

When symbolic spatial cues go before numbers

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This work explores the effect of spatial cueing on number processing. Participants performed a parity judgment task. However, shortly before the target number, a cue (arrow pointing to left, arrow pointing to right or a cross) was centrally presented. In Experiment 1, in which responses were lateralized, the cue direction modulated the interaction between response side and numerical size. In Experiment 2, there was a single response key, and in one block participants responded only to odd numbers and in the other block they responded only to even numbers. The results showed an association between symbolic spatial cues and numbers (i.e., small/left and large/right). We interpreted the joint results as indication of an early activation of spatial representation of numerical values produced independently of type of response requirements.

A common view in the number processing literature is that numerical magnitude is analogically represented in a *mental number line* (Dehaene, 1992), formally given by a set of units in which nearby numbers are represented with overlapping distributions of activation (for different implementations of this kind of representation, see Verguts, Fias, & Stevens, 2005). The mental number line is suggested to be arranged from left to right, which might account for the findings about a relationship between numbers and spatial information. The more examined finding has

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been the so-called SNARC (Spatial-Numerical Association of Response Codes) effect (Dehaene, Bossini, & Giraux, 1993). It consists of shorter reaction times (RTs) to small numbers with left side responses than with right side responses and shorter RTs to large numbers with right side responses than with left side responses. The SNARC effect is interpreted as the result of an association between the relative numerical magnitude and the response side (i.e., small/left and large/right). Therefore, the numerical magnitude is considered responsible for the activation of spatial codes that may or may not be in accordance with the side of the required response (e.g., Dehaene et al., 1993; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Fischer, Warlop, Hill, & Fias, 2004). However, the SNARC effect occurs even when the numerical magnitude information is not relevant to the task (e.g., Dehaene et al., 1993; Fias et al., 1996), indeed, most of the researchers have used a parity judgment task in which the magnitude information is irrelevant (Dehaene et al., 1993).

The similarity between the SNARC effect and other stimulus-response compatibility effects (e.g., Simon effect) led Gevers, Verguts, Reynvoet, Caessens, and Fias (2006) to suggest a computational model based on a dual-route architecture. In the model, the numerical stimulus produces the activation of a common spatial response code from two independent sources. On the one hand, a spatial code associated to the numerical magnitude activates the response code (unconditional route, independent of instructions). In this route, there is an intermediate step between the magnitude representation (i.e., the mental number line) and the response representation, in which numbers are categorized as either small or large. On the other hand, the response code is also activated by the response defined by the task instructions (conditional route). When both sources activate the same response code, decisions are faster because the threshold response at the selection stage is reached faster. However, when both sources activate different response codes, the selection stage takes more time to reach the threshold and thus, responses are slower. The congruence/incongruence between both routes, therefore, determines the difference in the response times at the response-selection stage. Behavioral and electrophysiological studies support the response-selection stage as the locus of SNARC effect (Gevers, Caessen, & Fias, 2005; Gevers, Ratinckx, De Baene, & Fias, 2006; Keus, Jenks, & Schwarz, 2005; Keus & Schwarz, 2005; although see Mapelli, Rusconi, & Umiltà, 2003).

However, the association between numbers and space also occurs at earlier processing stages. Several studies have shown that the mere presence of a number at the fixation point induces an attentional bias so that smaller numbers facilitate stimuli detection in the left visual side while larger

numbers facilitate stimuli detection in the right visual side (e.g., Cassarotti, Michielin, Zorzi, & Umiltà, 2007; Fischer, Castel, Dodd, & Pratt, 2003; Ristic, Wright, & Kingstone, 2006).

All these studies indicate that numbers induce the activation of spatial features that may influence the subjects' responses at different processing stages. In addition, the complementary question of whether spatial cues are able to influence number processing is also relevant. Keus and Schwarz (2005) manipulated the spatial position (right to or left to a fixation point) of target numbers in a parity judgment task. They hypothesized that the lateralization of digit stimuli could influence the time required to form an initial mental number representation. Thus, SNARC-like effects could arise at an early space-related number representation by the congruency/incongruency between the side in which the digits were presented and their relative location in the mental number line. They failed to find the expected interaction between the numerical magnitude and the spatial position of the target both with vocal response (Experiment 1) and with manual lateralized response (Experiment 2), only the magnitude by side of response interaction (i.e., the SNARC effect) was found. More recently, Stoianov, Kramer, Umiltà, and Zorzi (2008) re-examined the Keus and Schwarz's study. They suggested that the lack of influence of spatial cues on number processing could be due to the concurrent presentation of visuospatial and numerical information. Since the physical spatial information is coded fast, it could decay or be inhibited before the spatial numerical information was activated. Therefore, they predicted that presenting the spatial cue after the number could result in the expected effect. In order to test this hypothesis, Stoianov et al. conducted two experiments in which subjects vocally responded to the numerical magnitude (Experiment 1) and to the number parity (Experiment 2). A physical spatial cue (i.e., a dot placed to the right or to the left of the fixation point) was presented before or after the onset of the target number. They found that a spatial cue affected number processing when it followed the numerical target (i.e., backward priming), but not when the spatial cue was presented first (i.e., forward priming). They argued that semantic processing of a target digit must be preceded by its perceptual processing, whereas a non-numerical visuospatial prime does not require any more than just perceptual processing. Therefore, the absence of forward priming could be explained by assuming that the spatial coding of visuospatial primes was faster processed and disappeared before the processing of the spatial information associated to the target number.

In this article, we explore a prediction derived from the previous argument. If forward spatial priming in number processing is not found due

to the fast processing of physical spatial cues, this effect could probably be found by introducing spatial cues requiring additional processing. That is the case for spatial symbols such as arrows. Even when arrows are conventional over-learned signs, their spatial meaning are not directly obtained from the perceptual processing. Similar to other symbols (e.g., numbers or words), additional semantic processing is needed to retrieve the spatial meaning. Therefore, we could presume that forward priming could occur by using symbolic spatial cues. We investigated this hypothesis in two experiments in which subjects had to respond to number parity. Shortly before the target appeared, a task irrelevant arrow was centrally presented. In Experiment 1 the responses were lateralized and in Experiment 2 the responses were not lateralized.

EXPERIMENT 1

In Experiment 1, we explored the effect of symbolic spatial cues in a parity judgment task with lateralized responses. In each trial, an irrelevant cue (i.e., an arrow or a cross) was presented previously to the number. Participants were explicitly told that the cues were non-predictive and that they could be ignored. We expected that the SNARC compatibility might affect the subject's responses because they were lateralized. In addition, following previous suggestions, we would expect to find an interaction between cue and numerical size. For example, a left pointing arrow might prime numbers associated to the left meaning, so smaller numbers in the tested range would be favoured.

METHOD

Participants. Twenty students (19 females; 1 left-handed) at the University of Trieste participated for course credits. The range of age was between 18 and 31 years old ($M = 22$ years). All had normal or corrected-to-normal visual acuity.

Stimuli and Apparatus. The experiment was controlled by a Genuine-Intel compatible PC 1.73 GHz, using E-prime experimental software, 1.1 version (Schneider, Eschman, & Zuccolotto, 2002). Instructions and stimuli were presented on a 17" screen located at approximately 50 cm in front of the subject. Arabic numbers from 1 to 9 (except 5) were used as targets. The target digit was presented in Tahoma font and subtended a visual angle of 3.4° vertically and 2.3° horizontally.

The cue consisted of an arrow pointing to left, an arrow pointing to right, or a cross; all of them subtending a visual angle of 2.3° vertically and 3.4° horizontally. All stimuli were presented in black with a white background and were centred on the screen. The keyboard was used for giving responses.

Procedure and Design. Participants were told that digits between 1 and 9 (excluding 5) would be presented and that they had to indicate the parity of each number by pressing two keys with the index and middle fingers of their preferred hand. Instructions explicitly reminded that 1, 3, 7 and 9 were odd numbers and that 2, 4, 6 and 8 were even numbers. Subjects performed the task with only one response assignment (e.g., Gevers, Ratinckx et al., 2006; Mapelli et al., 2003). The response keys were “N” (right-key) and “B” (left-key) on the computer keyboard. Half of the subjects responded by using “N”/even and “B”/odd assignment while the others received the reverse response key assignment. A trial consisted of a cue presented for 200 ms followed by the target digit which remained on the screen until the subject’s response. The next trial began 1000 ms after the subject’s response. RTs were measured to the nearest millisecond. Participants knew that the cue provided no information about target identity.

The combinations of the eight targets (1, 2, 3, 4, 6, 7, 8, 9) and the three cues (left-arrow, right-arrow and cross) resulted in a set of 24 types of trials which were randomly presented three times each block (72 trials per block). There were four blocks with breaks between them (a total of 288 experimental trials). Before the experimental trials, an example was shown and participants performed ten practice trials. The experimental session lasted approximately 20 minutes.

RESULTS AND DISCUSSION

All RTs longer than three standard deviations or shorter than 200 ms were excluded from analyses (3%). A preliminary analysis including the response assignment indicated that this variable did not produce either significant main effect or interactions with other variables (all F s < 1), therefore, it was not considered any further. Mean RTs of correct responses were analyzed by applying a 3 x 2 x 2 analysis of variance (ANOVA) with Cue (cross, right-pointing arrow and left-pointing arrow), Size (small and large) and Response side (right and left) as within-subject factors. None of the main effects were significant (all p s > .05). However, the first-order Cue x Size interaction, $F(2, 38) = 4.97$, $MSE = 386$, $p < .05$; the Size x Response

side interaction, $F(1, 19) = 15.37$, $MSE = 4637$, $p < .001$; and the Cue x Response side interaction, $F(2, 38) = 4.40$, $MSE = 1056$, $p < .05$, were all significant. Moreover, the second order Cue x Size x Response side interaction also was significant, $F(2, 38) = 3.40$, $MSE = 452$, $p < .05$. A look at Figure 1 shows an appreciable difference in the SNARC effect as a function of the cue. Therefore, we proceeded to separately analyze the SNARC effect for each type of cue. The Size x Response side interaction was reliable for trials with left-pointing arrow (Figure 1a), $F(1, 19) = 6.38$, $MSE = 2495$, $p < .05$; for trials with a neutral cue (Figure 1b), $F(1, 19) = 30.23$, $MSE = 1291$, $p < .001$; and for trials with right-pointing arrow (Figure 1c), $F(1, 19) = 10.17$, $MSE = 1756$, $p < .01$. The second order interaction resulted because for left-pointing arrow, the RT difference between right and left responses was significant for small numbers (44 ms), $t(19) = 4.26$, $p < .001$, but it was not for large numbers (13 ms, $p > .05$). However, for right-pointing arrow, while the RT difference between right and left responses was significant for large numbers (45 ms), $t(19) = 3.87$, $p < .01$, it was not reliable for small ones (15 ms, $p > .05$). When the cue was neutral, the difference between response sides was significant for the both sizes, $t(19) = 3.93$ and $t(19) = 4.26$, for small (41 ms) and large (47 ms) sizes, respectively ($ps < .001$).

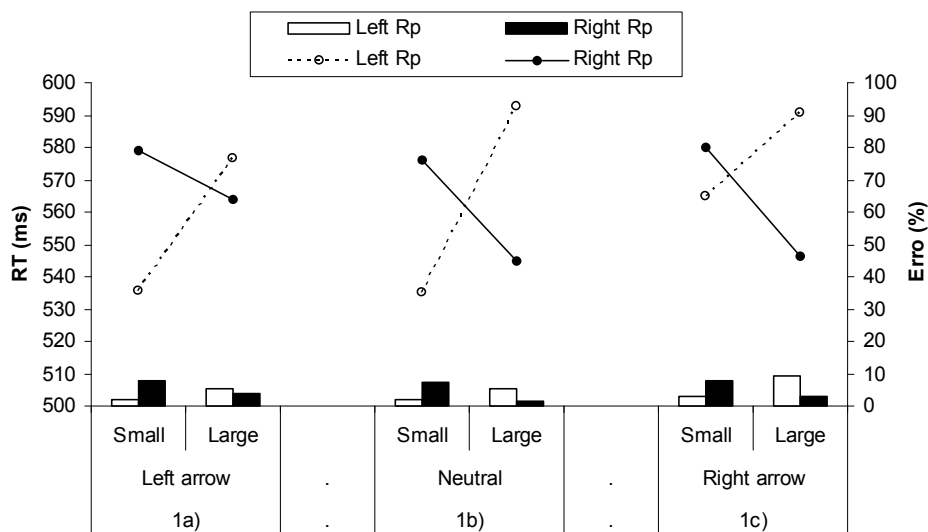


Figure 1. Mean RT in milliseconds (ms, lines) and error rates in percentage (% , bars) as a function of type of cue (Figure 1a, left arrow = arrow pointing to left; Figure 1b, neutral = cross; Figure 1c, right arrow = arrow pointing to right), numerical size (small and large) and response side (Right Rp = right and Left Rp = left).

The overall error rate was 5% (see Figure 1). A 3 x 2 x 2 ANOVA similar to that conducted over RTs indicated a significant Size x Response side interaction, $F(1, 19) = 18.06, p < .001$. As shown in Figure 1, the SNARC effect was also observed in accuracy. None other main effects or interactions were significant ($ps > .05$).

Summarizing, the results of Experiment 1 showed three types of association. We first consider the cue-response side association. Responses were faster when the arrow direction was compatible with the response side. We interpret this association as an effect related to stimulus-response compatibility due to the dimensional overlap of the irrelevant stimuli and the response set. Therefore, this effect might take place at the response selection stage (e.g., Kornblum, Hasbroucq, & Osman, 1990). A second association was observed between response side and relative magnitude, the SNARC effect. Again, this effect is assumed to occur at the response selection stage (e.g., Gevers et al., 2005; Keus et al., 2005). The third association was obtained between spatial cue and numerical size. Responses to small numbers were faster when were preceded by left-pointing arrow and neutral cue, but this advantage was lost with right-pointing arrow as cue. We suggested that the spatial meaning of the arrows might prime numbers related to the same spatial meaning, that is, left-pointing arrows would prime small numbers while right-pointing arrows would prime larger numbers on the tested range. Although the data did not fit exactly our predictions, they showed the effect of symbolic spatial cues on the number processing. Finally, the SNARC effect was modulated by the cue. SNARC compatibility was significant for both numerical sizes when the cue was spatially neutral, while it was not the case when the cue was an arrow. With right-pointing arrow as cue, the SNARC compatibility was observed only for the larger numerical size. With left-pointing arrow cue, the SNARC compatibility occurred only for the smaller numerical size. Therefore, the data showed that the SNARC effect was lost for number size contrary to that primed by the spatial cue. This interaction could come from two possible sources. On the one hand, the lack of SNARC effect might result from the influence of spatial symbolic cues on number processing. However, an alternative explanation of the three-way interaction might be that because spatial cues primed the lateralized responses, the observed pattern could be the result of the primed response advantage. For example, a left-pointing arrow could prime the left-side response and so, it could produce a left-side response advantage working against the SNARC effect for large numbers but in favour of SNARC effect for small numbers. The opposite would occur when a right-pointing arrow was presented (Gevers, Ratinckx et al., 2006). This explanation does not exclude the early effect of

cues over number representation. However, to clarify the effect, in Experiment 2, we evaluated our hypothesis by using non-lateralized responses.

EXPERIMENT 2

The Experiment 2 was conducted in order to eliminate the influence of lateralized responses. We used a go/no-go paradigm in which participants responded to odd numbers in one block and to even numbers in the other block.

METHOD

Participants. Eighteen students (two males; age range: 19-29, $M = 21$ years) at the University of Granada took part in the experiment for course credits. Three of them were left-handed and all had normal or corrected-to-normal visual acuity.

Stimuli and Apparatus. The stimuli and apparatus were the same as in Experiment 1, with the exception that only arrows were used as cues.

Procedure and Design. The experiment was divided into two blocks. These blocks were similar to those in Experiment 1, however, subjects responded to odd numbers (1, 3, 7, 9) in one block and to even numbers (2, 4, 6, 9) in the other block by pressing the space-bar with their preferred hand. Each block was divided into four sub-blocks with 48 trials each (3 times the 16 possible combinations of type of cue and target number). Therefore, the total number of trials in Experiment 2 was 384. The order of even/odd blocks was counterbalanced across participants. The temporal course of a trial was the same as explained in Experiment 1. The experimental session lasted approximately 30 minutes.

RESULTS AND DISCUSSION

Errors were rare and not analyzed further (2% of response omission and 2% of false alarms). All RTs longer than three standard deviations or shorter than 200 ms were excluded from analyses (3%). An ANOVA over correct responses on go-trials with Cue (left-pointing arrow and right-pointing arrow) and Size (small: 1, 2, 3, 4; large: 6, 7, 8, 9) as within-subject factors indicated a significant main effect of size, $F(1, 17) = 42.12$,

$p < .001$. Small numbers were responded to faster than large numbers. The main effect of cue was not reliable, but the Cue x Size interaction was significant, $F(1, 17) = 8.76$, $p < .01$. As shown in Table 1, small numbers were responded to faster when arrow pointed to left than when arrow pointed to right, and the pattern was reverted for large numbers. Therefore, we found a similar number-spatial association even when responses were not lateralized.

Table 1. Mean reaction times (RT, in milliseconds), false alarms (FA, in %) and response omissions (RO, in %) obtained in Experiment 2 as a function of numerical size (small and large) and type of cue (right arrow = arrow pointing to right, left arrow = arrow pointing to left).

	Small Numerical Size		Large Numerical Size	
	Left arrow	Right arrow	Left arrow	Right arrow
RT	442	449	469	460
FA (%)	1.54	1.81	1.73	1.31
RO (%)	0.85	1.45	2.16	1.55

GENERAL DISCUSSION

Previous research has shown that numbers can affect spatial processing related to response selection (e.g., Dehaene et al., 1993) and to the position of stimuli to be responded (e.g., Fischer et al., 2003). Recently, Stoianov et al. (2008) showed that spatial cues are also able to affect number processing. They used a lateralized cue (i.e., a dot-shaped: a set of dots arranged in a circle) and found that backward priming, but not forward priming, was effective. This result was interpreted assuming that backward priming compensates for the slower activation of spatial numerical representation relative to visuospatial representation. Whereas the latter requires only perceptual processing, the former requires both perceptual and semantic processing. Thus, the delay of the spatial prime enabled the prime and target to activate their spatial representations more concurrently.

In the present study we hypothesized that using a symbolic spatial cue as a prime could also compensate for differences in processing time (see Juola, Koshino, & Warner, 1995; for a comparison of symbolic and spatial cues on attentional effects). Although symbolic spatial cues produce similar effects as physical location cues (e.g., Hommel, Pratt, Colzato, & Godijn, 2001; Ristic & Kingstone, 2006), they should be perceptually and

semantically processed in order to activate the spatial representation. In two experiments using symbolic cues, we corroborated this hypothesis obtaining forward priming.

In Experiment 1, in which participants performed a parity judgment task with lateralized responses, we found the expected association between spatial cue and numerical size which, in addition, modulated the SNARC effect. The SNARC compatibility was significant only for numbers with magnitude representations presumably cued by a corresponding arrow (i.e., large numbers preceded by right-pointing arrow and small numbers preceded by left-pointing arrow). However, direct conclusions were limited because of the cue-response compatibility effect. Thus, an alternative explanation based on response priming instead of number priming could also be possible. In Experiment 2, in which responses were not lateralized, we found again the expected interaction between cue and magnitude. Therefore, the symbolic spatial cue effect occurred even when response priming was eliminated.

Summarizing, the present results show that spatial symbolic cues can prime spatial components associated with numbers. The priming found in the current study was independent of response which agrees with Stoianov et al.'s (2008) study. Zorzi, Priftis, and Umiltà (2002) found that patients with hemispatial neglect showed a similar pattern of errors when they were asked to bisect numerical intervals as when they were asked to bisect physical lines. The authors interpreted this result as additional evidence for the spatial nature of the mental number line which could be more than a metaphor. Thus, it could be interpreted as a visuospatial representation of numerical magnitude. Previous studies have shown that non-predictive spatial symbolic cues are able to shift subjects' spatial attention (e.g., Hommel et al., 2001; Ristic & Kingstone, 2006). Our results indicated that spatial symbolic cues are able to shift the subjects' spatial attention to different locations over the mental number line. However, we prefer to be cautious with this interpretation. Spatial components of numbers have been shown to be context-dependent (e.g., Bachtold, Baumüller, & Brugger, 1998). Moreover, recent evidence indicates that the spatial code might be constructed during task execution and is dependent on working memory. This working memory dependency varies as a function of the task subjects are performing. For example, in a comparison task the SNARC effect disappears under a visuospatial load, but not under a verbal load; while in a judgment parity task the SNARC effect is hindered under a verbal load, but not under a visuospatial load (Herrera, Macizo, & Semenza, 2008; Van Dijck, Gevers, & Fias, 2009). Therefore, the numerical spatial component

might be represented in at least two different codes. Which of them is primed in the present study is an issue for further research.

To conclude, previous research has failed to find forward spatial priming between spatial cues and target numbers (e.g., Stoianov et al., 2008). We demonstrate that forward priming is possible when symbolic spatial cues precede numbers in a parity judgement task.

RESUMEN

Cuando las señales simbólicas espaciales van antes de los números. Este trabajo explora el efecto del señalamiento espacial en el procesamiento numérico. Los participantes realizaron una tarea de juicios de paridad. Sin embargo, brevemente antes del número objetivo, una señal (una flecha señalando a la izquierda, una flecha señalando a la derecha o una cruz) fue presentada en el centro. En el Experimento 1, donde las repuestas estaban lateralizadas, la dirección de la señal moduló la interacción entre el lado de respuesta y el tamaño numérico. En el Experimento 2 había solamente una tecla de respuesta, en un bloque los participantes respondían a los números impares y en el otro bloque respondían a los números pares. Los resultados mostraron una asociación entre la señal simbólica espacial y los números (i.e., menor/izquierda y mayor/derecha). Nosotros interpretamos el conjunto de resultados como indicación de una activación temprana de características espaciales producida independientemente de la respuesta requerida.

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