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Negative numbers eliminate, but do not reverse, the attentional SNARC effect

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Abstract Three experiments are reported examining whether the presentation of irrelevant negative numbers at central fixation interacts with attentional orienting beyond fixation. It has been previously shown that number perception influences spatial attention, with the presentation of spatially nonpredictive numbers resulting in the allocation of attention to the left when the number is low (e.g., 1 or 2) and to the right when the number is high (e.g., 8 or 9). In the present experiment, it is examined whether this attentional spatial numerical association of response codes (SNARC) effect is influenced by the presentation of negative numbers, which should have spatial properties that are in direct opposition to their positive counterparts (e.g., −1 or −2 would be considered high numbers relative to −8 or −9, which would be considered low numbers). Though the presentation of negative numbers does not lead to a reversal of the attentional SNARC effect, it does lead to an elimination of the effect, providing insight into how the attentional SNARC effect develops.

Negative numbers eliminate, but do not reverse, the attentional SNARC effect

Traditionally, the study of visual spatial attention has focused on exogenous and endogenous shifts of visual attention. Exogenous shifts are bottom-up and reflexive, and tend to occur when new stimuli are presented in the periphery, whereas endogenous shifts of attention are top–down and volitional, occurring when individuals perform tasks like looking for their car in a parking lot. Though a great deal of research has sought to isolate the influence of exogenous attention from the influence of endogenous attention, it is now well established that the two forms of attention can interact to influence behavior. For example, Hommel, Pratt, Colzato, and Godijn (2001; see also Eimer, 1997; Pratt & Hommel, 2003) have shown that spatially nonpredictive arrows or directional words (e.g., "left") result in targets being detected more quickly at the location consistent with the cue's directional meaning, reflective of the fact that these spatially nonpredictive cues lead to a reflexive shift of attention in the cued direction. Though interesting, these findings are relatively intuitive given that the presentation of arrows in the real world is generally meaningful (Gibson & Kingstone, 2006; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002).

Beyond directional arrows and words, it has also been demonstrated that the presentation of numbers can influence the allocation of visual spatial attention as a function of numerical magnitude. The influence of numbers on attention was first reported by Dehaene, Bossini, and Giraux (1993), who had participants make parity judgments, indicating whether a number was odd or even via a left- or right-hand key press. Participants were faster to respond to low odd digits (e.g., 1) relative to high odd digits (e.g., 9) with their left hand and were faster to respond to high even digits (e.g., 8) relative to low even digits (e.g., 2) with their right hand. Dehaene et al. concluded that this was attributable to the mental organization of numbers, which they posited as being represented in a mental number line running from left to right—with low digits occupying left space and high digits occupying right space. Accordingly this was coined the spatial numerical association of response codes (SNARC) effect and was subsequently shown to influence performance across a

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variety of tasks (Bächtold, Baumüller, & Brugger, 1998; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Fischer, 2001). This work was later extended by Fischer, Castel, Dodd, and Pratt (2003), who demonstrated that the presentation of an irrelevant digit at fixation could evoke an attentional shift to the left or right visual field. In their study, the presentation of a nonpredictive low digit (e.g., 1 or 2) facilitated target detection on the left while the presentation of a nonpredictive high digit (e.g., 8 or 9) facilitated target detection on the right.

Though numbers influence attention in a manner similar to arrows and directional words, it was initially unclear whether other ordinal sequences influenced attention in the same manner. In their original work, Dehaene et al. (1993) included a condition in which they used letters rather than numbers but they did not observe any evidence of a SNARC effect. More recently, though, Gevers, Reynvoet, and Fias (2003, 2004) have shown that SNARC effects can be observed for ordinal sequences such as letters of the alphabet, days of the week, and months of the year (though see Price & Mentzoni, 2008). In these tasks, participants are asked to make order-relevant (e.g., does this month occur before or after July) or order-irrelevant (e.g., does this month end in the letter R) decisions about items presented at fixation and a SNARC effect was observed for both task types. This led Gevers et al. to suggest that the spatial component of ordinal sequences is automatically activated. Dodd, Van der Stigchel, Leghari, Fung, and Kingstone (2008), however, examined whether the presentation of numbers, days, months, or letters at fixation would influence the allocation of attention in a target detection task and failed to observe an attentional SNARC effect for any item but numbers, unless an order-relevant judgment about the ordinal item was required after target detection.

That numbers influence the allocation of spatial attention in a way that other ordinal sequences do not has led to the suggestion that numbers are in some way special, and are processed in a manner that is distinctly unique from other ordinal sequences. Hubbard, Piazza, Pinel, and Dehaene (2005) have suggested that numerical–spatial interactions are the result of shared parietal pathways underlying visual spatial attention and the internal representation of numbers. Zorzi, Priftis, Meneghello, Marenzi, and Umiltà (2006) have also provided evidence from neglect patients, which suggest that numbers are processed differently than other ordinal sequences (see Cohen Kadosh, Lammertyn, & Izard, 2008, for a review of why numerical processing may have a special status). On the other hand, both Cantlon, Platt, & Brannon (2009) and Walsh (2003) have concluded that number processing is not specialized and are instead related to an overall magnitude system, which is related to other nonnumerical judgments. In any case, it is unclear whether the influence of numbers is attributable to numbers conveying ordinal information in a more salient manner than other stimuli, or whether these effects occur because numbers are processed differently than other stimuli. Dodd and Wilson (2009) have demonstrated that attentional SNARC-like effects can be obtained by training individuals to treat nonspatial stimuli (e.g., color patches) in a spatial manner. In their study, participants initially performed a target detection task in which a nonpredictive cue (a blue or green color patch) was presented at fixation prior to target presentation. As participants should have no preexisting associations between color and space, the cue did not influence target detection in any manner (participants were equally fast to respond to left and right targets independent of cue). Following this initial session, participants performed an 800 or 1,200 trial training task, which was designed to create an association between color and space: either the color cue was now always predictive of a target location or a directional response on a joystick was required on each trial in response to each color. Following this training session, participants again took part in a target detection task with a nonpredictive color cue, but now detection was facilitated when the target appeared in a location that was consistent with the previously learned association between color and space. It could certainly be the case, therefore, that attentional SNARC effects are attributable to an overlearning of the association between numbers and space in the same way the relationship between arrows and space develops over time.

One way to behaviorally determine whether there is something unique about number processing is to determine whether attentional SNARC effects also occur for negative numbers. The mental number line is well established as proceeding from left to right, such that the number 1 would be represented to the left with 9 to the right. But with negative numbers, the opposite should be true. As −1 is a larger value than −9, −1 would be represented to the right and −9 would be represented to the left. While this is logically consistent with the organization of numbers along a number line, however, the majority of individuals has far less experience with negative numbers, and may not have the same overlearned associations with negative numbers and space that they do for positive numbers and space. Were this to be the case, one would not expect the presentation of negative numbers to affect target detection in any way. If, on the other hand, there are shared parietal pathways between visual attention and numerical representation, then the presentation of negative numbers may lead to a reversal of the standard attentional SNARC effect, with −1 and −2 represented in right space and −8 and −9 represented in left space. One final possibility is that independent of whether a number is presented as being

Journal : Large 426 | Dispatch : 5-4-2010 | Pages : 8
Article No. : 283 | LE | TYPESET
MS Code : PRPF-D-10-00023 | CP | DISK

positive or negative, participants will be influenced by the absolute value of the number, and a standard attentional SNARC effect will be observed.

Experiment 1

The existing literature on negative numbers to this point has been mixed. For example, Fischer and Rottmann (2005) have provided evidence that response bias when making a parity judgment regarding a negative number is influenced only by the absolute magnitude of the number itself and not by the negative representation. Shaki and Petrusic (2005), on the other hand, observed a SNARC effect for negative numbers (faster response to these numbers when a left hand response was required) when positive and negative numbers were intermixed whereas Nuerk, Iversen, and Willmes (2004) observed a SNARC effect for all number types with the exception of negative numbers. Moreover, Loftus, Nicholls, Mattingley, Chapman, and Bradshaw (2009) have demonstrated that number line effects extend to negative numbers in a bisection task but to date, it has not been determined whether negative numbers produce an attentional SNARC effect. That is the purpose of the present experiment.

Methods

Participants

Thirty-seven undergraduate students from the University of Nebraska-Lincoln underwent individual 60-min sessions, receiving course credit as remuneration for participating. All had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Materials, apparatus, and procedure

The methods, apparatus, and procedure were all modeled after Fischer et al. (2003) and Dodd et al. (2008) with the exception that the numbers −1, −2, −8, and −9 were used instead of the positive representation of those same numbers.

The experiment, programmed in Visual C++, was individually conducted on Pentium IV PCs with VGA monitors in a testing room equipped with soft lighting and sound-attenuation. Participants were seated approximately 44 cm from the computer screen, and made responses using the spacebar on a keyboard in front of them.

At the beginning of each trial, an experimental display consisting of a central fixation point (white, 0.2° in diameter) and two white outline square placeholders (each 1.0° in diameter and 4° to the left and right side of the fixation point) was presented on the computer monitor with a black background (Fig. 1).

Participants were instructed to fixate the central fixation point, and to not move their eyes for the duration of the experiment. Eye movements were not monitored as it has been shown that these do not account for the attentional SNARC effect (Fischer et al., 2003). Following a period of 500 ms, one of four numbers (−1, −2, −8, or −9) was presented at fixation for 300 ms. Participants were instructed to ignore the item presented at fixation as it was irrelevant to their task and did not predict the location of the upcoming target. A variable cue-target stimulus onset asynchrony (SOA) of 250, 500, and 750 ms preceded target presentation (a white circle subtending 0.8°) inside one of the two placeholder squares. The target was equally likely to appear in either of the two placeholders, and remained on the screen until a response was recorded. Participants were instructed to press the spacebar as quickly as they could once they detected the target. Responses <100 ms or >1,000 ms were considered errors, and a short error tone was presented if either of these occurred. The next trial began 1,000 ms after each response. The experiment consisted of 720 trials. Short breaks were offered after every 120 trials. Prior to the experiment, participants were given five practice trials to familiarize themselves with the task.

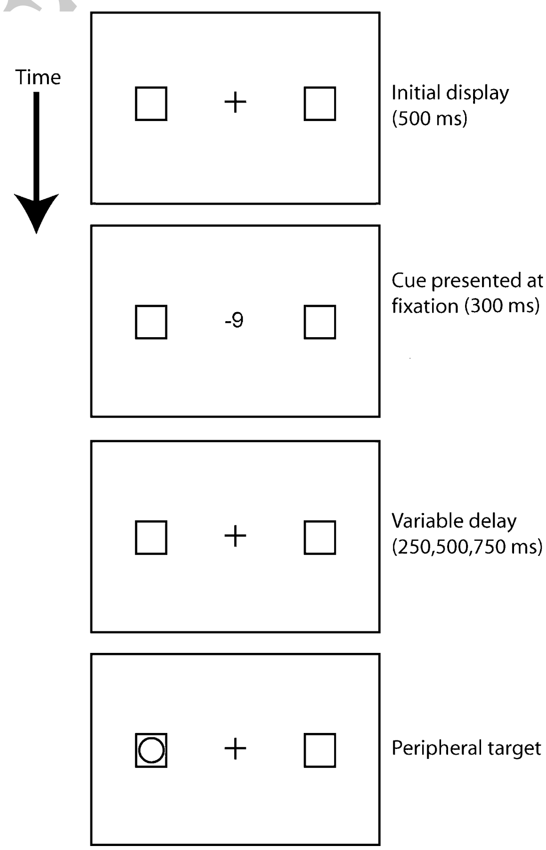

Fig. 1 Trial sequence used in the present study

Journal : Large 426 Dispatch : 5-4-2010 Pages : 8
Article No. : 283 LE TYPESET
MS Code : PRPF-D-10-00023 CP DISK

Table 1 Mean RTs (in ms) and standard deviations (in brackets next to each RT) for targets appearing at each possible location as a function of cue type and SOA in Experiment 1

Cue type:	Left cue (−8 or −9)			Right cue (−1 or −2)		
SOA:	250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Left target	365 (47)	332 (45)	318 (42)	361 (48)	331 (48)	317 (44)
Right target	364 (49)	334 (50)	319 (43)	362 (43)	330 (47)	316 (44)

Results and discussion

At the conclusion of the experiment, participants were asked if they were familiar with the concept of negative numbers and whether they thought the number −1 or −9 was larger. All participants were familiar with the concept of negative numbers and all but one participant indicated that −1 was a larger number than −9. This participant was excluded from all subsequent analyses.

Errors occurred on <1.2% of all trials and these trials were eliminated from all subsequent analyses. Reaction times (RTs) and standard deviations for targets appearing at each target location as a function of cue type are presented in Table 1. For the four cue numbers, RTs were collapsed for the left and right values (e.g., RTs for targets following '−1' and '−2' were collapsed as were RTs for targets following '−8' and '−9') after preliminary analyses indicated no difference between these items.

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 2 (cue type: low/high digit) × 2 (target location: left/right target) × 3 (SOA 250, 500, 750 ms) analysis of variance (ANOVA). There was a significant main effect of SOA, $F(2, 70) = 185.09$, $MSE = 415.21$, $p < 0.001$, signifying the fact that responses were faster at longer SOAs reflecting a standard foreperiod effect. Critically, there were no other significant main effects or interactions (all Fs < 1) meaning that the presentation of negative numbers did not lead to a reversal of the standard attentional SNARC effect, but it did lead to the elimination of the effect.

Though an attentional SNARC effect—or a reversal of the attentional SNARC effect—was not observed in Experiment 1, a single null effect on its own is fairly uninformative. It is possible that an attentional SNARC effect was not observed in the present experiment because (1) participants did not process the central negative number or (2) negative numbers need to be mixed with positive numbers in order to observe attentional SNARC effects.[1] These two possibilities are explored in Experiments 2 and 3.

[1] I would like to thank Carlo Umiltà and two anonymous reviewers for these suggestions.

Experiment 2

The purpose of Experiment 2 was to ensure that participants were processing the central negative number during the target detection task. Though the attentional SNARC effect has been replicated a number of times (Dodd et al., 2008; Galfano, Rusconi, & Umiltà, 2006; Nicholls, Loftus, & Gevers, 2008), it has been suggested that the effect may be dependent on top–down control, meaning an effect may not be observed if the irrelevant cues are not meaningfully processed (Galfano et al., 2006; Ristic, Wright, & Kingstone, 2006). Previously, Dodd et al. (2008) have demonstrated that an attentional SNARC effect can be observed for ordinal sequences other than numbers (e.g., letters of the alphabet) so long as the irrelevant cues are processed in an order-relevant manner. In that study, participants had to indicate whether the cue was greater or less than a referent following the target detection decision, which ensured that the central cue was processed. One of the central reasons participants may not elicit an attentional SNARC effect for negative numbers, however, is that they have less experience with negative numbers, meaning an order-relevant judgment could prove difficult (e.g., is this number greater than or less than −5). Consequently, rather than requiring an order-relevant judgment, in the present experiment participants were asked to verbally report what the central digit on each trial had been following target detection. This method was recently used by Casarotti, Michielin, Zorzi, and Umiltà (2007) and ensures that participants are processing central cues without imposing any additional processing requirements that could bias target detection.

Methods

Participants

Twenty-two undergraduate students from the University of Nebraska-Lincoln underwent individual 60-min sessions, receiving course credit as remuneration for participating. All had normal or corrected-to-normal vision and were naïve about the purpose of the experiment. None of the participants had taken part in Experiment 1.

Materials, apparatus, and procedure

The materials, apparatus, and procedure were all identical to Experiment 1 with the exception that after each target detection response, participants were required to verbally report, which number had appeared at fixation into a microphone (all individuals were told to report the negative sign as part of the number, such that −1 was reported as "negative one" and not just "one").

Journal : Large 426 | Dispatch : 5-4-2010 | Pages : 8
Article No. : 283 | ☐ LE | ☐ TYPESET
MS Code : PRPF-D-10-00023 | ☑ CP | ☑ DISK

Results and discussion

At the conclusion of the experiment, participants were asked if they were familiar with the concept of negative numbers and whether they thought the number −1 or −9 was larger. All participants were familiar with the concept of negative numbers and all but one participant indicated that −1 was a larger number than −9. This participant was excluded from all subsequent analyses.

Errors occurred on <0.9% of all trials and these trials were eliminated from all subsequent analyses. RTs and standard deviations for targets appearing at each target location as a function of cue type are presented in Table 2. For the four cue numbers, RTs were collapsed for the left and right values (e.g., RTs for targets following '−1' and '−2' were collapsed as were RTs for targets following '−8' and '−9') after preliminary analyses indicated no difference between these items.

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 2 (cue type: low/high digit) × 2 (target location: left/right target) × 3 (SOA 250, 500, 750 ms) ANOVA. There was a significant main effect of SOA, $F(2, 40) = 100.00$, $MSE = 635.37$, $p < 0.001$, signifying the fact that responses were faster at longer SOAs reflecting a standard foreperiod effect. Critically, there were no other significant main effects or interactions (all Fs < 1 except the interaction between Target and SOA, $F(2, 40) = 1.36$, $MSE = 258.87$, $p = 0.27$) meaning that the presentation of negative numbers did not lead to a reversal of the standard attentional SNARC effect, but it did lead to the elimination of the effect.

The results of Experiment 2 replicate that of Experiment 1. Despite the fact that participants were now forced to process the central digit, the presentation of negative numbers at fixation did not reverse that attentional SNARC effect but did lead to an elimination of the effect.

Experiment 3

In the previous two experiments, the presence of negative numbers at fixation did not influence target detection in any manner. To this point, however, neither of the reported experiments has investigated whether the presentation of negative numbers at fixation will influence target detection if positive numbers are also presented at fixation on some trials. That is the purpose of the present experiment. Importantly, by intermixing the presentation of negative and positive numbers at fixation, it can be determined whether (1) negative number reverse the attentional SNARC effect if their positive counterparts are also presented, or (2) negative numbers continue to be unrelated to target detection. To visually equate the cue items, positive numbers were presented as +1, +2, +8, and +9 in the present experiment. This also allows for an investigation as to whether the attentional SNARC effect is contextually influenced. Though the previous analyses have focused on the difference between low negative numbers and high negative numbers, the present paradigm allows for an additional comparison between all negative numbers and all positive numbers (e.g., will all negative numbers shift attention left while all positive numbers shift attention right, independent of the magnitude of each number?).

Methods

Participants

Thirty undergraduate students from the University of Nebraska-Lincoln underwent individual 60-min sessions, receiving course credit as remuneration for participating. All had normal or corrected-to-normal vision and were naïve about the purpose of the experiment. None of the participants had taken part in either of the previous experiments.

Materials, apparatus, and procedure

The materials, apparatus, and procedure were all identical to Experiment 1 with the exception that on half of all trials, the central cue now consisted of a positive number rather than a negative number. Positive numbers were presented as +1, +2, +8, and +9 so that the negative and positive cues were as perceptually similar as possible.

Results and discussion

At the conclusion of the experiment, participants were asked if they were familiar with the concept of negative numbers and whether they thought the number −1 or −9 was larger. All but one participant was familiar with the concept of negative numbers and of those who were familiar with negative numbers, only one participant indicated that −1 was a larger number than −9. These two participants were excluded from all subsequent analyses.

Table 2 Mean RTs (in ms) and standard deviations (in brackets next to each RT) for targets appearing at each possible location as a function of cue type and SOA in Experiment 2

Cue type:	Left cue (−8 or −9)			Right cue (−1 or −2)		
SOA:	250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Left target	372 (48)	337 (61)	319 (60)	373 (47)	332 (42)	318 (51)
Right target	370 (55)	336 (50)	319 (50)	374 (48)	330 (43)	316 (44)

Journal : Large 426 | Dispatch : 5-4-2010 | Pages : 8
Article No. : 283 | LE | TYPESET
MS Code : PRPF-D-10-00023 | CP | DISK

Table 3 Mean RTs (in ms) and standard deviations (in brackets next to each RT) for targets appearing at each possible location as a function of cue type (negative versus positive number) and SOA in Experiment 3

Cue type:	Left cue (−1, −2, −8 or −9)			Right cue (+1, +2, +8, or +9)		
SOA:	250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Left target	413 (96)	354 (65)	328 (49)	402 (90)	347 (65)	321 (50)
Right target	414 (85)	354 (68)	328 (54)	400 (87)	349 (43)	322 (52)

Table 4 Mean RTs (in ms) and standard deviations (in brackets next to each RT) for targets appearing at each possible location as a function of cue type and SOA in Experiment 3

Cue type:	Left cue (−8 or −9)			Right cue (−1 or −2)		
SOA:	250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Negative numbers						
Left target	415 (98)	355 (77)	332 (53)	411 (98)	353 (74)	324 (58)
Right target	414 (91)	354 (66)	331 (57)	414 (92)	354 (68)	324 (52)
Cue type:	Left cue (+1 or +2)			Right cue (+8 or +9)		
SOA:	250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Positive numbers						
Left target	402 (86)	342 (57)	317 (45)	402 (94)	351 (64)	325 (45)
Right target	399 (89)	356 (68)	323 (52)	400 (86)	341 (56)	320 (52)

Errors occurred on less than 1.4% of all trials and these trials were eliminated from all subsequent analyses. RTs and standard deviations for targets appearing at each target location as a function of cue type are presented in Tables 3 and 4. The means are presented in two different ways. First, as a function of RTs with all negative values collapsed together and all positive values collapsed together (Table 3), and then with low negative (−8, −9), high negative (−1, −2), low positive (+1, +2) and high positive (+8, +9) presented individually (Table 4).

Negative versus positive numbers

Though the focus of all previous analyses have been on the difference between low and high numbers, the present paradigm affords an opportunity to determine whether all negative numbers are represented in left space whereas all positive numbers are represented in right space. This would lead to the expectation that left target detection would be facilitated when a negative number is presented at fixation relative to a positive number, while right target detection would be facilitated when a positive number is presented at fixation relative to a negative number.

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 2 (cue type negative/positive digit) × 2 (target location left/right target) × 3 (SOA 250, 500, 750 ms) ANOVA. There was a significant main effect of SOA, $F(2, 54) = 94.31$, MSE = 2,112.17, $p < 0.001$, signifying the fact that responses were faster at longer SOAs reflecting a standard foreperiod effect. Critically, there were no other significant main effects or interactions (all Fs < 1 except the interaction between cue and target, $F(1, 27) = 1.36$, MSE = 516.64, $p = 0.25$) meaning that the presentation of negative numbers did not lead to a reversal of the standard attentional SNARC effect, but it did lead to the elimination of the effect. Thus, while Galfano et al. (2006) have provided evidence that SNARC effects can be observed when negative and positive numbers are mixed together, the same does not seem to hold for the attentional SNARC effect.

Low negative versus high negative and low positive versus high positive numbers

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 4 (cue type: low negative/high negative/low positive/high negative digit) × 2 (target location: left/right target) × 3 (SOA 250, 500, 750 ms) ANOVA. There was a significant main effect of SOA, $F(2, 54) = 94.31$, MSE = 4,224.34, $p < 0.001$, signifying the fact that responses were faster at longer SOAs reflecting a standard foreperiod effect. Critically, the only other significant effect was between cue type and target location, $F(3, 81) = 2.65$, MSE = 650.17, $p = 0.05$, representing the attentional SNARC effect: right targets were detected faster when preceded by high digits and left targets were presented faster when preceded by low digits. To determine at which SOAs's and for which cue types the effect was present, post hoc t tests were conducted. A significant attentional SNARC effect was found at the 500-ms SOA for both the left and right target locations when positive number cues were presented, $t(27) = -2.50$, $p < 0.05$ and $t(27) = 2.25$, $p < 0.05$, respectively. There were no other significant effects. Thus, the standard attentional SNARC effect was observed for positive numbers but not for negative numbers.

General discussion

The purpose of the present study was to determine whether the presentation of negative numbers at fixation would

Journal : Large 426 | Dispatch : 5-4-2010 | Pages : 8
Article No. : 283 | ☐ LE | ☐ TYPESET
MS Code : PRPF-D-10-00023 | ☑ CP | ☑ DISK

influence the manner in which attention is allocated during a target detection task. Fischer et al. (2003) extended the earlier work of Dehaene et al. (1993) demonstrating that the presentation of irrelevant numbers at fixation influenced the manner in which attention is shifted across the visual field: left target detection is facilitated when a low number is presented at fixation relative to a high number, while the opposite is true for right target detection. Since this initial report, there has been mixed evidence as to whether other ordinal sequences also influence attention, or whether there is something unique about the manner in which numbers are processed as it relates to spatial attention. By examining whether the attentional SNARC effect is reversed with negative numbers (since −1 is a greater value than −9, it should be represented in right space relative to left space, while the opposite is true for positive numbers), it can be determined whether the attentional SNARC effect is attributable to overlearned associations between numbers and space, or whether there is something unique about number processing, such as shared processing pathways between numbers and spatial attention.[2]

The results of the present study are clear. The presentation of negative numbers at fixation did not lead to a reversal of the attentional SNARC effect. It did, however, lead to a complete elimination of the attentional SNARC effect in all three experiments. This was the case even when participants were required to process the central cues (Experiment 2) and when positive and negative numbers were intermixed (Experiment 3). Even when positive and negative values were mixed, however, a standard attentional SNARC effect was obtained for positive numbers meaning the attentional SNARC effect was still observed under these conditions. That negative values eliminate, but do not reverse, the attentional SNARC effect provides important insight into how the effect develops. Previously, three possible outcomes for the present study were outlined: negative numbers would not alter the attentional SNARC effect in any way, negative numbers would lead to a reversal of the attentional SNARC effect, or that negative numbers would lead to an elimination of the SNARC effect. Each of these possibilities will now be discussed in turn.

That the presentation of negative numbers at fixation in a target detection task led to an elimination of the attentional SNARC effect suggests that the mere presentation of the numbers 1, 2, 8, or 9 does not, in itself, produce a corresponding shift of attention based on numerical magnitude. Participants clearly processed the negative sign associated with the numbers, meaning that spatial attention is not influenced by absolute value. It is unlikely that the present results are merely a failure to replicate the standard attentional SNARC effect as this effect has been replicated numerous times in numerous labs (Dodd et al., 2008; Galfano et al. 2006; Nicholls et al. 2008) and was still apparent in Experiment 3 when positive values were intermixed with negative values. Rather, negative numbers were treated in a manner different than what would be the case for positive numbers. Thus, perception of numbers does not influence attention independent of other contextual details.

The presentation of negative numbers also failed to lead to a reversal of the attentional SNARC effect, a finding that seems inconsistent with the notion that the attentional SNARC effect is attributable to shared parietal pathways between numerical processing and spatial attention. If shared processing between number perception and spatial perception were the main reason that the attentional SNARC effect is observed then it would be expected that the effect would be obligatory and independent of number type or magnitude. This does not mean that shared parietal pathways do not exist but they do not seem to be the main determinant of the attentional SNARC effect. Rather, the failure to observe an attentional SNARC effect with negative numbers seems most consistent with the notion that the effect occurs due to overlearned associations between numbers and space. This finding is consistent with previous findings by Dodd et al. (2008)—who demonstrated that while attentional SNARC effects occur for numbers, they do not occur for other ordinal sequences (e.g., letters, months, days) unless an order-relevant decision is required—and Dodd and Wilson (2009) who observed attentional SNARC-like effects by training individuals to treat nonspatial stimuli (color patches) in a spatial manner.

In summary, the present experiment provides additional evidence that the oft observed interactions between central cues and reflexive attention are attributable to overlearned spatial associations of certain cues. Further research will be required, however, to further characterize these interactions. For example, perhaps the presentation of negative numbers would have led to a reversal of the attentional SNARC effects in certain populations, such as mathematicians, who have substantial experience with how these numbers would be represented along a number line. Independent of this, however, the present results are the first demonstration that the attentional SNARC effect does not extend to negative numbers, which provides important insight into how the attentional SNARC effect develops.

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[2] It is worth noting that these two possibilities could co-exist, though the failure to demonstrate a SNARC effect—or a reversed SNARC effect—seems somewhat inconsistent with the notion that there are shared processing pathways between numbers and spatial attention.

Journal : Large 426 | Dispatch : 5-4-2010 | Pages : 8
Article No. : 283 | ☐ LE | ☐ TYPESET
MS Code : PRPF-D-10-00023 | ☑ CP | ☑ DISK

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