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Automatic response activation of implicit spatial information: Evidence from the SNARC effect

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Abstract

In the present paper, we focus on how irrelevant implicit spatial information is processed. By irrelevant we mean information that is not required to fulfill the task and by implicit we mean information that is not directly available in the external stimulus. A good example of a task in which such information exists is the SNARC task [Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General,* 122, 371–396]. The SNARC effect shows that the magnitude of a number, although irrelevant to the task, activates spatial codes that may interfere with the task-related response. These spatial associations exist both for the horizontal and the vertical direction. In Experiment 1, response keys were discriminating in the vertical or the horizontal direction. It is shown that the impact of the numerical spatial codes on overt behavior, although automatic, depends on the response discrimination of the horizontal or the vertical dimension. In Experiment 2, response keys were assigned such that both the horizontal and the vertical direction of the response were discriminating. In this case, the horizontal and the vertical dimension of the irrelevant numerical spatial codes were shown to interact. In general, the results are in line with the response-discrimination account [Ansorge, U., & Wühr, P. (2004). A response-discrimination account of the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance,* 30, 365–377].

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1. Introduction

The perception of numbers elicits spatial codes that are associated with the magnitude of the number (for recent reviews see Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005). Evidence for such spatial codes comes from the Spatial Numerical Association of Response Codes or SNARC effect (Dehaene, Bossini, & Giraux, 1993). Dehaene and colleagues had participants perform a parity judgment task (odd vs. even) in a bimanual response setting. Although magnitude information is irrelevant to perform parity judgment relatively small numbers were responded to faster with the left hand and relatively large numbers were responded to faster with the right hand (Dehaene et al., 1993). Writing direction has been described as a key determinant for the SNARC effect. French monoliterates who use a left-to-right writing system persistently showed a stronger SNARC compared to high skilled French-Persian biliterates who use both a left-to-right and a right-to-left writing systems (Dehaene et al., 1993; see also Zebian, 2005).

Since this influential paper (Dehaene et al., 1993), the SNARC effect was observed with a variety of tasks like magnitude comparison, orientation discrimination (Fias, Lauwereyns, & Lammertyn, 2001; Lammertyn, Fias, & Lauwereyns, 2002) and phoneme monitoring (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996). Additionally, the SNARC effect has been shown to be effector-independent as it was demonstrated with unimanual responses (Fischer, 2003), bimanual responses (Dehaene et al., 1993) and eye movements (Fischer, Warlop, Hill, & Fias, 2004; Schwarz & Keus, 2004).

Important for the present purposes, the SNARC effect is not restricted to a left-to-right orientation. Schwarz and Keus (2004) observed that downward saccades were initiated faster in response to relatively small numbers whereas upward saccades were initiated faster in response to relatively large numbers. Further evidence for the existence of a SNARC effect in the vertical dimension comes from a study by Ito and Hatta (2004). In a bimanual response setting, Japanese subjects showed an association with small numbers represented at the lower half of space and larger numbers at the upper half of space. These results corroborate the existence of spatial-numerical effects within the vertical dimension. However, unlike the SNARC effect in the horizontal dimension, the spatial association with the magnitude of a number in the vertical dimension does not seem to be the result of reading and writing habits. As Ito and Hatta (2004) pointed out, reading and writing is performed from top to bottom, which should result in an association of small magnitudes with up and large magnitudes with down whereas the opposite pattern is observed. We believe that a plausible explanation for the association in the vertical dimension is provided by daily life experience. Or as Lakoff (1987, p. 276) puts it quite clearly: "Whenever we add *more* of a substance—say, water to a glass—the level goes *up*. When we add *more* objects to a pile, the level *rises*. Remove objects from the pile or water from the glass, the level goes *down*. The correlation is overwhelming: more correlates with up, but less correlates with down".

A number of recent studies investigated the locus of the SNARC effect by relating the SNARC effect to the Simon effect (Gevers, Caessens, & Fias, 2005; Keus & Schwarz, 2005; Mapelli, Rusconi, & Umiltà, 2003). In a typical Simon task, subjects are asked to respond with a left or right response key to the color of a stimulus that is presented to the left or right of the fixation cross. In this case, only the color of the stimulus is relevant and the location of the stimulus should be ignored. However, RTs are faster when the irrelevant stimulus location corresponds with the response location (for an overview see Simon, 1990). Traditionally, the Simon effect is explained by dual-route models in which it is assumed that upon the presentation of the stimulus two routes are activated in parallel (e.g. De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). One unconditional route is activated by the irrelevant stimulus location and automatically primes an ipsilateral response. At the same time, the relevant information (e.g. color of the stimulus) is processed through a slower conditional and controlled route. This general processing architecture seems to be responsible for the SNARC effect as well.

Studying the SNARC effect together with the Simon effect, Gevers, Caessens, et al. (2005), Gevers, Ratinckx, De Baene, and Fias (in press) Gevers, Verguts, Reynvoet, Caessens, and Fias (in press) (see also Keus & Schwarz, 2005) found that the relationship between the Simon and the SNARC effect depends on the relevance of the magnitude information. Additionally, psychophysiological measurements showed that the Simon and the SNARC effect have the same ERP-signature (Gevers, Ratinckx, et al., in press; Keus, Jenks, & Schwarz, 2005).

The lateral presentation of a stimulus in the Simon task is usually thought to automatically activate the spatially compatible response (De Jong et al., 1994; Hommel, 1995; Kornblum et al., 1990). However, Valle-lnclán and Redondo (1998) showed that the automatic activation of explicit irrelevant spatial information is limited. Using electrophysiological measurements, they showed that ipsilateral response activation was absent in a Simon task if the response-key assignment was provided after the target stimulus was presented. Therefore, it was concluded that unconditional response activation requires a predefined stimulus–response mapping rule. Recently, Ansorge and Wühr (2004) confirmed and extended this interpretation by arguing that the spatial features associated with the response need to be represented in working memory for the unconditional response activation to occur. In addition, these spatial features only influence the response when they discriminate between alternative responses. A Simon task was conducted in which participants had to respond to the color of a stimulus while ignoring its position. Two modifications of the standard Simon design were introduced. First, the stimuli appeared along both a vertical (below or above the fixation point) and a horizontal axis (left or right of the fixation point). Second, the location of the response was manipulated such that it discriminated for one axis whereas it did not for the other (Ansorge & Wühr, 2004, Experiment 1). For instance, subjects were required to press a response key located at the bottom-left and the upper-left of a central home key. With this mapping, the responses discriminated along the vertical axis (e.g. up or down depending on the color of the stimulus), but not along the horizontal axis (e.g. all responses are to the left of the central home key). A Simon effect was observed in the discriminating vertical dimension (faster responses with top response key when stimulus was presented above fixation, than when stimulus was presented below fixation and faster responses with bottom response when stimulus was presented below fixation than when stimulus was presented above fixation), but not in the horizontal dimension (responses to left response key not faster than response to right response key), Similarly, if the horizontal response axis discriminated between responses (e.g. if red press upper-left key, if green press upper-right key), a Simon effect was observed in the horizontal dimension but not in the vertical dimension. Finally, when both axes discriminated between alternative responses (e.g. press bottom-left and upper-right key) a Simon effect was observed in both the horizontal and the vertical dimension.

These data show that the automatic response activation in the Simon task depends on response characteristics. Presenting a stimulus left of the fixation cross does not result in response priming of the left response, if no left–right discrimination is required. The response-discrimination account states that top-down controlled response representations (i.e. discriminating spatial information that is relevant for the task) are crucial for the response priming of explicit spatial information. Although the Simon and the SNARC effect are amenable to a mutual underlying processing architecture, they differ in one important aspect, namely the kind of irrelevant spatial information that is being processed. In a Simon task, this spatial information is explicitly presented by varying the position of a stimulus on the screen, whereas in a SNARC context, this information is implicitly conveyed in the magnitude representation of a number. Therefore, the key question of the present paper is whether the automatic activation of implicit irrelevant spatial information is governed by the same rules as its explicit counterpart. To this end, we applied the logic of the response-discrimination hypothesis to the SNARC task.

2. Experiment 1

The first experiment directly investigated to what extent the activation of implicit spatial information is automatic. We modeled the present experiment after the study of Ansorge and Wühr (2004, Experiment 1). If the response-discrimination hypothesis holds for the conflict in the SNARC task (with centrally presented stimuli), a horizontal but not a vertical SNARC effect is predicted if the responses discriminate along the horizontal axis. Otherwise, if the responses discriminate along the vertical axis, a vertical but not a horizontal SNARC effect is expected. On the other hand, if implicit spatial information is automatically activated, regardless of whether the responses discriminate or not, a SNARC effect is also expected along the non-discriminating response axis.

2.1. Participants

Sixteen subjects (age range: 19–25 years) participated in the experiment. All subjects had normal or corrected-to-normal vision. They participated for course credit and filled out an informed consent. All subjects were right handed.

2.2. Stimuli and response measurement

Stimuli were presented on a 17 in. color screen. Presentation of the stimuli was controlled by a PC-compatible Pentium computer. Reaction times (RTs) were measured to the nearest millisecond (ms) using Tscope programming language (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press) and responses were given on the numerical keypad. In order to avoid interference from the numbers on the numerical keypad, all numerical keys were covered by non-transparent stickers. To start a trial, participants pressed the central key (5). Subsequently, depending on the mapping (see below), participants had to respond with one of the following target keys: downward left (1), downward right (3), upper-left (7) or upper-right (9).

Stimuli were the Arabic digits 1, 2, 8 or 9 (Arial narrow) presented at the centre of the screen and subtending 0.86° in height and 0.40° in width at a viewing distance of 100 cm. A pound sign (#) served as the fixation mark.

2.3. Procedure

Each trial started with the fixation point at the center of the screen. This fixation point stayed on the screen until the participant pressed the middle key with the index finger of the right hand. Once this button was pressed, the fixation mark was immediately replaced by the target number which remained on screen until a response was given. Depending on whether the presented target was odd or even, the subject had to press the appropriate target key. Participants were specifically asked to withhold the movement towards the response key until they knew the parity status of the number. If no response was initiated, the screen went blank after 3000 ms and a new fixation mark appeared at the center of the screen. Two types of S-R mappings were used (balanced within subjects).

All participants performed the task in both the horizontal and vertical dimensions. Within the horizontal dimension, subjects performed only one type of vertical movement, namely, upward left and upward right or downward left and downward right. Likewise, for the vertical dimension participants only made one type of horizontal movement, meaning that they had to make movements with their right index finger to the upper-left side and the lower-left side, or alternatively to the upper-right and lower-right side. The assignment to the respective response-mapping groups and the order of performance was counterbalanced.

In the horizontal mapping condition, the horizontal axis was discriminating whereas no response discrimination was required along the vertical axis (e.g. all responses either to the upper or to the lower response keys). Similarly, in the vertical mapping condition the response mappings varied on the vertical axis but remained constant along the horizontal axis.

Before the experimental session began, all the participants had to perform a block of practice trials in which all possible target numbers were presented four times in a random order. During the practice block, participants received instant feedback about their performance. The practice block was discarded from analysis. During the experimental session each Arabic number was presented 40 times leading to a total of 160 trials per condition. Stimuli were pseudo-randomly presented such that each target number followed the other target numbers (including itself) 10 times. The participants were instructed to respond both fast and accurately.

2.4. Results

Mean RT of the correct responses as well as error rates were analysed. Latencies faster than 200 ms and slower than 1000 ms were excluded from analysis. Overall, 2.77% errors were made.

Small numbers (e.g. 1 and 2) responded to with a left key and large numbers (e.g. 8 and 9) responded to with a right key are regarded as SNARC compatible. The reverse mappings (e.g. 1/2 to a right key and 8/9 to a left key) are regarded as SNARC incompatible. Similarly, in the vertical dimension, small numbers (1 and 2) requiring a lower response key and larger numbers (8 and 9) requiring an upper response key are also regarded as SNARC compatible whereas their counterparts are regarded as SNARC incompatible. RT and number of errors were entered in a 2 (discrimination: discriminating/non-discriminating) $\times$ 2(dimension: horizontal/vertical) $\times$ 2 (compatibility: compatible/incompatible) repeated measures ANOVA. There was a main effect of compatibility, $F(1,15) = 7.60$; MSe = 1026.59; $p < .05$. SNARC compatible trials were responded to about 16 ms faster than SNARC incompatible trials. SNARC compatibility also interacted with discrimination, $F(1,15) = 8.37$, MSe = 555.54; $p < .05$. When the response dimension discriminated, SNARC compatible trials were responded to about 28 ms faster than SNARC incompatible trials ($F(1,15) = 9.59$; MSe = 1276.73; $p < .01$, with planned comparisons). Within the non-discriminating dimension a non-significant 3 ms advantage for SNARC compatible trials was obtained ($F(1,15) = .66$; MSe = 305.40; $p = .43$). SNARC compatibility also interacted with dimension, ($F(1,15) = 14.13$; MSe = 139.32; $p < .01$). Overall, the SNARC effect was stronger in the horizontal (23 ms) compared to the vertical dimension (8 ms). However, it is unlikely that the SNARC effect in the horizontal dimension is functionally distinct from the SNARC effect in the vertical dimension because there was a high correlation between the size of the SNARC effect in the vertical and the horizontal dimension, $r(16) = .75$, $p < .001$. Finally, planned comparisons showed that when the response dimension did not discriminate, the SNARC effect was significant in the horizontal dimension (11 ms: $F(1,15) = 5.63$; MSe = 184.17; $p < .05$) although it was smaller compared to the horizontal SNARC effect in the discriminating condition ($F(1,15) = 9.05$; MSe = 257.95; $p < .01$). In the vertical dimension (4 ms in the advantage of SNARC incompatible trials: $F(1,15) = .61$, MSe = 236.75; $p = .45$), no SNARC effect was obtained when the responses did not discriminate (see Fig. 1). No significant effects were obtained in a similar analysis on the error data.

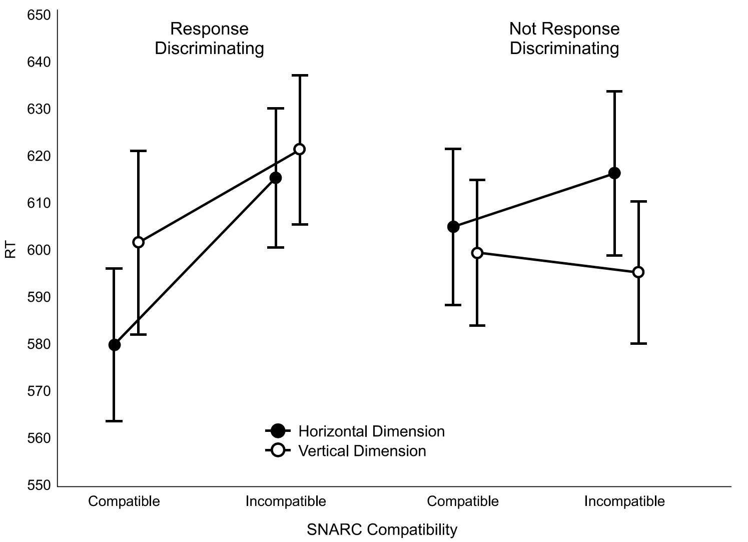

Fig. 1. The SNARC effect in the response discriminating (left pane) and not response discriminating (right pane) dimension for both the horizontal (filled circle) and the vertical (unfilled circle) dimension.

2.5. Discussion

The present results are clear-cut and largely in line with the response-discrimination account as proposed for the Simon effect (Ansorge & Wühr, 2004). When the spatial dimension (horizontal or vertical) discriminates between the responses, large SNARC effects were found, whereas this SNARC effect was absent (vertical dimension) or significantly reduced (horizontal dimension) when there was no response-relevant discrimination along that dimension. The fact that the SNARC effect is still present in the horizontal dimension even when that dimension is irrelevant, suggests that, at least with implicit spatial information, the automatic priming of spatial responses should not be interpreted in binary terms, but rather as a gradually varying mechanism with decreasing or increasing effect sizes. If a particular dimension is irrelevant, response priming according to this dimension will be suppressed. For the stronger horizontal SNARC effect, this results in a reduced SNARC effect, while for the weaker vertical version, the SNARC effect disappears.

3. Experiment 2

Ansorge and Wühr (2004, Experiment 2) found that the Simon effect was present both in the vertical and the horizontal dimensions when the responses required discrimination along both the horizontal and the vertical axes. Stimuli were again presented both in the horizontal (left or right of screen centre) and the vertical (above or below screen centre) dimensions but now participants had to make a movement to an upper-left or a lower-right key. A Simon effect was obtained with stimuli presented both in the horizontal and the vertical dimensions. Note that the compatibility between the stimuli and the responses alternates with the position of the stimuli on the screen. A stimulus presented in the vertical dimension (up or below fixation point) elicits a spatial code that is dominantly associated with responses along the vertical axis (up or down response side) whereas a stimulus presented in the horizontal dimension (left or right of fixation point) elicits a spatial code that is dominantly associated with responses along the horizontal axis (left or right response side). One could ask what happens if the spatial codes associated with the position on the screen convey compatibility with the responses along both the horizontal and the vertical axes simultaneously. More specifically, from Experiment 1 it is clear that the magnitude of a number elicits spatial codes both in the horizontal and in the vertical dimensions. How will these spatial codes interact if the responses are discriminating along both the horizontal and the vertical axes? This question can be studied by presenting the numbers centrally, but varying the responses along a left-diagonal (lower-right and upper-left response keys) and a right-diagonal (lower-left and upper-right response keys) axes. A SNARC effect should show up in the right-diagonal condition. This is predicted because a small number requiring a response to the lower-left response key is compatible with both the horizontal and the vertical dimension while the same number requiring a response to the upper-right key is incompatible on both dimensions. This congruency between both irrelevant spatial codes is not present in the diagonal-left condition. For instance, a small number requiring an upper-left response key is compatible on the horizontal but incompatible on the vertical dimension. If both irrelevant spatial codes point toward a different response then a significantly reduced or no SNARC effect should be observed in the diagonal-left condition. If on the other hand, only one spatial code is activated, one should observe a SNARC effect that is compatible with either the horizontal or the vertical dimension.

3.1. Participants

Sixteen subjects (age range: 19–25 years) participated in the experiment. All subjects were right-handed and had normal or corrected-to-normal vision. They participated for payment and filled out an informed consent.

3.2. Procedure

Except for the response assignment, the procedure was exactly the same as in the previous experiment. All participants completed two conditions, one with the responses to the upper-left and the lower-right and one with the upper-right and the lower-left key. The order of the conditions was counterbalanced across subjects. From now on, these response mappings will be referred to as the left-diagonal and the right-diagonal condition, respectively. Within each condition, the response assignment was based on the parity of the number (e.g. odd is upper-left, even is lower-right), counterbalanced between subjects.

In the right-diagonal condition, according to both the horizontal and the vertical dimensions, small numbers (1 and 2) towards the lower-left and large numbers (8 and 9) towards the upper-right response keys are regarded as SNARC compatible. For the left-diagonal condition we had to make a choice according to which dimension SNARC compatibility is defined. For this condition, we arbitrarily chose to define compatibility in terms of the horizontal dimension in the sense that small numbers to the upper-left and large numbers to the lower-right response keys are regarded as SNARC compatible. With the present definition of compatibility, a positive effect (compatible faster and/or less errors than incompatible) would reflect a SNARC effect resulting from the horizontal dimension, whereas a benefit for SNARC incompatible trials would reflect a SNARC effect resulting from the vertical dimension. If the spatial codes of the horizontal and the vertical dimensions interact before a response is activated, an effect size of approximately zero is predicted.

3.3. Results and discussion

Totally, participants made 2.4% errors. The mean RT for the target numbers 1, 2, 8 and 9 were 585 ms, 580 ms, 578 ms and 596 ms, respectively. Both errors and RT were entered in a 2 (Diagonal: left-diagonal/right-diagonal) × 2 (Compatibility: SNARC compatible/SNARC incompatible) repeated measures ANOVA. For the latencies, there was a main effect for compatibility, $F(1,15) = 5.91$, $\mathrm{MSe} = 672.51$, $p < .05$. Importantly, an interaction between diagonal and compatibility was obtained, $F(1,15) = 11.85$; $\mathrm{MSe} = 602.92$; $p < .01$. Fig. 2 shows a SNARC effect in the right-diagonal and no SNARC effect in the left-diagonal. This was confirmed by a planned comparisons analysis showing a highly significant SNARC effect in the right-diagonal condition, $F(1,15) = 25.50$; $\mathrm{MSe} = 427.09$; $p < .001$. SNARC compatible trials were responded to about 37 ms faster than SNARC incompatible trials. In contrast, in the left-diagonal condition, no significant advantage for SNARC compatible or incompatible trials resulted, $F(1,15) = .27$; $\mathrm{MSe} = 848.34$; $p = .61$. The results of the analysis of the error data mirrored the results of the latency analysis. First, there was a main effect of compatibility, $F(1,15) = 5.10$; $\mathrm{MSe} = 9.70$; $p < .05$. Second, there was an interaction between dimension and compatibility, $F(1,15) = 4.52$; $\mathrm{MSe} = 9.98$; $p = .05$. More errors were made in the right-diagonal condition to SNARC incompatible trials

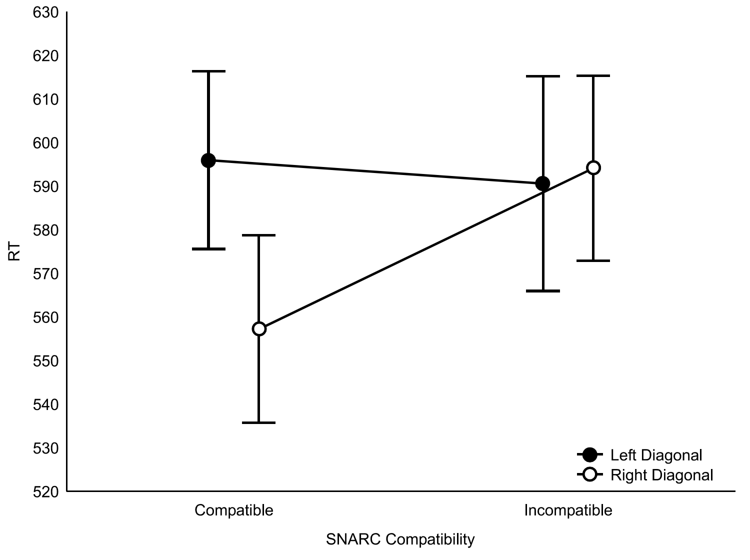

Fig. 2. The SNARC effect when responses were required in the left-diagonal and the right-diagonal direction.

($F(1, 15) = 19.52$; MSe = 4.84; $p < .001$), whereas no difference was obtained in the left-diagonal condition, $F(1, 15) = .01$; MSe = 14.84; $p = .96$.

Both the latencies and the error analysis confirm a SNARC effect in the diagonal-right condition whereas there is no SNARC effect in the diagonal-left condition. This result can be explained if we assume that a response is activated on the basis of the horizontal and the vertical spatial information associated with the magnitude of the number. In the right-diagonal, this results in an additive effect of the horizontal and vertical SNARC effect since both dimensions are associated with the same response (small number will prime left-bottom response). In the left-diagonal on the other hand, the vertical and the horizontal spatial code of numbers prime different responses (small number will prime left-top response on the basis of horizontal dimension and right-bottom response on the basis of vertical dimension). However, an alternative explanation requires consideration. A null effect in the left-diagonal is also predicted when participants idiosyncratically choose one dimension for which a response is primed. When half of the participants use the vertical and the other half use the horizontal dimension, this too would result in an overall absent SNARC effect. If this is the case, then one predicts that the distribution of effect sizes is bimodal (two-peaked) rather than unimodal (single-peaked) because a number of subjects would show a negative SNARC effect (vertical dimension) whereas other subjects would show a positive SNARC effect (horizontal dimension). A Kolmogorov–Smirnov test showed that the effect sizes did not deviate significantly from the normal distribution, Dmax = .15, $p > .2$. Further, we fitted both a unimodal (normal) distribution and a bimodal (two-peaked) distribution to the effect size distribution (Leisch, 2004). Unimodal and bimodal models were compared by the model fit measures Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), which take into account both the absolute fit of a model and the model's complexity. The model with the lowest AIC or BIC measure is chosen as the most appropriate one (Myung, 2000). AIC values were 167.39 and 172.74 for the unimodal and bimodal models, respectively; BIC values were 168.96 and 176.60, respectively. In sum, the unimodal model provided a better fit, confirming the conclusion of a single-peaked distribution and horizontal and vertical codes working in parallel.

4. General discussion

Two experiments were conducted in which the response-discrimination account was further investigated by means of the SNARC effect. The response-discrimination account states that for a spatial response feature to be represented, it needs to effectively discriminate between alternative response dimensions. Originally designed to explain the general findings and some exceptions on the Simon effect, the present study shows that the response-discrimination hypothesis can be applied to the SNARC effect as well. In the first experiment, subjects had to respond to relatively small and large numbers while one response dimension was discriminating whereas the other was not. When the response dimension was discriminating, a clear SNARC effect was obtained both in the vertical and in the horizontal dimensions. When, on the other hand, the dimension was not response-discriminating, the SNARC effect was absent in the vertical dimension and present but significantly smaller in the horizontal dimension. The observation of a SNARC effect in the horizontal dimension even without response-discrimination points to a difference with the processing of explicit spatial information. It implies that the spatial information associated with the magnitude of a number is able to influence behavior even when no response discrimination is required, given that its effect size is sufficiently large.

The second experiment further investigated the SNARC effect when both the horizontal and the vertical dimensions were response discriminating. In the right-diagonal condition, numbers were compatible or incompatible on both the horizontal and the vertical dimensions and a clear SNARC effect was observed. In the left-diagonal condition, on the other hand, no SNARC effect was observed.

The present results generalize the response-discrimination account originally formulated for the Simon task to the SNARC task (Ansorge & Wühr, 2004). This observation shows that the response-discrimination account is not only valid with explicit spatial information but is also applicable to implicit spatial codes. Indeed, in the Simon task, the irrelevant spatial codes are the result of the explicit position of the stimuli on the screen. In the SNARC task, the stimuli are presented centrally on the screen but the irrelevant spatial codes are the result of the representation of the magnitude associated with the numbers. This further suggests that, although the origin of both spatial codes is different, the irrelevant spatial codes are processed along a similar processing architecture. It is generally believed that the Simon task is processed along a dual-route architecture (De Jong et al., 1994; Kornblum et al., 1990). Recently it has been proposed that a similar processing architecture is responsible for the SNARC effect as well (e.g. Gevers, Caessens, et al., 2005; Gevers, Ratinckx, et al., in press; Gevers, Verguts, et al., in press). In brief, upon presentation of a stimulus, two routes are activated in parallel. The first route, the conditional route, codes for the task instructions and is under voluntary control. The second route, the unconditional route, automatically codes the irrelevant spatial information. If both routes converge, a response can be initiated relatively fast. If, on the other hand, the unconditional route codes for a different response, the response needs to be aborted and a new response has to be initiated on the basis of the conditional route only.

The results of Experiment 1 confirm the argument of the response-discrimination account that the unconditional information is liable to top down control, even when this discrimination is based upon implicit information. When these spatial response features are not represented, no SNARC or a significantly reduced SNARC effect is observed. In Experiment 2, the spatial response features of both the horizontal and the vertical dimensions are likely to be represented because they discriminate between alternative stimulus dimensions. Hence, a large SNARC effect is observed. A post-hoc analysis revealed that the absent SNARC effect in the left-diagonal condition was not caused because subjects chose for one dimension. Therefore, it seems that a response is primed according to both dimensions leading to an interaction between both spatial codes. This results in relative slow response times (e.g. in the diagonal-left condition, the latencies are comparable to the SNARC incompatible condition of the right-diagonal condition, see Fig. 2) but no SNARC effect. In order to capture more specifically how we interpret this interaction, consider the situation in which a subject has to respond to the numbers 1 and 9 in the diagonal-left condition and the response assignment is such that an odd number requires a response to the upper-left location. Upon its presentation, the number 1 will automatically activate the spatial codes 'left' and 'below' whereas the number 9 will automatically activate the spatial codes 'up' and 'right'. As a result, both responses will be activated automatically, regardless of the number that is presented. The net effect is that there is no SNARC effect in the left-diagonal condition. However, because the irrelevant information also activates the wrong response dimension, an overall slowing of the latencies is expected, as we observed.

The present observations also replicate recent findings that the SNARC effect is not restricted to the horizontal dimension (e.g. Ito & Hatta, 2004; Schwarz & Keus, 2004). The magnitude of the numbers elicits spatial codes producing compatibility in the vertical dimension as well: relatively small numbers are compatible with the lower half of space while relatively large numbers are compatible with the upper half of space. The vertical SNARC effect can be explained by assuming that besides a horizontal number line, there also exists a vertical number line with small numbers on the bottom and large numbers on the top. However, it is also possible to think of magnitude representations in terms of spatial saliency. More specifically, it has been shown that the processing of spatial locations follows a top/right-bottom/left advantage (see Cho & Proctor, 2003, for review). That is, with a horizontal response setting, right hand responses are initiated faster to stimuli on the top while left hand responses are initiated faster to stimuli on the bottom half of the screen. Moreover, it has also been shown that this top/down-bottom/left advantage is also present when the location of the stimulus is irrelevant to the task (Cho & Proctor, 2003). According to their asymmetric coding account the top-right/bottom-left advantage is the result of a congruency between the saliency of the respective spatial codes. That is, in the horizontal dimension, the right position is dominant with right handed subjects (Olson & Laxar, 1973, 1974) whereas in the vertical dimension the top position is dominant (Chase & Clark, 1971; Chambers, McBeath, Schiano, & Metz, 1999). Recently, Rusconi and colleagues (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, in press) reported a Spatial Musical Association of Response Codes (SMARC) effect and reached a similar conclusion. Subjects showed a preference for high pitches with an upper response hand while lower pitches were responded to faster with a lower response. Interestingly, and in agreement with the present results, subjects also showed a preference for responding to high pitches with a right hand response side and to lower pitches with a left hand response side. Therefore, it may very well be that the spatial codes associated with the magnitude of a number are mapped according to this spatial saliency representation. Although this is a speculative issue, it would also explain the high correlation between the occurrence of the SNARC effect in the vertical and the horizontal dimensions.

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