of the functional interaction between space and number processing is the SNARC effect (*Spatial-Numerical Association of Response Codes*, Dehaene, Bossini, & Giraux, 1993). The SNARC reflects the observation that when healthy humans are asked to provide judgements of number magnitude (e.g., higher or lower than 5?) or number parity (e.g., odd or even?) by choosing between a response key on the left-hand side and a response key on the right-hand side, they provide faster responses to small magnitudes with the key on the left side and faster responses to large magnitudes with the key on the right side (Dehaene, Dupoux, & Mehler, 1990). Different interpretations of the SNARC were advanced to date (for reviews see Cohen Kadosh, Lammertyn, & Izard, 2008; Wood, Nuerk, Willmes, & Fischer, 2008). Some authors claim that the SNARC depends on the correspondence between the inherent spatial position that numbers occupy on the mental equivalent of a left-to-right organised ruler, i.e., the Mental Number Line (MNL; Restle, 1970), and the position of response keys (Hubbard, Piazza, Pinel, & Dehaene, 2005). Other authors emphasise that the SNARC depends on a culturally based association between "left/right" and "small/large" semantic codes (Gevers et al., 2010; Proctor & Cho, 2006; Santens & Gevers, 2008). Some other authors have proposed that during the performance of the SNARC task, the mental left-to-right organization of number magnitudes is generated by the left/right spatial codes that are used for the selection of the motor response (Ishihara et al., 2006; Müller & Schwarz, 2007). This "response-related" interpretation of the SNARC effect is supported by investigations with Event Related Potentials (ERPs) showing that the SNARC arises at the response-related stage, i.e., during the selection of the left versus right response key, rather than at an early stage of perceptual or visual imagery processing (Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Keus & Scwarz, 2005). In summary, no univocal explanation of the SNARC effect has yet been established and no consensus has yet been reached on the stage of cognitive processing in which the association between left/right spatial codes and the coding of number magnitude takes place.

In a relatively recent and frequently quoted study, Fischer, Castel, Dodd, and Pratt, (2003) have documented a behavioural effect that seems pointing at the inherent and response-independent left-to-right spatial organization of number magnitudes. In two experiments run in relatively small samples of fifteen (Experiment 1) and ten participants (Experiment 2), these authors used a modification of the typical attention-cuing paradigm proposed by Posner (1980). At the beginning of each trial a digit cue (i.e., 1, 2, 8 or 9) was presented at central fixation. Following a varying Cue-Target Interval (CTI), a dot-target was randomly presented in the left or the right visual field. Participants were required to press a central key in response to target appearance. They were also informed that digit cues were irrelevant to target detection and did not predict target location. At 500 msec and 750 msec CTIs, Fischer et al. (2003) observed relatively faster RTs to left side targets when these were preceded by small digit cues, i.e., 1 or 2, and relatively faster RTs to right side targets when these were preceded by large digit cues, i.e., 8 or 9. The authors concluded that the perception of small number magnitudes induces automatic leftward shifts of attention whereas the perception of large numbers induces rightward shifts of attention. This effect, which is based on simple unimanual RTs has been called Attentional SNARC (Att-SNARC; van Dijck, Abrahamse, Acar, Ketels, & Fias, 2014; Dodd, Van der Stigchel, Leghari, Fung, & Kingstone, 2008) to differentiate it from the classical SNARC effect that is observed when motor responses in the left and right side of space must be reciprocally contrasted and associated to number magnitude or number parity.

Results from ensuing studies have provided important qualifications of the Att-SNARC and suggest that, at variance with the SNARC effect, the Att-SNARC is elusive (see Rossetti et al., 2011; for a review). Some authors (Galfano, Rusconi, & Umiltà, 2006; Ristic, Wright, & Kingstone, 2006) have replicated the Att-SNARC but have also pointed out that this is driven by strategic top-down factors rather than being a truly automatic effect [see Fischer (2006) for a similar proposal on the SNARC effect and the review by Price and Mattingley (2013) showing no strong evidence for automatic Att-SNARC among people with sequence-space synaesthesia]. This was especially demonstrated by the possibility of reversing the direction of the Att-SNARC, just by changing task instructions and asking participants to imagine a MNL running in the right-to-left rather than left-to-right direction (Ristic et al., 2006). In the same way Galfano et al. (2006) observed an inversion of the Att-SNARC when participants were asked to shift attention leftward in response to large numbers and rightward in response to small numbers. To maximize the activation of the left-right coding of the MNL, Galfano and co-workers also included the digit "5" among cue numbers, to implicitly provide participants with a landmark of the midpoint separating small, i.e., 1 and 2, from large, i.e., 8 and 9, cue numbers. Finally, in another study Dodd et al. (2008, Exp. 1) found the Att-SNARC only at one (500 msec) out of the two CTIs (500 msec and 750 msec) at which the effect was originally observed by Fischer et al. (2003).

Others authors have failed to replicate the Att-SNARC both using simple RTs (Bonato, Priftis, Marenzi, & Zorzi, 2009; van Dijck et al., 2014; Hubbard, Ranzini, Piazza, & Dehaene, 2009; Jarick, Dixon, Maxwell, Nicholls, & Smilek, 2009; Ranzini, Dehaene, Piazza, & Hubbard, 2009) and temporal order judgements (Casarotti, Michielin, Zorzi, & Umiltà, 2007). Among these studies the investigation by van Dijck et al., (2014) and the series of experiments by Zanolie and Pecher (2014) are particularly relevant. Both of these studies adopted the same procedure employed by Fischer et al. (2003; Exp. 2). van Dijck et al. (2014) did not replicate the Att-SNARC in a large sample of 43 participants, a number of participants that was well above the estimated number of participants, i.e., 31, needed to obtain a power of .90 based on the effect sizes reported in Fischer et al. (2003) and Dodd et al. (2008). In two repetitions of the original Exp. 2 by Fischer et al. (2003), Zanolie and Pecher also (2014; Exp. 1 and 4) found no Att-SNARC. In another experiment from the same study (Exp. 3), some evidence for the Att-SNARC was provided when participants were asked to judge the magnitude of numerical cues (i.e., higher or lower than 5). However, this finding was not replicated in a control re-test experiment (Exp. 6). Finally, in two