Brief article

The SNARC effect does not imply a mental number line

Seppe Santens *, Wim Gevers

Department of Experimental Psychology, Ghent University, H. Dunantlaan 2, B-9000 Gent, Belgium

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Abstract

In this study, we directly contrast two approaches that have been proposed to explain the SNARC effect. The traditional direct mapping account suggests that a direct association exists between the position of a number on the mental number line and the location of the response. On the other hand, accounts are considered that propose an intermediate step in which numbers are categorized as either small or large between the number magnitude and the response representations. In a magnitude comparison task, we departed from the usual bimanual left/right response dimension and instead introduced the unimanual close/far dimension. A spatial–numerical association was observed: small numbers were associated with a close response, while large numbers were associated with a far response, regardless of the movement direction (left/right). We discuss why these results cannot be explained by assuming a direct mapping from the representation of numbers on a mental number line to response locations and discuss how the results can be explained by the alternative accounts.

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* Corresponding author. Tel.: +32 9 264 64 41; fax: +32 9 264 64 96.
E-mail address: seppe.santens@ugent.be (S. Santens).

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1. Introduction

When making a parity (odd/even) judgment, people generally respond faster with the left-hand side to relatively small numbers and with the right-hand side to relatively large numbers. In other words, even when magnitude information is irrelevant, an interaction is observed between number magnitude and the response location. This SNARC effect (Spatial-Numerical Association of Response Codes) was first investigated by Dehaene, Bossini, and Giraux (1993) and has been replicated in a wide variety of experimental settings (for recent reviews, see Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005). Dehaene et al. (1993) gave the following explanation for their findings:

A representation of number magnitude is automatically accessed during parity judgments of Arabic digits. This representation may be likened to a mental number line (Restle, 1970), because it bears a natural and seemingly irrepressible correspondence with the left–right coordinates of external space. (p. 394)

It is thus suggested that numbers are represented on a spatially oriented mental number line. The SNARC effect is then the result of the position of a number on this mental representation and an irrepressible correspondence with the position of a response in external space (we will call this the “direct mapping account”). A study reported by Bächtold, Baumuller, and Brugger (1998) provided an interesting example of this mapping between number representations and response positions. Here, the representation of numbers was reversed by imagining numbers as presented on a clock face (where small numbers are represented on the right, and large numbers on the left). A reversed SNARC effect was obtained: small numbers were responded to faster with the right-hand side and large numbers with the left-hand side.

The idea of a direct association between numbers spatially positioned on an imagined line and a spatial response has been challenged recently on two accounts. First, Gevers, Verguts, Reynvoet, Caessens, and Fias (2006) presented a computational model to account for the SNARC effect. The model consists of three layers. In between the bottom layer representing the numerical representation and the upper layer representing the response alternatives, a middle layer was introduced. This middle layer is responsible for conceptually categorizing numbers as small/large, odd/even, or any given category that is required by the task. These categorical representations are then associated with their corresponding alternative on a specific response dimension. In a recent conceptual update, the model has been extended with an abstract spatial code (Notebaert, Gevers, Verguts, & Fias, 2006). Consequently, a number that is categorized as small or large will first activate an abstract spatial code such as “left” or “right” before activating the response.

Second, Proctor and Cho (2006) also presented an account that breaks with the idea that a spatially oriented mental number line is necessary to explain the SNARC effect. This account is not restricted to number processing but can be extended to tasks ranging from word-picture verification to implicit association. Here, it is argued that stimuli and responses are represented at an intermediate level as negative (−) or positive (+) polarity, as long as they can be coded on a bipolar dimension. To
account for the SNARC effect, the polarity correspondence principle assumes that small numbers are coded as − polarity and large numbers as + polarity. The response location is coded in a similar way: − polarity for a left response and + polarity for a right response. Because corresponding polarities cause faster response selection, small numbers will be responded to faster with the left hand and large numbers with the right hand.

In sum, both accounts (Gevers, Verguts, et al., 2006; Proctor & Cho, 2006) argue in favor of an extra step in which numerical information is categorized before the activation of a response side. In both “intermediate coding” accounts, numbers are first coded as either small (−) or large (+) and this representation of magnitude is then directly or indirectly associated with spatially defined responses.

A spatial–numerical association of response codes does not only exist for the horizontal (left/right) dimension. For example, it has been shown that for responses defined in the vertical dimension, responding to relatively large numbers is faster with a top response and responding to relatively small numbers is faster with a bottom response (Gevers, Lammertyn, Notebaert, Verguts, & Fias, 2006; Ito & Hatta, 2004; Schwarz & Keus, 2004). In the present study, evidence is provided for the existence of an association between number magnitude and close and far responses. The specific design of the experiment allowed to establish this spatial–numerical association independently of an association with left or right. During the experiment, participants had to judge the magnitude of a number (1, 4, 6 or 9) relative to a predefined standard (5), by moving their right index finger either to a close or to a far location on a computer keyboard. Participants were allowed to move in one direction only: half of the participants moved their finger to a close or far location on the left side, while the other half moved their finger to a close or far location on the right side. This manipulation was implemented to let participants discriminate between close and far responses but not between left and right responses. In line with observations by Ansorge and Wühr (2004), it has been shown that the SNARC effect is largely reduced or even eliminated if participants do not have to discriminate on the relevant response dimension (Gevers, Lammertyn, et al., 2006). For instance, only a weak association between numbers and left and right responses was observed when the task required a discrimination between top and bottom responses. Similarly, the association between magnitude and top and bottom responses was eliminated when a discrimination in the horizontal response dimension was required. In the present task, participants always moved their finger in the same horizontal direction (always to the left or always to the right). As such, the response does not discriminate between left and right, only between close and far. Therefore, no interaction between number magnitude and movement direction is expected.

Most importantly, our study was designed to differentiate between predictions stemming from the direct mapping account on the one hand and the intermediate coding accounts on the other. The predictions from the latter are fairly straightforward. According to these accounts, numbers are coded as smaller (− polarity) or larger (+ polarity) than a task-specific standard (5), before being associated with a response. Therefore, these accounts predict that small numbers (1 and 4) should be associated with a close response and large numbers (6 and 9) with a far response.
(for a discussion on the association of concepts based on linguistic markedness, see Proctor & Cho, 2006). In other words, an interaction should be observed between the relative magnitude of a number and the location of the response: a close response should be faster for small numbers (1 and 4) than for large numbers (6 and 9), while a far response should be faster for large numbers (6 and 9) than for small numbers (1 and 4).

Different predictions are derived from the direct mapping account. In a magnitude comparison task, the mental number line metaphor suggests that the middle of the range of target numbers is used both as a standard to define the magnitude of numbers and as a spatial referent to define locations on the number line. For explaining the horizontal SNARC effect, a direct mapping is assumed between the left/right position of a number relative to the standard on the number line and the left/right position of a response in external space. The same reasoning can be applied to predict the nature of an association between numbers and close and far responses. On the mental number line, 4 and 6 are located close to the standard 5, whereas 1 and 9 are located far from 5. If a direct mapping between locations on the number line and locations in external space is assumed, then close responses should be facilitated more strongly for numerically close numbers (4 and 6) than for numerically far numbers (1 and 9), whereas far responses should be facilitated more strongly for numerically far numbers than for numerically close numbers. In other words, we should observe an interaction between the numerical distance of the target number relative to the standard and the location of the response.

2. Methods

Fifteen right-handed students of Ghent University participated for course credits (9 female, mean age: 18 years, range: 18–20 years). The procedure was based on the experiments described by Gevers, Lammertyn, et al. (2006). Both the instructions and the experimental task were presented on a 17" computer monitor using the Tscope library for the C programming language (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Participants had to classify the numbers 1, 4, 6, or 9 as smaller or larger than 5 (magnitude comparison task). The stimuli were presented as Arabic digits in Arial font. They appeared centrally on screen and covered a visual angle of approximately 1.2° horizontally and 1.8° vertically at a viewing distance of approximately 50 cm. Responses had to be made using five adjacent letters on the second row of a standard qwerty computer keyboard (g, h, j, k, and l). The letters were covered with a yellow sticker dot. A trial started with the presentation of a hash mark (#) centrally on screen. Participants were instructed to press the “middle” key (j) with their right index finger to start the trial. As soon as this key was pressed, the hash mark was replaced by a target number. The target had to be judged as smaller or larger than 5 by giving a “close” or a “far” response. The response mapping from magnitude (smaller or larger than 5) to the close or far response keys was manipulated within subjects and changed every block: in one block, participants had to indicate that a number was smaller than 5 by pressing the close response key, while in the
following block they had to indicate that a number was smaller than 5 with a far response (vice versa for numbers larger than 5). Which response mapping was received first was counterbalanced over participants. The direction in which the participants had to move was counterbalanced between subjects: half of the participants always moved their finger to the left (from the “middle key” j to the “close left key” h or the “far left key” g); the other half of the participants always moved their finger to the right (from the “middle key” j to the “close right” key k or the “far right” key l). After the response or after 3 s, there was a 500 ms pause until the next trial started. There were four blocks of 80 trials, so each target number was repeated 20 times per block. The order in which the numbers were presented was randomized every block. Sixteen practice trials preceded each experimental block, to make sure that the participants were adapted to the correct response mapping during the critical trials. Response keys were consequentially labeled as being close or far from the middle key, no references to small or large movements or to the letters on the keyboard were made. As in Gevers, Lammertyn, et al. (2006), no specific instructions were given concerning the speed of pressing and releasing the middle key. Both accuracy and speed were emphasized with respect to the actual response to the target number.

3. Results

Overall, participants made few errors (2.3% of all trials). A mixed ANOVA with a 2 (movement direction: left or right) by 4 (number: 1, 4, 6, or 9) by 2 (response location: close or far) design was applied to the error rates. Movement direction was treated as a between subjects variable; number and response location were treated as within subjects variables. Importantly, there was no significant effect of number on the error rates \(F < 1\) nor did number interact with any other variable \([all p > .14]\).

Because no specific instructions were given with regard to the speed of pressing and releasing the middle key, the analyses focus on total response times (RTs), which entail the interval between stimulus onset and response. The interval measured from pressing to releasing the middle key (pressing time) was generally short \((M = 121 \text{ ms}, SD = 30 \text{ ms})\), suggesting that participants did not wait to release the middle key before a decision was made upon the specific response to make. This was confirmed statistically by applying the same mixed ANOVA as below to the pressing times, which yielded no significant effects.

Only correct trials entered the RT analysis. We trimmed these data, keeping only the responses that were made between 200 and 1000 ms after stimulus onset. 3.5% of the correct trials were omitted from the analysis this way. A mixed ANOVA was run with a 2 (movement direction: left or right) by 4 (number: 1, 4, 6, or 9) by 2 (response location: close or far) design. Movement direction was treated as a between subjects variable; number and response location were treated as within subjects variables. The main effect of movement direction did not reach significance \(F < 1\): participants making a movement to the left were equally fast as participants making a movement to the right. There was a significant main effect of number \(F(3, 39) = 17.65;\)
showing a comparison distance effect (Moyer & Landauer, 1967): responses to numbers that are numerically close to the standard (4 and 6) were slower than responses to numbers numerically far from the standard (1 and 9). As could be expected, a main effect of response location \( F(1, 13) = 45.82; p < .01 \) was observed: responses to a response key that was physically close to the middle key were executed faster than responses to a far key. Importantly, there was a significant interaction between number and response location \( F(3, 39) = 5.53, p < .01 \). No other interactions reached significance [number by movement direction: \( F(3, 39) = 1.37, p = .27 \); response location by movement direction and three-way interaction: both \( F < 1 \)]. In a next step, planned comparisons were used to test our specific predictions. There was no interaction between numerical distance from the standard and response location \( F < 1 \). Instead, there was an interaction between number magnitude relative to the standard and response location \( F(1, 13) = 7.24, p < .05 \): close responses were faster to small numbers (1 and 4) than to large numbers (6 and 9), while far responses were faster to large numbers than to small numbers (Fig. 1).

### 4. Discussion

In this study, we implemented the close/far response dimension in a typical SNARC paradigm. The results show that in a magnitude comparison task, close responses are associated with small numbers and far responses with large numbers. Consistent with the response-discrimination account (Ansorge & Wühr, 2004; Gevers, Lammertyn, et al., 2006), there was evidence only for an interaction between numbers and the response dimension on which participants had to discriminate.

![Fig. 1. Response times for each number, separated for close and far responses. For convenience of inspection, numbers with the same numerical distance from the standard are grouped.](image-url)
(close/far) and not between numbers and movement direction. The mental number line metaphor proposes a direct mapping between the number representation on a mental number line and the corresponding response location in external space. Therefore, it predicts an association between numbers close to the standard on the number line and close responses and between numbers far from the standard and far responses. There was no evidence for this.

Like the model by Gevers, Verguts, et al. (2006) and the account by Proctor and Cho (2006), the present study argues in favor of an intermediate categorization of numbers as relatively small (− polarity) or large (+ polarity) in order to explain the SNARC effect. These intermediate representations are subsequently linked with their corresponding alternatives on a response dimension (left/right, bottom/top, close/far, . . .). It has already been shown that the specific coupling of these representations with response alternatives depends on the task at hand and the specific experimental conditions (e.g. see Bächtold et al., 1998; Fischer, 2006; Gevers, Lammertyn, et al., 2006; Notebaert et al., 2006). Future research and computational modeling will have to investigate in more detail how the connection between the representation of magnitude and certain response alternatives is specifically established. Evidently, a mechanism that enables the categorization of numbers as either relatively small or large is still needed. However, as has already been shown with the computational model by Gevers, Verguts, et al. (2006), there is no need for spatial representations to accomplish this. The same model also predicts the specific characteristics of response times associated with the SNARC effect. Furthermore, it has been shown that a very similar modeling approach can account for the comparison distance and size effect without assuming the characteristics commonly attributed to the mental number line (Verguts, Fias, & Stevens, 2005).

The present study shows that a spatial–numerical association of response codes (SNARC) can no longer be taken as evidence for the existence of a spatially oriented mental number line. Although it is possible that the use of a mental number line metaphor remains useful and that such a numerical representation may very well exist, this cannot be concluded on the basis of the SNARC effect.

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