Cognition 108 (2008) 810–818

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Brief article

Attentional SNARC: There's something special about numbers (let us count the ways) ☆

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ARTICLE INFO

Article history:
Received 6 June 2007
Revised 21 April 2008
Accepted 27 April 2008

Keywords:
Attention
SNARC effect
Ordinal sequences

ABSTRACT

We report a study that examines whether the presentation of irrelevant, ordinal information at central fixation interacts with the allocation of attention beyond fixation. Previous research has demonstrated that number perception influences the allocation of spatial attention, such that the presentation of a spatially nonpredictive number at fixation results in attention being allocated to the left when the central number is low (e.g., 1), and attention being allocated to the right when the central number is high (e.g., 9). Here, we examine whether this attentional SNARC effect (spatial numerical association of response codes) generalizes to other ordinal sequences: letters, days, and months. Though we replicate the attentional SNARC we find that this effect is number-specific, unless participants are required to process the cue in an order-relevant fashion. This discovery of number-specificity has important implications both for the functional separation between SNARC and attention-SNARC effects, as well as lending support to recent theories regarding the specificity of a shared neural architecture between numbers and visuospatial attention.

1. Introduction

As we navigate our visual world, we are continually confronted with more information than we can process simultaneously. Consequently, a critical function of our visual system is to efficiently direct attention to features of our environment to determine which items are to be processed and which are to be ignored. Attention is often said to shift throughout the environment in one of two ways: endogenously or exogenously. Endogenous shifts of attention are those that occur in a volitional (top-down) manner, such as when one scans a crowd looking for a friend. In the laboratory, endogenous attention is often studied by presenting a central cue, such as an arrow, that indicates where a target is likely to appear. That target detection is speeded at cued relative to uncued locations is taken as evidence that participants shifted attention voluntarily based on the cue's meaning (Posner, 1980; Ristic & Kingstone, 2006). Exogenous shifts of attention are reflexive (bottom-up), and in the laboratory they are often studied by presenting a sudden spatially nonpredictive visual cue, such as a light pulse, in the periphery (e.g., Posner, 1980; Yantis & Hillstrom, 1994). Target detection is speeded at cued relative to uncued locations when the target appears immediately after the cue, suggesting that spatial attention was pulled automatically to the cued location.

While the aforementioned paradigms are commonly used to study endogenous and exogenous visual spatial

☆ This research was supported by a Killam post-doctoral fellowship and a Natural Sciences and Engineering Research Council (NSERC) post-doctoral fellowship to M. Dodd and NSERC grant to A. Kingstone. We would like to thank Wieske van Zoest, Ipek Oruc, Sharon Morein-Zamir, Michael MacIsaac, and two anonymus reviewers for their insight at various stages of this project. We would also like to thank Kristin Divis for assistance in collecting the data.

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doi:10.1016/j.cognition.2008.04.006

attention, it has also been established that attention can be influenced by the presentation of overlearned, spatially meaningful, symbols at fixation, even when these symbols do not predict the upcoming target location. For example, Hommel, Pratt, Colzato, and Godijn (2001; see also Eimer, 1997; Pratt & Hommel, 2003) demonstrated that the presentation of a spatially nonpredictive arrow or directional word (e.g., "left") results in targets being detected more quickly at the location consistent with the cue's directional meaning. That a cuing effect occurred for these spatially nonpredictive cues suggests that attention was shifted reflexively in the direction of these cues. Of course, given that the presentation of an arrow in the real world is almost always spatially predictive and meaningful makes findings such as the above relatively intuitive (see also Gibson & Kingstone, 2006; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002).

Less intuitive, however, is the finding that the presentation of numbers at fixation also seems to influence the allocation of attention in the visual field. Dehaene, Bossini, and Giraux (1993) had participants indicate whether a number was odd or even with a left- or right-hand keypress. 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. posited that this finding was attributable to the mental organization of numbers, which may be stored 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 SNARC effect (Spatial Numerical Association of Response Codes). SNARC effects have subsequently been reported in a variety of tasks, such as phoneme detection of digits' names (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996), digit magnitude classification (Bächtold, Baumüller, & Brugger, 1998), and even for the midpoint localization of long digit strings (Fischer, 2001). These findings led Fischer, Castel, Dodd, and Pratt (2003) to ask whether the presentation of an irrelevant digit at fixation could evoke an attentional shift to the left or right visual field. Consistent with this idea 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. This finding is particularly interesting in that numbers, which under some circumstances have spatial meaning in the real world (e.g., spatial coordinates on a map, the left-to-right ordering of numbers on rulers and tape measures, the ascending/descending nature of house addresses on most North American city streets), do not have the same strong spatial connotation that other spatial cues do, such as arrows.

That irrelevant numbers influence the allocation of attention in a target detection task leaves open the question of whether other related stimuli may have a similar effect, or whether the effect observed by Fischer et al. (2003) is specific to numbers. Although it was originally believed that the SNARC effect was restricted to numerical values (Dehaene et al., 1993), it has recently been demonstrated that a SNARC effect is obtained for other ordinal stimuli such as letters of the alphabet, days of the week, and months of the year (Gevers, Reynvoet, & Fias, 2003, 2004).[1] In these studies participants were presented with items at fixation and were required to make an order-relevant decision (e.g. does this month occur before or after July) or order-irrelevant decision (e.g., does this month end in the letter 'R'). Critically, a SNARC effect was observed in both the order-relevant and order-irrelevant tasks, as participants were faster to respond to *left* ordinal information (e.g., months occurring before June) when they responded with their left hand relative to their right hand, and faster to respond to *right* ordinal information (e.g., months occurring after June) when they responded with their right hand relative to their left hand. Gevers et al. suggested that these findings are evidence that the mental representation of ordinal sequences, and not just numbers, is spatially coded. Moreover, the finding that the SNARC effect is observed in a task in which ordinal information is irrelevant was taken as evidence that the spatial component of ordinal sequences is automatically activated.

Given that numbers—much like letters, days, and months—convey ordinal meaning, it is important to determine whether numerical sequences and non-numerical ordered sequences share similar processing mechanisms, or whether the aforementioned findings are separable. For example, while Gevers et al. (2003) provide evidence that non-numerical ordinal sequences activate spatial representations, a recent study by Zorzi, Priftis, Meneghello, Marenzi, and Umilta (2006) with neglect patients suggests that numbers are processed differently than other ordinal sequences. To this end, the present study adopts the attention paradigm used by Fischer et al. (2003) to investigate whether the ordinal sequences of letters, days, and months will also influence the allocation of attention. If an attentional SNARC effect is observed when this range of irrelevant ordinal information is placed at fixation, it would suggest that numerical and non-numerical ordered sequences share similar processing mechanisms. If, on the other hand, an attentional effect is specific to numbers it would suggest that numbers may represent a special class of ordinal information that, in turn, will provide important insights into the processes that underlying both the SNARC and attentional SNARC effects.

2. Method

2.1. Participants

Thirty undergraduate students from the University of British Columbia underwent individual 45-min sessions, receiving course credit as remuneration for participating in the study. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

[1] Interestingly, in their seminal work, Dehaene et al. (1993) also conducted an experiment in which they used letters rather than numbers but found no evidence that the SNARC effect generalized to these stimuli.

2.2. Apparatus and procedure

The experiment, programmed in Visual C++, was individually conducted on Pentium IV PC's 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 a central fixation point (white, 0.2° in diameter) and an experimental display of 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 (see Fig. 1).

Participants were instructed to fixate on the central fixation point, and not to make any eye movements. Eye movements were not monitored as it is shown that these do not account for the attentional SNARC effect (Fischer et al., 2003). Following a period of 500 ms, one of four cue types was superimposed over the fixation point for 300 ms. Respective of the block, the cue was either a number, letter, day of the week, or month in the year. 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. To avoid anticipatory responses the cue-target SOA was randomly varied across trials. Responses less than 100 ms or greater than 1000 ms were considered errors, and a short error tone was presented if either of these occurred. The next trial began 1000 ms after each response.

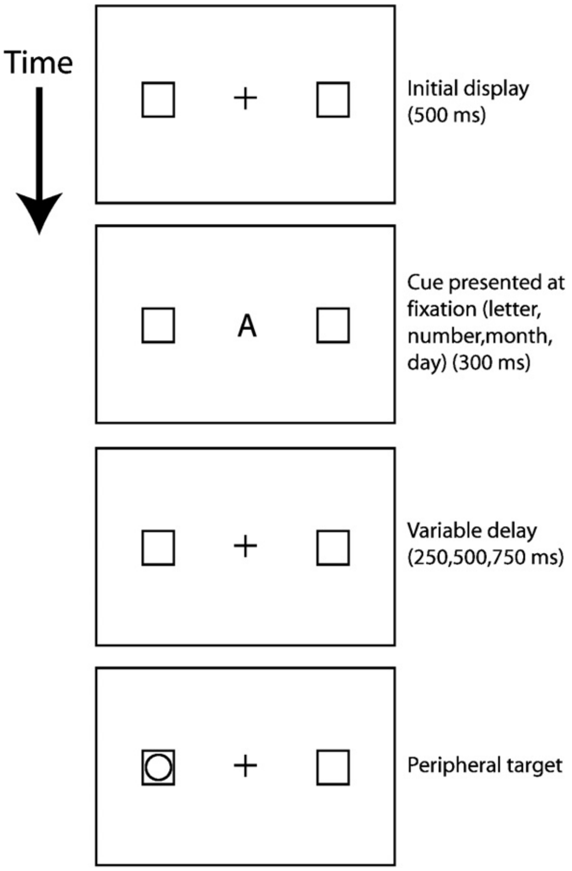

Fig. 1. Trial sequence used in the present study for each of the four blocks of trials. The only difference between block was the type of cue stimuli presented at fixation (days, months, letters, or numbers).

2.3. Design

The experiment consisted of four randomized blocks of 240 trials. Each block consisted of a different cue type: numbers (1, 2, 8, 9), letters (a, b, y, z), days of the week (Monday, Tuesday, Friday, Saturday), or months in the year (January, February, November, December). The cues were selected to represent the far left and far right ends of the ordinal sequence they were sampled from ("Sunday" was excluded as a day-cue as it can represent either the start or end of a week). Short breaks were given after every 120 trials.

3. Results and discussion

Errors occurred on less than 2.3% 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 condition are presented in Table 1. Moreover, Fig. 2 presents the RTs as a function of cue-target congruency. For all four stimulus types (numbers, letters, days, and months), RTs were collapsed for the left and right values (e.g. RTs for targets following 'a' and 'b' were collapsed as were RTs for targets following 'y' and 'z'). Attentional effects as a function of each stimulus type are reported in turn.

3.1. Numbers

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 2 (Cue Type: low/high digit) X 2 (Target Location: left/right target) X 3 (SOA: 250, 500, 750 ms) analysis of variance (ANOVA). There was a significant main effect of SOA, $F(2,58) = 107.93$, $MSE = 920.50$, $p < 0.001$, signifying the fact that responses were faster at longer SOAs reflecting a standard foreperiod effect. Critically, the only other significant effect was the interaction between Cue Type and Target Location, $F(1,29) = 4.05$, $MSE = 606.88$, $p < 0.05$, representing the attentional SNARC effect: right targets were detected faster when preceded by high digits and left targets were detected faster when preceded by low digits. To determine at which SOAs's 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, $t(29) = -2.48$, $p < 0.05$ and $t(29) = 2.34$,

Table 1
Experiment 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

Cue type		Left cue			Right cue		
SOA		250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Numbers	Left target	363 (49)	312 (34)	313 (46)	368 (54)	328 (44)	311 (46)
	Right target	370 (51)	323 (50)	314 (50)	363 (50)	317 (49)	313 (44)
Letters	Left target	365 (51)	321 (49)	310 (49)	360 (51)	317 (51)	313 (49)
	Right target	359 (48)	318 (53)	306 (54)	360 (52)	324 (51)	314 (53)
Days	Left target	374 (48)	330 (50)	317 (53)	370 (52)	327 (46)	313 (49)
	Right target	374 (59)	323 (50)	312 (53)	366 (55)	320 (49)	310 (46)
Months	Left target	358 (44)	322 (41)	310 (45)	362 (44)	327 (49)	306 (44)
	Right target	351 (40)	319 (46)	302 (46)	356 (48)	320 (45)	304 (46)

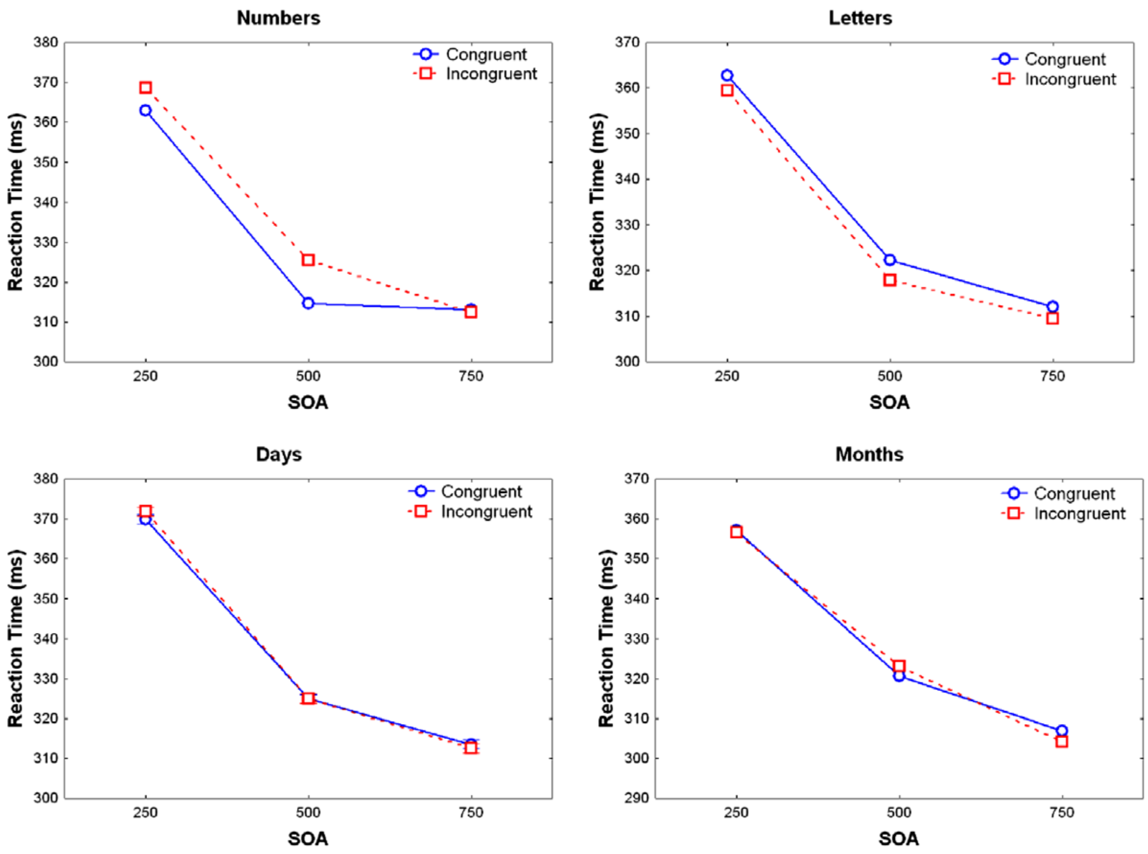

Fig. 2. Reaction times (ms) to detect targets at each SOA as a function of cue-target congruency (e.g., if the cue is a 1 or 2, a target appearing to the left would be considered congruent while a target to the right would be considered incongruent; the opposite would hold true if the cue was an 8 or 9) following the presentation of a left or right item in the ordinal sequence.

$p < 0.05$, respectively. Thus, the attentional SNARC effect, as reported by Fischer et al. (2003), replicates here: number magnitude influenced target detection despite the fact that the number presented at fixation was irrelevant to the detection task. There were no significant effects for the other SOAs (p's > 0.20).

3.2. Letters

Mean RTs were analyzed with a 2 (Cue Type: left/right letter) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was a significant main effect of SOA, $F(2,58) = 147.72$, $MSE = 582.39$, $p < 0.001$, signifying a foreperiod effect. There were no other significant main effects or interactions; $F(1,29) < 1$ for the critical interaction between Cue Type and Target Location.

3.3. Days

Mean RTs were analyzed with a 2 (Cue Type: left/right day) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was again a significant main effect of SOA, $F(2,58) = 95.51$, $MSE = 1172.74$, $p < 0.001$, reflecting a foreperiod effect. There were no other significant main effects or interactions; $F(1,29) < 1$ for the critical interaction between Cue Type and Target Location.

3.4. Months

Mean RTs were analyzed with a 2 (Cue Type: left/right month) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was a significant main effect of SOA, $F(2,58) = 175.73$, $MSE = 470.64$, $p < 0.001$, signifying a foreperiod effect. There were no other significant main effects or interactions; $F(1,29) < 1$ for the critical interaction between Cue Type and Target Location.

4. Experiment 2

In Experiment 1, we observed an attentional SNARC effect for number stimuli, replicating previous work, but failed to observe such an effect with letters, days, and months.[2] Critically, the stimulus at fixation was irrelevant to the target detection task. This result suggests that there are processing mechanisms that are specific to numbers and do not generalize to other ordinal sequences. It is the case, however, that SNARC effects have previously been observed with letters, days, and months, when the presentation of such items at fixation are not irrelevant. Gevers et al. (2003, 2004) obtained a SNARC effect for all of the aforementioned ordinal sequences when an order-relevant decision was required in a choice SNARC task (e.g. does the month presented at fixation precede or follow "July"). In the present experiment, we sought to determine whether an attentional SNARC effect would be obtained for letters, days, and months, if participants were forced to process the item at fixation and make an order-relevant decision about that item after target detection.

4.1. Participants

Twenty-two undergraduate (14 from the University of British Columbia and eight from the University of Nebraska—Lincoln) underwent individual 60-min sessions, receiving course credit as remuneration for participating in the study. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

4.2. Apparatus and procedure

The apparatus and procedure for Experiment 2 was identical to that for Experiment 1, with one key exception: when the letter/number/day/month appeared at fixation, participants were instructed to determine whether that item came before or after an item in the middle the ordinal sequence (e.g. before or after "m" in the letters block; before or after "5" in the numbers block; before or after "Wednesday" in the days block, and before or after "July" in the months block). After a target detection response was made, participants were required to say aloud whether the fixation item came before (say "before") or after (say "after"). Participants were informed that the cue event was not predictive of the upcoming target location, but the expectation was that the secondary task would force subjects to process the cue in a spatial/ordered manner, which may lead to an attentional SNARC effect for letters, days, and months.

5. Results and discussion

Given the fact that the present experiment consisted of two tasks (target detection followed by before/after decision), two types of errors were possible: target detection errors and before/after judgment errors. Target detection errors occurred on less than 1.8% of all trials while before/after judgment errors occurred on less than 0.3% of the trials. All trials in which an error occurred were eliminated from all subsequent analyses. Reaction times (RTs) and standard deviations for targets appearing at each target location as a function of cue condition are presented in Table 2. Fig. 3 presents the RTs as a function of cue-target congruency. For all four stimulus types (numbers, letters, days, and months), RTs were collapsed for the left and right values as in Experiment 1. Attentional effects as a function of each stimulus type are reported in turn.

5.1. Numbers

To examine the RT by numerical magnitude effects, the mean RTs were analyzed with a 2 (Cue Type: low/high digit) X 2 (Target Location: left/right target) X 3 (SOA: 250, 500, 750 ms) ANOVA. There was a significant main effect of SOA, $F(2,42) = 161.19$, $MSE = 1353.45$, $p < 0.001$, reflecting a standard foreperiod effect. Critically, the only other significant effect was the interaction between Cue Type and Target Location, $F(1,21) = 9.67$, $MSE = 1004.17$, $p < 0.01$, representing the attentional SNARC effect: right targets were detected faster when preceded by high digits and left targets were detected faster when preceded by low digits. To determine at which SOAs's 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, $t(21) = -3.47$, $p < 0.01$ and $t(21) = 2.22$, $p < 0.05$, respectively. Thus, the attentional SNARC effect, observed in Experiment 1, replicates here. There were no significant effects for the other SOAs (p's > 0.10).

5.2. Letters

Mean RTs were analyzed with a 2 (Cue Type: left/right letter) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was a significant main effect of SOA, $F(2,42) = 10.50$, $MSE = 11562.83$, $p < 0.001$, signifying a foreperiod effect. Critically, the only other significant effect

[2] Given that the conclusions of Experiment 1 are essentially based on a series of null results, it raises the question as to whether we had sufficient power to detect SNARC effects for non-numerical ordinal stimuli. A careful examination of Table 1, however, shows that with non-numerical stimuli, not only is there no hint of an attentional SNARC effect but often the results are in the opposite direction of what would be expected (faster to the left following a right cue or to the right following a left cue), meaning power is not likely an issue here.

Table 2
Experiment 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

Cue type		Left cue			Right cue		
SOA		250 ms	500 ms	750 ms	250 ms	500 ms	750 ms
Numbers	Left target	418 (76)	344 (50)	320 (64)	432 (72)	360 (55)	328 (56)
	Right target	416 (53)	371 (64)	327 (59)	418 (70)	346 (53)	318 (55)
Letters	Left target	415 (95)	355 (73)	345 (83)	420 (94)	379 (77)	344 (69)
	Right target	416 (78)	371 (90)	341 (102)	405 (87)	354 (69)	333 (77)
Days	Left target	393 (68)	339 (53)	329 (58)	407 (57)	359 (60)	343 (54)
	Right target	403 (66)	360 (57)	323 (59)	383 (73)	336 (57)	307 (49)
Months	Left target	409 (69)	340 (59)	315 (58)	418 (66)	354 (48)	325 (53)
	Right target	408 (62)	350 (65)	319 (49)	405 (61)	331 (51)	324 (61)

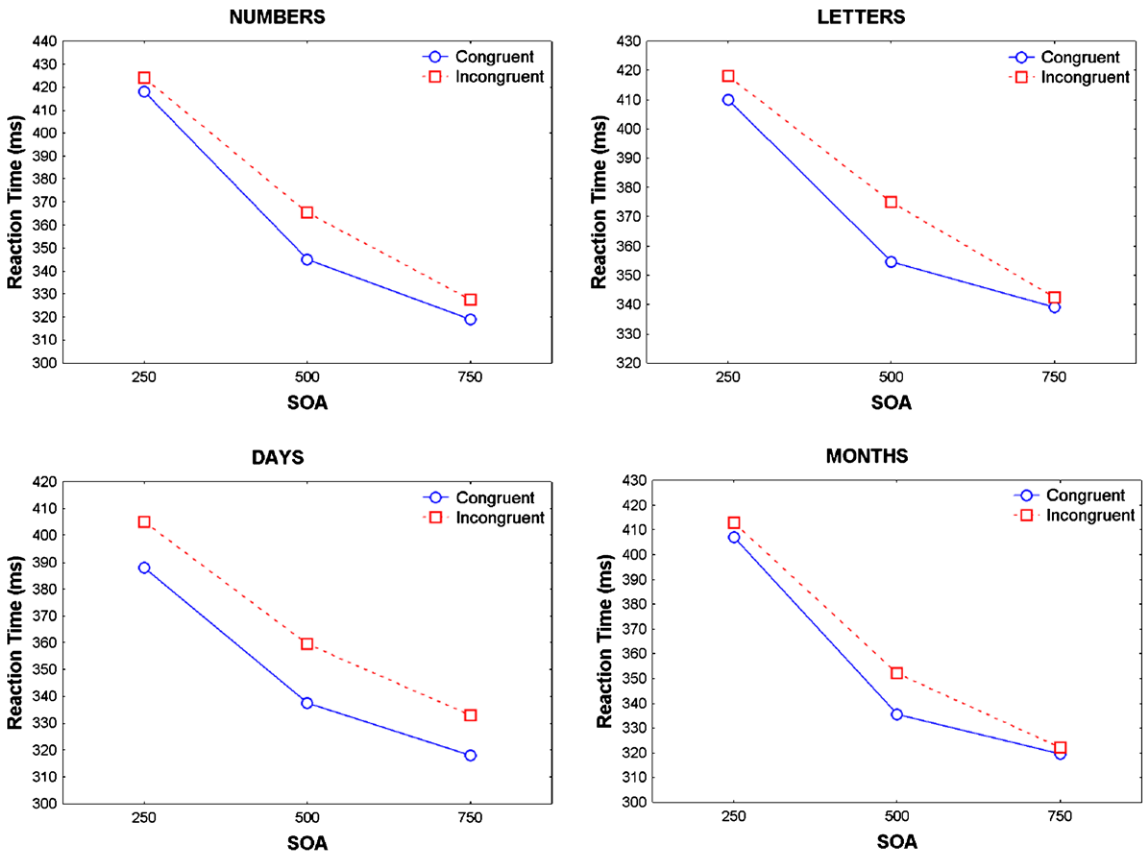

Fig. 3. Reaction times (ms) to detect targets at each SOA as a function of cue-target congruency (e.g., if the cue is a 1 or 2, a target appearing to the left would be considered congruent while a target to the right would be considered incongruent; the opposite would hold true if the cue was an 8 or 9) following the presentation of a left or right item in the ordinal sequence.

was the interaction between Cue Type and Target Location, $F(1,21) = 6.46$, $MSE = 1185.89$, $p < 0.05$, representing the attentional SNARC effect: right targets were detected faster when preceded by the letters y or z and left targets were detected faster when preceded by the letters a or b. To determine at which SOAs's the effect was present post-hoc *t*-tests were conducted. A significant attentional SNARC effect was found at the 500 ms SOA for the right target location, $t(21) = 3.59$, $p < 0.01$ while the attentional SNARC effect for the left target location brushed significance, $t(21) = -1.50$, $p < 0.10$. Thus, the attentional SNARC effect observed for numbers is also observed for letters in a task where participants are forced to process the cues in an order-relevant manner. There were no significant effects for the other SOAs (*p's* > 0.10).

5.3. Days

Mean RTs were analyzed with a 2 (Cue Type: left/right letter) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was a significant main effect of SOA, $F(2,42) = 26.15$, $MSE = 4397.90$, $p < 0.001$, reflecting a foreperiod effect. There was also an unexpected main effect of target location, $F(2,42) = 5.82$, $MSE = 1019.90$, $p < 0.05$, with faster responses to right targets relative to left targets. Critically, the only other significant effect was the interaction between Cue Type and Target Location, $F(1,21) = 19.76$, $MSE = 1083.86$, $p < 0.001$, representing the attentional SNARC effect: right targets were detected faster when preceded by the days Friday or Saturday and left targets were detected faster when preceded by the days Monday or Tuesday. To determine at which SOAs's 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, $t(21) = -2.96$, $p < 0.01$ and $t(21) = 2.90$, $p < 0.01$, respectively. In keeping with the main effect of target location, participants were also significantly faster to respond to right targets following the presentation of high numbers at the 250 ms and 750 ms SOAs, $t(21) = 2.90$, $p < 0.01$ and $t(21) = 4.19$, $p < 0.01$, respectively. Thus, the attentional SNARC effect observed for numbers is also observed for days in a task where participants are required to process the cues in an order-relevant manner.

5.4. Months

Mean RTs were analyzed with a 2 (Cue Type: left/right letter) X 2 (Target Location: left/right target) X 3 (SOAs) ANOVA. There was a significant main effect of SOA, $F(2,42) = 160.36$, $MSE = 1175.04$, $p < 0.001$, signifying a foreperiod effect. Critically, the only other significant effect was the interaction between Cue Type and Target Location, $F(1,21) = 4.50$, $MSE = 988.62$, $p < 0.05$, representing the attentional SNARC effect: right targets were detected faster when preceded by the months November or December and left targets were detected faster when preceded by the months January or February. To determine at which SOAs's the effect was present post-hoc *t*-tests were conducted. A significant attentional SNARC effect was found at the 500 ms SOA for the right target location, $t(21) = 2.69$, $p < 0.05$ while the attentional SNARC effect for the left target location approached, but did not reach, conventional levels of significance, $t(21) = -1.20$, $p < 0.12$. Thus, the attentional SNARC effect observed for numbers is also observed for months when targets appear on the right, and is suggested for targets on the left, in a task where participants are forced to process the cues in an order-relevant manner. There were no significant effects for the other SOAs (p's > 0.10).

6. General discussion

The purpose of the present study was to determine whether nonpredictive central cues conveying ordinal information would influence the manner in which attention is allocated during a target detection task. Recently, Fischer et al. (2003) extended the earlier work of Dehaene et al. (1993) demonstrating that the presentation of an irrelevant number at fixation influences 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. Given that Gevers et al. (2003, 2004) have also extended the work of Dehaene et al. (1993) and demonstrated that SNARC-like effects can be obtained with other ordinal sequences (e.g., days, letters, months), this led to the present question of whether numerical sequences and non-numerical ordered sequences share similar processing mechanisms, and whether letters/days/months would lead to attentional SNARC effects in the Fischer et al. paradigm. In Experiment 1, the presentation of a day/letter/month/number at fixation was incidental to the target detection task. As would be expected based on previous research, an attentional SNARC effect was observed for numbers, however, an attentional SNARC effect was not observed for any of the other ordinal sequences. This result is inconsistent with Gevers et al.'s results regarding days/letters/months. It is worth noting, however, that in the Gevers et al. tasks, left–right ordinal information was made salient via task instruction (e.g., press one key if the month presented precedes July, press another key if the month presented follows July). In our Experiment 1, participants were told that the information presented at fixation was irrelevant and uninformative to the primary target detection task, meaning that the ordinal sequence itself was not directly tied to the task. That being said, it was clear during debriefing that all subjects were aware of the fact that the items being presented were the extreme ends of an ordinal sequence.

In Experiment 2, we had participants make an order-relevant decision regarding the cue after the target detection response and found evidence for an attentional SNARC effect for all four cue types, consistent with Gevers et al. Thus, an attentional SNARC effect for all of the aforementioned ordinal sequences is elicited when participants are required to process the cue in an order-relevant manner. But when the cue is entirely incidental to the target detection task, as in Experiment 1, an attentional SNARC effect is only observed for number stimuli. The results of these experiments suggest that there are processing mechanisms that are specific to numbers, and do not automatically generalize to other ordinal sequences. Thus the present study suggests a clear and important distinction between the influence of ordinal non-numerical sequence stimuli on the activation of response codes (standard SNARC effect) and the perceptual processing efficiency of visual information vis-a-vis the allocation of spatial attention (attentional SNARC). That is, ordinal non-numerical information appears to influence performance by biasing the response system independent of any effects on attentional perceptual processing efficiency.

A critical and conceptually converse question to the above is why number representation interacts with both response codes and the allocation of spatial attention, whereas other non-numerical ordinal representations do not? One possibility is that numbers convey ordinal information in a more salient manner than the other sequence types. Numbers are frequently used to organize lists, categories, and sequences, as well as to represent days and months (for example, "January" is often thought of as the first month of the year and as such, the word "January" often evokes the concept of "1", but this relationship is not necessarily bi-directional: the number "1" does not immediately evoke the thought of "January"). Given that numbers are associated with so many of these ordinal sequences, it may just be that the spatial representation of numbers is overlearned, in a similar manner to other stimuli like arrows, and this is what causes the attentional SNARC effect (see also Galfano, Rusconi, & Umiltà, 2006; Ristic, Wright, & Kingstone, 2006). This possibility would seem to be enhanced by our finding of attentional SNARC effects for other ordinal stimuli when participants are required to process items in an order-relevant manner. Thus, it could be that number/space associations are overlearned to the point that the presentation of a number automatically activates a spatial representation. A similar activation can occur for letters/days/months, but not when the presentation of these items is incidental to the task. Another possibility is that there is an overlap in the manner that the brain organizes space and number perception that does not exist for other ordinal sequences. Recently, Hubbard, Piazza, Pinel, and Dehaene (2005) have argued that numerical-spatial interactions are attributable to shared parietal pathways between visuospatial attention and the internal representations of numbers. Although a recent study has shown that areas of the parietal cortex responsible for the cognitive representation of numerical quantity are equally sensitive to numbers and letters (Fias, Lammertyn, Caessens, & Orban, 2007), the present study suggests that the overlap in parietal circuits between visuospatial attention and non-numerical ordinal sequences might not be functionally similar. That is, an absence of functional similarity between these shared pathways predicts that numbers but not ordinal stimuli such as letters, days, and months, should produce an attentional SNARC effect. This is precisely what our present data show.[3] It is worth noting that in Experiment 2 we observed an attentional SNARC effect when participants were required to actively process stimuli in an order-relevant manner, which could lead to the suggestion that active processing is the critical predictor of parietal involvement. We are unable to determine, however, whether this activation is critical to involuntary attentional orienting.

It is perhaps worth noting that the present results have considerable practical application to Gibson and Kingstone's (2006) distinction between projective and deictic cues. Recently, these researchers have suggested that because numerous stimulus cues influence reflexive orienting, it may be useful to classify stimulus cues in terms of their deictic and projective relations (see also Logan, 1994, 1995). Deictic cues are thought to be easier to process because their meaning is simple to determine independent of any reference frame, whereas the processing of projective cues is more dependent on the reference frame and/or context with which the cue is presented. It is possible, therefore, that numerical cues are more deictic in nature, given the overlearned spatial relationship between numbers and space, making them effective visuospatial cues under a variety of circumstances, whereas non-numerical ordinal sequences may be more projective in nature, meaning the effectiveness of the cue would strongly influenced by the context in which that cue was presented.

In sum, the present study has drawn an important functional distinction between SNARC and attention-SNARC effects. The former is sensitive to numerical and non-numeral ordinal stimulus information whereas the latter is specific to numerical ordinal stimuli. This dovetails with the current conceptualization that the SNARC and attention-SNARC effects are driven by qualitatively different representations. The former reflects response code activation and the latter reflects changes in visual processing effects due to the allocation of spatial attention. In addition the present study has suggested that the distinction between numerical and non-numerical ordinal information may represent a fundamental difference between how this information is represented within the underlying neural architecture. Specifically, it appears that only number are preferentially processed by the visuospatial parietal network. Finally, the results of the present study suggest an important line for future investigation regarding whether numerical and non-numerical stimuli can be captured by a new taxonomy that is based on linguistic categories of spatial relations whereby spatial cues are categorized as either deictic or projective.

[3] It is worth noting that Ristic et al.'s account for the attentional SNARC effect and Hubbard et al.'s (2005) neurobiological account of the SNARC effect need not be mutually exclusive. Rather, there may be an interaction between learning/experience and neural structures that has developed for numbers over time and which may develop for other ordinal sequences on the basis of extensive experience. Given that Gevers et al. (2003) have observed a SNARC effect for months and letters (arguing that the spatial component of ordinal sequences is automatically activated even when ordinal information is not relevant to a task), however, we would have expected to observe an attentional SNARC effect to be observed for non-numerical ordinal sequences had such an interaction existed.

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