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BRIEF REPORT

Beyond left and right: Automaticity and flexibility of number-space associations

Sophie Antoine[1] **· Wim Gevers**[1]

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Abstract Close links exist between the processing of numbers and the processing of space: relatively small numbers are preferentially associated with a left-sided response while relatively large numbers are associated with a right-sided response (the SNARC effect). Previous work demonstrated that the SNARC effect is triggered in an automatic manner and is highly flexible. Besides the left-right dimension, numbers associate with other spatial response mappings such as close/far responses, where small numbers are associated with a close response and large numbers with a far response. In two experiments we investigate the nature of this association. Associations between magnitude and close/far responses were observed using a magnitude-irrelevant task (Experiment 1: automaticity) and using a variable referent task (Experiment 2: flexibility). While drawing a strong parallel between both response mappings, the present results are also informative with regard to the question about what type of processing mechanism underlies both the SNARC effect and the association between numerical magnitude and close/far response locations.

Keywords Number · Close/far dimension · SNARC · Dual-route

✉ Sophie Antoine
sophie.antoine@ulb.ac.be

[1] Center for Research in Cognition and Neurosciences (CRCN) - ULB Neurosciences Institute (UNI), Université Libre de Bruxelles, Brussels, Belgium

Introduction

Research from the past 20 years has repeatedly shown that number and space are associated. Strong evidence of this association is the Spatial-Numerical Association of Response Codes (SNARC effect; Dehaene, Bossini, & Giraux, 1993), which refers to the observation that relatively small numbers preferentially elicit a left-sided response and large numbers a right-sided response. The first important characteristic of the SNARC effect is its automaticity. The SNARC effect is not only observed when numerical magnitude is relevant for performing the task, such as in the magnitude comparison task (i.e., indicate whether a presented digit is smaller or larger than the reference 5), but also in a variety of other tasks that do not require direct access to magnitude information, such as parity judgment (i.e., indicate if a digit is odd or even; Dehaene et al., 1993), orientation discrimination (e.g., is an overlying triangle or line oriented upwards or downwards; Fias, Lauwereyns, & Lammertyn, 2001; is a digit upright or tilted to the right; Lammertyn, Fias, & Lauwereyns, 2002), or phoneme monitoring (i.e., does the presented digit contain an e-sound or not; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996). A second important characteristic of the SNARC effect is its flexibility. A marker of this flexibility is range dependency: in a parity judgment task, the digits 4 and 5 are associated with a right-sided response when the tested range is 0–5, but with a left-sided response if the tested range goes from 4 to 9 (Dehaene et al., 1993; Fias et al., 1996). More recently, Ben Nathan, Shaki, Salti, and Algom (2009) observed in a magnitude comparison task, in which the referent varied on a trial-by-trial basis, that the SNARC effect is driven by the relative magnitude of a number rather than by the absolute (range-based) magnitude. The same number of the tested range was associated with a left (right)-sided response if it was smaller (larger) than the referent, regardless of its absolute magnitude. For instance, participants categorized the number 7 faster with the left-hand side if it had to be judged as being smaller than 8, whereas it was responded to faster with the right-hand side if judged as being larger than 6. Any explanatory framework of the SNARC effect must be able to account for these two properties, namely automaticity and flexibility.

In his seminal study, Dehaene et al. (1993) suggested that the SNARC effect emerges from the automatic activation of an analog representation of numbers. The magnitude of a presented number, relative to other previous targets, would be activated along a spatially defined representation oriented from left-to-right, termed the mental number line. The SNARC effect would be the result of the spatial (in)congruency between the position of an activated magnitude relative to other magnitudes on the mental number line and the position of the response. Later studies suggested that functionally and anatomically similar spatial attention mechanisms might operate on both the mental number line and external space (Hubbard, Piazza, Pinel, & Dehaene, 2005; Zorzi, Priftis, & Umiltà, 2002).

Alternative explanatory frameworks of the SNARC effect have progressively questioned the mental number line hypothesis. The idea underlying these alternative frameworks is that, even though numbers can be organized on a number line, its existence is not implied by the SNARC effect. Gevers, Verguts, Reynvoet, Caessens, and Fias (2006) implemented this idea in a computational model producing the SNARC effect along a dual-route architecture. When a number is presented, its relative magnitude is automatically coded through an unconditional route, while another route conditionally codes for the task instruction (e.g., if odd, press left; if even, press right). Along the unconditional route, numbers are automatically categorized as being small or large at an intermediate level, and this categorization is associated with left- and right-sided responses, respectively. Numbers are responded to faster when both the unconditional and the conditional routes converge on the same response. Thus according to the model, the SNARC effect does not result from a direct mapping between the activation of a position on a number line and a spatial response. Rather, the SNARC effect is observed because of an intermediate magnitude coding level, in which numbers are automatically categorized as small or large, and it is this categorization that is associated with a certain response side. Several observations were made providing good explanations regarding the origin of the association between numbers and space. These are for instance reading and writing directions (Dehaene et al., 1993; Shaki, Fischer, & Petrusic, 2009; Zebian, 2005), innate imbalance (Rugani, Regolin, & Vallortigara, 2010), or association of concepts on the basis of linguistic markedness (for a discussion, see Proctor and Cho, 2006). The dual route account does not refute any of these possibilities nor does it provide evidence favoring one or the other of these factors. These factors may very well constitute the reason why classifications of small or large are associated with a certain response side. The important aspect differentiating the dual route account from the number line view is that spatial responses are associated with numerical magnitude codes extracted at an intermediate level rather than through a direct mapping with a number position on a visuo-spatial representation.

In its current form, the model only represents left- and right-sided responses because these are the typical responses used in SNARC-tasks. However, the model can easily be extended to other response dimensions such as up or down. Indeed, spatial-numerical effects were also observed in the vertical dimension with small numbers associated with down and large numbers associated with up (Ito & Hatta, 2004; Schwarz & Keus, 2004). Furthermore, what seems to be important for the SNARC effect is the possibility to discriminate between response alternatives: Gevers, Lammertyn, Notebaert, Verguts, and Fias (2006) observed that when the vertical and horizontal dimensions were both present but that only one dimension was response-discriminative to perform the task, the SNARC effect was strongly reduced or even eliminated for the non-discriminative dimension. For instance, in one block, responses were given either in a down-left or in a down-right location; in the other block, responses were given to the left or to the right in the upper locations. The horizontal, but not the vertical SNARC effect was observed because responses discriminated between left and right but not between up and down response locations.

The importance of response discrimination was also illustrated when numbers were categorized using close/far response locations (Santens & Gevers, 2008). Participants were asked to perform a magnitude comparison task by pressing a button close to or far from a starting position. Half of the participants performed the task by doing a leftward movement (i.e., close and far responses were placed to the left of the starting position) while the other half of the participants performed the task by doing a rightward movement (i.e., close and far responses were placed to the right of the starting position). No interaction was observed between number magnitude and movement direction (leftward or rightward). The results were also informative regarding the processing mechanism underlying the association with the close/far responses. On the basis of a direct mapping between the position of the number on the number line and the position of the response, faster responses were predicted for numbers close to the reference 5 (e.g., 4 and 6) with close responses and faster responses for numbers far from the reference 5 (e.g., 1 and 9) with far responses. This was, however, not observed. Instead, an association was observed between the magnitude of the number and close/far located responses: faster to close response locations for small numbers (1 and 4) and faster to far response locations for large numbers (6 and 9). These results suggest that the traditional left-right SNARC effect might be only one instantiation of the dual-route model of Gevers, Verguts et al. (2006). The observed associations between close-far responses and magnitude categorizations could be another one. If the same dual-route mechanism underlies the association between small/large and left/right as the association between small/large and close/far, then both associations should share the same properties. In other words, the association between small/large and close/far should also be automatically and flexibly activated. To date these assumptions have not been empirically tested.

Experiment 1: Automaticity

Santens and Gevers (2008) observed an association between small numbers and close responses and between large numbers and far responses. This association was observed in a magnitude comparison task in which magnitude is relevant to correctly perform the task. If this association results from the same processing mechanism as the SNARC effect, then it should also be observed in magnitude-irrelevant tasks. To verify this prediction, participants again classified numbers using close and far located response buttons. Participants had to judge whether a number was numerically close or numerically far from the referent 5. This way, numerical distance (close/far) and numerical magnitude (small/large) are orthogonal: the numbers 4 and 6 are both close in numerical distance to the referent number 5, but 4 is small and 6 is large. Similarly, the numbers 1 and 9 are both far in numerical distance from the referent number 5, but 1 is small while 9 is large. This orthogonal relation between numerical magnitude and numerical distance of the target numbers renders the categorization of target numbers as small or large useless in performing the task, as in a parity judgment task.

Alternatively, we could have opted to use a parity judgment task as a magnitude-irrelevant task. However, the problem with that task is that both the mental number line account and the dual route account would make essentially the same prediction: numbers 1 and 4 associated with the close response button and numbers 6 and 9 associated with the far response button. Indeed, in a parity judgment task, an explicit referent number to which the numbers have to be compared is lacking. Assuming a mental number line, it is therefore likely that participants would use the origin instead of the middle of the number line as an implicit standard to define the spatial location of the numbers. As a result, 1 and 4 would be associated with the close response button (because encountered first) while 6 and 9 would be associated with the far response button (because encountered further on the number line).

Method

Participants Thirty-seven right-handed undergraduate students from the Université Libre de Bruxelles (ULB) participated for course credits (28 females, mean age: 20 years). All had normal or corrected-to-normal vision and were naïve concerning the purposes of the experiment.

Materials and procedure Instructions and experimental design were presented on a 17-inch monitor using E-Prime 2 Professional Software (Psychology Software Tools; Schneider, Eschman & Zucolotto, 2002). Participants were seated in a quiet room approximately 50 cm from the screen with a resolution of 1280 × 1024 pixels. Arabic numbers (1, 4, 6, and 9), presented in Courier New font, size 22, appeared at the center of the screen. Participants responded with their right index finger on an AZERTY keyboard, with relevant response buttons covered by colored stickers. A trial started with the presentation of a hash mark (#) centrally on the screen. By pressing the starting position (J-button covered by a blue sticker), a target number replaced the hash mark. Participants categorized the target as being numerically close or numerically far from the reference number 5 by giving a close or a far response. Response mapping was manipulated within participants: in one block, participants had to indicate that a number was numerically close (far) from 5 by pressing the close (far) response button, while in the following block they had to indicate that a number was numerically close (far) from 5 with a far (close) response. Which response mapping was received first was counterbalanced across participants. In addition, half of the participants produced a leftward movement to respond (G and H buttons covered by yellow stickers) while the other half produced a rightward movement to respond (K and L buttons covered by yellow stickers). Response buttons were labeled as being close or far from the starting position, no references to small or large numbers nor to small or large response movements were made. Finally, no references were made to the letters on the keyboard. There was no time limit, and the inter-trial interval was set to 500 ms. Each number was repeated in random order 20 times resulting in 80 trials per response mapping. Sixteen practice trials preceded each block, to ensure that participants were familiarized with the current response mapping. Participants were asked to respond as fast and as accurately as possible.

Results and discussion

Participants made on average very few errors (error mean was 3 %). A mixed ANOVA with 2 (movement direction: left or right) × 2 (response location: close or far) × 4 (target number: 1, 4, 6, or 9) design was applied on the median reaction times (time from starting position press to response button press). Movement direction was treated as a between-subjects variable while target number and response location were within-subjects variables. Only correct trials were entered in the response-time (RT) analyses. A main effect of response location was observed [$F(1,35) = 42.22$; $p < .001, \eta_p^2 = .55$]: responses to the close button (747.2 ms) were responded to faster than responses to the far button (808.2 ms). Replicating earlier results (Santens & Gevers, 2008), no interaction was observed between number and left-right movement directions [$F(3,105) = 1.82$; $p = .15$, $\eta_p^2 = .05$]. There was a significant interaction between number and response location [$F(3,105) = 6.81$; $p < .001$, $\eta_p^2 = .16$]. Because of the response characteristics, reaction times are different between physically close and physically far response locations. Therefore, planned comparisons were limited to targets within the same response location. A significant interaction was observed between numerical magnitude of target numbers and response location [$F(1,35) = 10.50$; $p < .01$, $\eta_p^2 = .23$, see Fig. 1] such that the close response button was pressed faster for small numbers (i.e., 1 and 4; 728.9 ms) than for large numbers (i.e., 6 and 9; 765.5 ms, [$F(1,35) = 7.18$; $p < .05$, $\eta_p^2 = .17$]), while the far response button was pressed faster for large numbers (798.3 ms) than for small numbers (818.2 ms, [$F(1,35) = 4.47$; $p < .05$, $\eta_p^2 = .11$]). This finding demonstrates that numerical magnitude associates with close/far responses even when magnitude is irrelevant to the task. Post hoc analyses also revealed a significant interaction between numerical distance and response location [$F(1,35) = 6.87$; $p = .013$, $\eta_p^2 = .16$]: the close response button was pressed faster for numerically close numbers (i.e., 4 and 6; 723.3 ms) than for numerically far numbers (i.e., 1 and 9; 771.1 ms, [$F(1,35) = 4.50$; $p < .05$, $\eta_p^2 = .11$]), while the far response button was pressed faster for numerically far numbers (773.6 ms) than for numerically close numbers (842.9 ms, [$F(1,35) = 6.95$; $p < .05$, $\eta_p^2 = .17$]; see general discussion for a detailed discussion of this interaction).

Finally, a main effect of target number was observed [$F(3, 105) = 8,10$; $p < .001$, $\eta_p^2 = .19$]. This pattern of results did not accord with the distance effect (e.g., faster responses for numerically far numbers 1 and 9 than for numerically close numbers 4 and 6, regardless of the response; Moyer and Landauer, 1967, [$F(1,35) = 1.15$; $p = .29$, $\eta_p^2 = .03$]). Instead, planned comparisons showed that responses to the target numbers 4 and 9 were significantly faster than to the numbers 1 and 6, [$F(1,35) = 20.97$, $p < .001$, $\eta_p^2 = .37$]. Numbers sharing the same response code (e.g., number 4 is associated with the close response button because it is numerically small and numerically close) are responded to faster than numbers activating opposite response codes (e.g., number 1 is associated with the close response button because it is numerically small, but also with the far response button because it is numerically far).

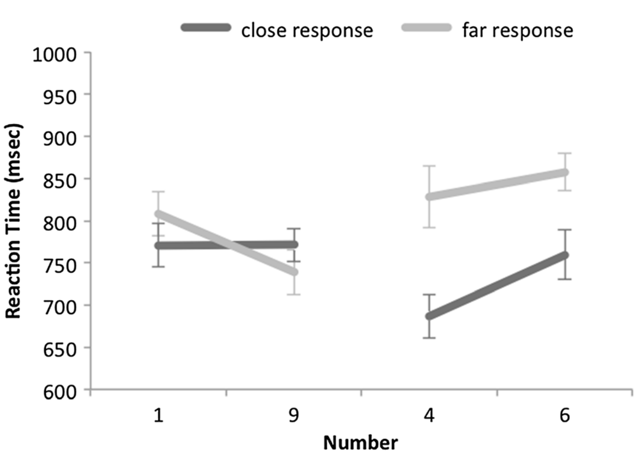


Fig. 1 Reaction times for each number, separated for close and far responses. Error bars reflect standard errors

Experiment 2: Flexibility

The previous experiment demonstrated that associations between magnitude information and close/far responses can be observed in magnitude-irrelevant tasks. Experiment 2 further investigates the flexibility of this association. Participants again classify numbers using close and far response locations. In this experiment, magnitude information is made relevant (e.g., magnitude comparison task) but numbers have to be classified using a variable referent (cf. Ben Nathan et al., 2009). The specific question is whether the association between magnitude and close/far responses flexibly follows the relative mapping towards the referent (e.g., the target 3 is larger than the referent 2 and thus associated with a "far" response) or whether the association is observed as a function of the absolute magnitude of the number (e.g., 3 is small within the range of numbers used, and therefore associated with close responses).

Method

Participants Fifty-eight right-handed undergraduate students from the Université Libre de Bruxelles (ULB) participated in this experiment (49 females, mean age: 20 years). All had normal or corrected-to-normal vision and were naïve concerning the purposes of the experiment.

Materials and procedure A trial started with the presentation of a hash mark at the center of the screen, replaced after 500 ms by the reference number printed in red in Times New Roman, size 22. As soon as the participant pressed the starting position, the target number replaced the reference number. Target numbers were printed in black in Courier New, size 22, in order to make them distinctive from the reference numbers. Participants categorized the target as numerically smaller or larger than the reference number by pressing a close or a far response button. Response mapping was manipulated within participants: in one block, participants had to indicate that a number was smaller than the referent by pressing the close response button, while in the following block they had to indicate that a number was smaller than the referent with a far response (vice versa for numbers larger than the referent).

Which response mapping was received first was counterbalanced across participants. Again, half of the participants produced only leftward movements while the other half produced only rightward movements to respond. Eight pairs of reference-target combinations were used: (2-1), (2-3), (4-3), (4-5), (6-5), (6-7), (8-7), and (8-9). Each pair was repeated in random order 16 times per block, giving 128 pair trials per response mapping. The extreme target numbers (1 and 9) were excluded from the analyses because they cannot be relatively smaller *and* larger with single-digit reference numbers, as well as the target 5 because it cannot be considered as absolutely (i.e., based on the range) small or large. As a consequence, only the number targets 3 and 7 were considered in the analyses.

Results and discussion

Two participants were excluded from the analyses because of a chance level of performance (50.4 % and 64.8 % of correct responses) while all other participants had on average 96 % of correct responses. A mixed ANOVA with a 2 (movement direction: left or right) × 2 (response location: close or far) × 2 (relative magnitude: smaller or larger) × 2 (absolute magnitude: small or large) design was applied on the median reaction times (time from starting position press to response button press). Movement direction was treated as a between-subjects variable; while the other variables were treated as within-subjects variables. Only correct trials were entered in the RT analyses.

A main effect of response location was again observed [F(1, 54) = 43.77; p < .001, η_p^2 = .45]: responses to the physically close button (777 ms) were responded to faster than the physically far button (849 ms). This advantage for the physically close button tended to be more pronounced with rightward movements, as indicated by a marginally significant interaction between response location and movement direction [F(1,54) = 3.25; p = .08, η_p^2 = .06]. Importantly, response locations were not associated with absolute magnitude [F(1,54) = 0.01; p = .92, η_p^2 < .001, see Fig. 2b], but there was an interaction between response location and relative magnitude [F(1,54) = 39.97; p < .001, η_p^2 = .43, see Fig. 2a]. Close responses were faster for relatively small numbers (710.8 ms) than for relatively large numbers (824.2 ms, [F(1, 54) = 28.72; p < .0001, η_p^2 = .35]), while far responses were faster for relatively large numbers (783.1 ms) than for relatively small numbers (914.3 ms, [F(1,54) = 39.39; p < .0001, η_p^2 = .42]). In addition, the significant three-way interaction between relative magnitude, response location, and movement direction [F(1,54) = 8.95; p < .01, η_p^2 = .14] indicated that this association between smaller-close and larger-far was less pronounced, but still present in the leftward [F(1,54) = 5.75; p = .019, η_p^2 = .10] compared to the rightward movement group [F(1,54) = 41.87; p < .001, η_p^2 = .44]. This

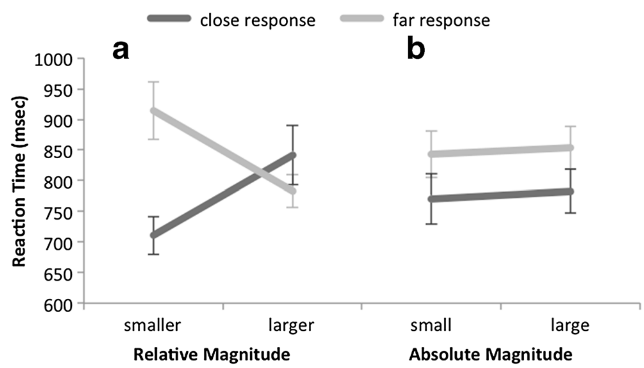


Fig. 2 Reaction times for relative magnitude (**a**) and absolute magnitude (**b**), separated for close and far responses. Error bars reflect standard errors

three-way interaction may be a consequence of the fact that the advantage for the physically close response compared to the physically far response was more pronounced in the rightward movement group (as shown by the above-mentioned interaction between response location and movement direction).

Finally, the three-way interaction between absolute magnitude, relative magnitude, and response location was significant [F(1,54) = 10.72; p < .01, η_p^2 = .17], indicating that absolute magnitude was extracted during task performance. Closer inspection of this interaction revealed a semantic congruity effect (Banks, Fujii, & Kayra-Stuart, 1976) between relative and absolute magnitude that was observed with close [F(1,54) = 13.86; p < .001, η_p^2 = .20] but not with far responses [F(1,54) = 1.75; p = .19, η_p^2 = .03]. For the close response button, participants were faster to categorize numbers as being relatively smaller compared to larger than a referent if the number was also small within the tested range [F(1,54) = 39.75; p < .0001, η_p^2 = .42], while they were faster to categorize numbers as being larger compared to smaller than a referent if the number was also large in the tested range [F(1,54) = 12.13; p < .001, η_p^2 = .18]. It remains unclear why the semantic congruity effect was limited to the close responses. Nevertheless, while its presence indicates that the absolute magnitude of the number was processed, it was the relative magnitude and not the absolute magnitude that was associated with the spatially defined close/far responses.

General discussion

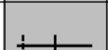
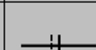
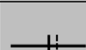
Previous work demonstrated that an association exists between the processing of magnitude information (e.g., small/large) and spatially defined responses (e.g., close/far; Santens & Gevers, 2008). While it was suggested that this association is the result of the same processing mechanism as the one underlying the well-known SNARC effect (e.g., association between magnitude and left/right response codes), this was never empirically tested. In the present study, two experiments were run to investigate whether the characteristics of the SNARC effect (e.g., automaticity and flexibility) also apply to the close/far response paradigm. The first experiment tested the automaticity assumption, introducing a magnitude-irrelevant task. Participants were asked to classify numbers as being numerically close or numerically far from the referent number 5 by pressing close/far response buttons. In this task, numbers have to be intentionally processed (is the target number numerically close or far from the reference?). However, numerical magnitude of the target number on itself cannot be used to solve the task. At this point, the parallel with the parity judgment task is complete. The parity judgment task is widely recognized as a task in which numbers are intentionally processed but magnitude is irrelevant (e.g., Dehaene et al., 1993). In both our close-far judgment task and the parity judgment task, the number has to be processed intentionally to be able to respond (e.g., is the number odd/even – is the number numerically close/far). A possibly important difference between these tasks is that in the parity judgment task, the semantics of the target number itself is sufficient to respond, while a comparison between the target number and the referent is needed in the close-far judgment task. However, crucially, in both tasks, numerical magnitude cannot be used to solve the task. This is the case because numerical magnitude of the target number (i.e., small-large) and the response buttons are orthogonal: in both tasks, both small and large numbers map onto the same response.

As Table 1 shows, in case the task would be solved by activating a mental number line (see row A: representational distance), 4 and 6 would associate with the close response button, while 1 and 9 would associate with the far response button. Alternatively, participants could have calculated the magnitude difference between the stimulus and the referent to solve the task (see row B: distance magnitude). In this case, stimuli 1 and 9 would be categorized as numerically far because the magnitude difference between the stimuli and the referent is large (e.g., 9 vs. 5 = 4; 5 vs. 1 = 4), whereas stimuli 4 and 6 would be categorized as close because the magnitude difference between the stimuli and the referent is small (e.g., 6 vs. 5 = 1; 5 vs. 4 = 1). In both these accounts (representational distance or distance magnitude), 1 and 9 would associate with a far response button, and 4 and 6 with a close response button. Neither of these accounts can explain the observed coupling of 1 and 4 with the close response button and the coupling of 6 and 9 with the far response button (see table row C). In sum, numbers had to be processed intentionally while numerical magnitude was not relevant to resolve the task. Still, numerical magnitude automatically associated with close/far response buttons.

The second experiment tested the flexibility of the association between magnitude and close/far responses. To this end, participants classified numbers as smaller or larger than a variable referent. Although the nature of the task emphasized relative magnitude coding (i.e., smaller or larger than the referent), the three-way interaction between absolute magnitude (i.e., small or large within the tested range of numbers used), relative magnitude, and response location demonstrated that absolute magnitude was coded as well. Further analyses indicated that this interaction was due to a semantic congruity effect (Banks et al., 1976) between absolute and relative magnitude for the close but not for the far response location. Crucially with regard to our hypothesis, even though absolute magnitude was coded, close/far response locations were associated with relative magnitude but not with absolute magnitude (as illustrated in Fig. 2). Similar to studies on the SNARC effect (e.g., Ben Nathan et al., 2009; Fias et al., 1996), our experiments demonstrate that the association between magnitude information and close/far response locations is activated in an automatic and flexible manner.

While drawing a strong parallel between both response mappings, the present results are also informative with regard to the question about what type of processing mechanism underlies both the SNARC effect and the association between

Table 1 The left side of the table illustrates the representations/codes associated with each target number; the right side of the table lists the predicted response association with these representations/codes

	Target Number				Predicted Response Association			
	1	4	6	9	1	4	6	9
row A. representational distance					far response	close response	close response	far response
row B. distance magnitude	large (4)	small (1)	small (1)	large (4)	far response	close response	close response	far response
row C numerical magnitude	small	small	large	large	close response	close response	far response	far response

numerical magnitude and close/far response locations. In Experiment 1, participants were encouraged to respond to the representational position of the number towards the referent number 5 on a mental line (e.g., is the target number numerically close or numerically far from the referent?). An interaction was observed showing a link between numerically close numbers (4 and 6) and close button responses and between numerically far numbers (1 and 9) and far button responses. However, on the basis of a direct mapping between a position on a mental number line and response location, a distance-like effect (Moyer & Landauer, 1967) could also have been expected with overall slower responses to the numbers 4 and 6 (because of higher representational overlap with the reference number 5) as to the numbers 1 and 9 (because of lower representational overlap with the reference number 5). This was, however, not observed. Participants responded faster to 4 and 9 compared to 1 and 6. In addition, small magnitudes (target numbers 1 and 4) were associated with the close response button and large magnitudes (target numbers 6 and 9) were associated with the far response button. While a direct mapping from the mental number line has difficulties in explaining both these observations, a dual-route processing mechanism with an intermediate magnitude-coding layer can readily incorporate both findings. Via the unconditional route, a number would automatically activate a magnitude code (e.g., small/large), which then associates with a response code (e.g., close/far response buttons, respectively). In parallel, these response codes are also activated via a conditional route coding for the task instruction (e.g., if numerically close, press the close button; if numerically far, press the far button). In experiment 1, this conditional route was biased in a way that a numerically close (far) number was responded to faster with the close (far) located button response. When both routes converge on the same response code, faster responses can be predicted. This is exactly what was observed. Numbers for which both routes converged on the same response code were responded to faster (number 4: numerically close/magnitude small; number 9: numerically far/magnitude large) compared to numbers for which both routes were associated with a different response code (number 1: numerically far/magnitude small; number 6: numerically close/magnitude large). Note that a highly similar pattern of results was previously observed within the context of the size congruity effect (Henik & Tzelgov, 1982), which refers to the observation that it is easier to find the numerically smaller (larger) number when it is also the physically smaller (larger) one. When the task entails judging numbers as a function of their numerical distance from a referent, congruency is no longer observed on the basis of numerical and physical magnitude, but instead on the basis of numerical and physical distance (Santens & Verguts, 2011). Contrary to the hypothesis of an analog magnitude representation (e.g., the mental number line), a decision approach implemented along a dual-route processing mechanism offers a unified framework to account for all these empirical observations.

Furthermore, the results of Experiment 2 are in disagreement with the idea that the observed association between magnitude and close/far responses is the result of spatial shifts of attention. Such shifts of attention were previously thought to be the functional cause of the SNARC effect (Fischer, Castel, Dodd, & Pratt, 2003). They demonstrated that numerical magnitude can induce shifts of spatial attention to the left or to the right. Using a variant of the Posner cueing task (Posner, 1980), it was observed that a left-sided (right-sided) target was detected faster if a small (large) number preceded the target. In line with the results of Ben Nathan et al. (2009), we observed that it is the relative magnitude code rather than the absolute magnitude that is associated with the response code. The results of Ben Nathan et al. (2009) could still be explained in terms of spatial shifts of attention. For instance, going from the reference number 4 to the target number 3 could induce a spatial shift of attention to the left along the number line, leading to faster left hand responses. Such an explanation can, however, not deal with close/far response codes used in our second experiment.

To conclude, this study showed that the association between numbers and close/far responses demonstrate the same characteristics as the SNARC effect, namely that the association is automatic and flexible. Those results can readily be explained using the dual-route account. In more general terms, they fit with the view that the associations between numbers and spatial responses (either left/right or close/far) are created during the decision/categorization process, as recently suggested (Van Opstal & Verguts, 2013).

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