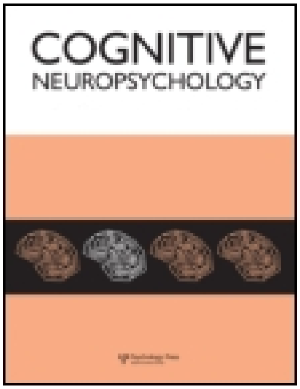

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The middle range of the number line orients attention to the left side of visual space

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Mental representation of numbers is believed to be spatial in nature, with small numbers occupying the left and large numbers the right side of a putative mental number line. Consistent with this, presentation of numbers from the low and high ends of the mental number line induces covert shifts of spatial attention to the left and right side of visual space, respectively. However, the effect of the presentation of the middle range (containing numbers below and above the midpoint) of the number line on visual perception has so far not been studied. Here we show in two experiments, using a line bisection task and a simple target detection task, that processing of middle-range numbers affects allocation of visuospatial attention in a similar way as processing of small numbers, with attention shifted to the left side of space. We suggest that this pattern of results arises due to "anchoring" heuristics that participants use in number processing.

Keywords: Line bisection; Target detection; Spatial priming; Mental number line; Number processing; Visual attention.

When perceiving numbers, we tend to mentally organize their magnitude along a left-to-right oriented horizontal mental number line, with the smaller numbers occupying leftward and larger numbers occupying rightward positions (see Dehaene, Bossini, & Giraux, 1993). The correspondence between the ordinal sequence of numbers and their mental representation is believed to extend to a more general representation of space, with small numbers being internally associated with the left side of the space and the large numbers with the right side of the space (Dehaene, 1992; Dehaene et al., 1993). The presence of such overlap between the mental representations of numerical and visual space is suggested by studies demonstrating similar biases in the

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Zaira Cattaneo and Juha Silvanto both contributed equally.

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perception of spatial distances and numerical intervals (see also Walsh, 2003). For instance, patients with left neglect resulting from a lesion to the right hemisphere show a similar rightward bias both when required to bisect a visual line and when required to indicate the midpoint of a numerical interval (Zorzi, Priftis, & Umiltà, 2002). Similarly, neurologically normal individuals have been shown to be slightly leftward biased in bisecting both physical lines (see Jewell & McCourt, 2000, for a review) and numerical intervals (Longo & Lourenco, 2007). There is also evidence that in normal observers spatial and number processing share common neural substrates (Cohen-Kadosh et al., 2007; Göbel, Calabria, Farnè, & Rossetti, 2006; Göbel, Walsh, & Rushworth, 2001).

The overlap between the mental representations of numbers and visual space also seems to account for a direct influence of the former on the latter. Specifically, numbers have been found to directly modulate the allocation of attentional resources to particular portions of both the egocentric and allocentric space; reaction times to smaller numbers (relative to larger numbers) are faster when responses are made with a left button-press, and the opposite pattern is found when responses are made with a right button-press (cf. the spatial−numerical association of response codes, SNARC, e.g., Dehaene et al., 1993). Similarly, participants are faster in detecting targets presented in the left hemifield if previously presented with a small-magnitude number, and, conversely, reaction times to right-hemifield targets are decreased by previous processing of a high-magnitude number (Fischer, Castel, Dodd, & Pratt, 2003; Fischer, Warlop, Hill, & Fias, 2004). In a modified version of the line bisection task requiring to bisect a series of strings consisting of the repetition of the same numerical digit, a leftward spatial bias was observed with smaller digits and a rightward spatial bias with greater digits (Fischer, 2001; see also de Hevia, Girelli, & Vallar, 2006). Furthermore, when estimating the length of space determined by two digits, individuals generally tend to overestimate distances, but they do less with small-magnitude than with large-magnitude numbers (De Hevia, Girelli, Bricolo, & Vallar, 2007). Bonato and colleagues (Bonato, Priftis, Marenzi, & Zorzi, 2008) recently found that right brain-damaged patients with left neglect were influenced by the magnitude of digit numbers used as flankers in a classic line bisection task. In particular, the bisection error was shifted contralesionally when the digit "1" was presented at each end of the to-be-bisected line, whereas it was shifted ipsilesionally when the digit "9" was used (but no effect was observed when the digits 1 and 9 were both used, one at each end of the line). Taken together, these findings demonstrate the interdependency between representations of numerical magnitude and visual space.

Previous studies investigating the influence of the mental number line on visuospatial judgements have essentially compared the effects of small- versus large-magnitude numbers. To our knowledge, the effect of spatial priming by the "middle" range of numbers (that is, numbers at and around the centre of the number line) on visual perception has not been studied so far. This was the objective of the present experiments. In Experiment 1, using a line bisection task, we investigated whether processing numbers belonging to the middle range of the numerical number line (that extends from 0 to 100) influences spatial allocation of attention in a different fashion than processing either small or large numbers. Our results revealed that processing of middle numbers biased attention to the left side of space, similarly to small numbers. In Experiment 2, we replicated this leftward bias induced by processing of middle numbers using a simple detection task (cf. Fischer et al., 2003).

EXPERIMENT 1

Method

Participants

A total of 18 participants (9 males, mean age of 27.89 years) took part in the experiment.

Line bisection task

The stimuli were presented on a 24-inch (1,240 × 1,024 pixels) monitor. Viewing distance was 57 cm. The stimuli for the bisection task were adapted from the study by Bjoertomt, Cowey, and Walsh (2002). The stimuli were black, horizontal, transected or bisected lines on a white background. The lines used in the tests were of five different lengths, with a mean length of 38° of visual angle within the range 36–40° (from a viewing distance of 57 cm), and the exposure duration was 200 ms. A short, black vertical line (2.2° long) transected the horizontal lines. All lines were 0.1° thick. The horizontal line was always presented such that the transection mark was at the sagittal midline of the participant, and the horizontal line was at eye level. When the line was asymmetrical about the transection, the elongated line segment was 1° longer than the shorter line segment. A mask was presented after the target offset. This mask, consisting of a thick horizontal line (thicker than the horizontal line of the stimulus) and a vertical line (with the same width as the transection mark) covered the entire area of the previously displayed stimulus and extended to the edges of the projected screen. The mask was displayed until the participant responded.

The participants were informed that each side of the target line was elongated in 50% of the trials, and they were therefore unaware of the presentation of an exactly bisected line in 25% of the trials. One block consisted of 120 trials. Each stimulus—one of eight types of line (two bisected, three left-elongated, and three right-elongated; see Bjoertomt et al., 2002, for further details)—was presented an equal number of times (i.e., 15 times per block). As in the study by Bjoertomt et al. (2002), two lengths were used for the bisected lines: 36° and 40°. The lengths used for the transected lines were 37°, 38°, and 39°.

Number processing in the line bisection task

Target line was preceded by exposure to number digits (see Figure 1). Three ranges of numbers were used: from 16 to 24 (small prime condition); from 46 to 54 (mid prime); and from 76 to 84

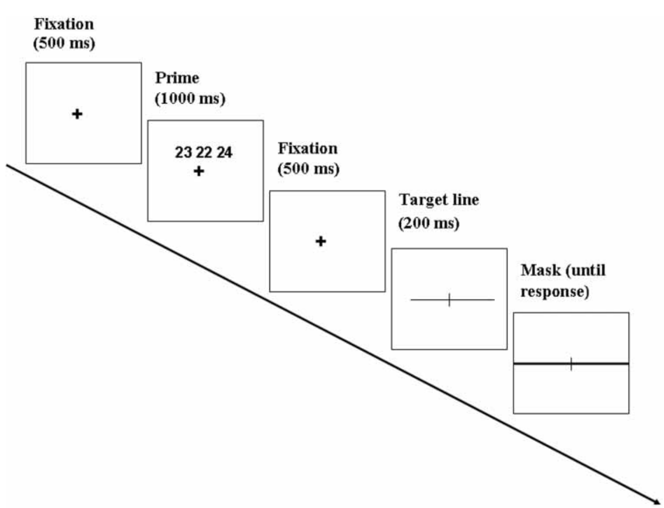

Figure 1. *The timeline of an experimental trial. Each trial began with a fixation cross appearing at the centre of the screen (500 ms), at which the participants were asked to fixate throughout the trial. The prime was then presented for 1,000 ms (with the fixation cross also present), followed by another 500 ms of fixation. This was followed by the target stimulus, the bisected/transected line. A mask appeared 200 ms after the onset of the target stimulus. This mask, consisting of a thick horizontal line (thicker than the horizontal line of the stimulus) and a vertical line (with the same width as the transection mark) covered the entire area of the previously displayed stimulus and extended to the edges of the projected screen. The mask was displayed until the participant responded.*

(large prime). These three priming conditions were tested in separate blocks of trials. On each trial, three numbers (height and width 0.5° per digit, respectively) appeared from the given range 3° above or below the fixation. Three numbers rather than 1 were used in order to focus participants' attention on "portions" of the mental number line (and—correspondingly—on segments of the physical lines that were presented). The numbers used in each triplet were all consecutive but they appeared in all different possible combinations in order to account for leftward versus rightward bias. Specifically, the triplets used in the small prime condition were [16–17–18], [19–20–21], [22–23–24] (all possible combinations, e.g., 16 17 18; 16 18 17; 17 16 18; 17 18 16; 18 16 17; 18 17 16), in the mid prime condition were [46–47–48], [49–50–51], [52–53–54], and in the large prime condition were [76–77–78], [79–80–81], [82–83–84]. A baseline condition was run in which asterisks were presented as primes. These asterisks appeared at the same spatial location as the number primes, and the quantity of items was identical to that in the number prime conditions (i.e., 6 digits).

Procedure
At the beginning of the testing session, approximately 100 practice trials were presented to familiarize participants with the bisection task. Half of the participants were asked to report which side of the line was shorter, and the other half was asked to report which side was longer. Participants responded by pressing one of two buttons with the right index and middle finger for "left" and "right" responses. All participants responded with their right hand. Participants were asked to maintain fixation at the centre of the screen throughout each trial. Before the main experiment participants were instructed that numbers ranging from 0 to 100 would appear on the screen on each trial. They were asked to pay attention to these numbers while maintaining fixation. The order of blocks was randomized. Accuracy was emphasized but participants were also encouraged to respond quickly.

Results

A total of 4 participants were not able to perform the task above chance level and were thus excluded. To obtain a relative measure of participants' behaviour, their responses in each number (small, large, mid) condition were normalized relative to their performance in the baseline (asterisk prime) condition. For analysis purpose, "long-side" responses were converted into "short-side" responses.

Bisected trials
On the bisected trials, any tendency to perceive one side as being shorter reflects a perceptual bias rather than any physical difference in the stimulus. In the baseline (asterisk) condition, participants did not consistently perceive either side as being shorter (mean percentage of trials on which the left and right sides were perceived as shorter were 51.36 and 48.64, respectively; $p = .72$). Figure 2 shows the normalized proportion of trials (as a function of the number

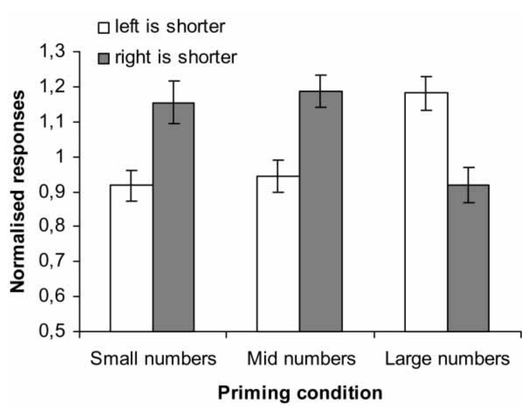

Figure 2. *The mean of participants' (n = 14) responses of trials in which the left and right sides of the line were of equal length (i.e., bisected trials). Participants' responses were normalized relative to their performance in the baseline condition. The white and grey bars indicate participants' tendency to perceive the left and the right side of the line, respectively, as shorter. In the mid and small prime conditions (relative to the large prime condition), participants were less likely to perceive the left side as shorter and more likely to perceive the right side as longer. Error bars depict standard error of the means.*

prime condition) on which the left side of the line was perceived as shorter and on which the right side of the line was perceived as shorter.

As the objective of this experiment was to determine whether priming by the mid numbers (i.e., numbers ranging from 46 to 54) influences spatial allocation in a different fashion than priming by either the small (16–24) or the large numbers (76–84), a 3×2 factorial analysis of variance (ANOVA), with priming condition (small numbers, mid numbers, large numbers) and response type (left side shorter or right side shorter) as main factors was carried out to compare whether the tendency to report one side as being shorter in the mid prime condition is more similar to that observed in the small or the large prime condition. The ANOVA indicated a significant interaction, $F(2, 26) = 6.52$, $MSE = 0.588$, $p = .005$.

This is confirmed by the statistical analysis. A 3×2 factorial analysis of variance (ANOVA), with priming condition (small numbers, mid numbers, large numbers) and trial type (left side shorter or right side shorter) as main factors indicated a significant interaction, $F(2, 26) = 6.52$, $MSE = 0.588$, $p = .005$. The main effect of either priming condition, $F(2, 26) = 0.582$, $MSE = 0.006$, $p = .566$, or trial type, $F(1, 13) = 0.206$, $MSE = 0.112$, $p = .657$, was not significant. Pairwise comparisons (two-tailed t tests) showed that the effect of priming by mid numbers on the visual bisection task is akin to priming by small numbers. The proportion of trials on which the right side was perceived as shorter was significantly higher in the mid prime condition than in the large prime condition, $t(13) = 3.574$, $p = .003$. In contrast, there was no significant difference between the mid and small prime conditions, $t(13) = 0.268$, $p = .793$. Furthermore, the proportion of trials on which the left side was perceived as shorter was significantly lower in the mid prime condition than in the large prime condition, $t(13) = 4.813$, $p = .0003$. Once again, there was no significant difference between the mid and small prime conditions, $t(13) = 0.387$, $p = .705$. These comparisons demonstrate that priming by mid numbers produced a pattern of bias that was akin to priming by small numbers and statistically different from the bias observed in the large prime condition.

As expected on the basis of previous results (Fischer et al., 2003), the proportion of trials on which the left side was perceived as shorter was significantly lower in the small prime condition than in the large prime condition, $t(13) = 2.448$, $p = .003$, and the proportion of trials on which the right side was perceived as shorter was significantly higher in the small prime condition than in the large prime condition, $t(13) = 2.590$, $p = .022$. These results suggest that in the small prime condition (relative to the large prime condition) more attentional resources were allocated to the left side of space, and thus the right side of the line was perceived as shorter than the primed (left) side; the opposite occurred in the right prime condition. Our findings are consistent with previous research demonstrating that number processing orients spatial attention depending on number magnitude, with small numbers enhancing target detection in the left hemifield and large numbers enhancing detection in the right hemifield (Fischer et al., 2003).

No difference was reported between participants that were asked to respond which side of the line was shorter and which side was longer.

Accuracy on trials with transected lines

On the transected trials, one side of the line was 1 degree of visual angle longer than the other side. Figure 3 shows the normalized detection accuracy (as a function of the number prime condition, normalized relative to the baseline condition) for these trials. Visual inspection of Figure 3 indicates that the detection accuracy in the mid prime was intermediate relative to the small and large prime conditions.

This is confirmed by the statistical analysis. A 3×2 factorial ANOVA, with priming condition (small numbers, mid numbers, large numbers) and trial type (left side shorter or right side shorter) as main factors indicated a significant interaction, $F(2, 26) = 3.49$, $MSE = 0.103$, $p = .045$. There was not a significant main effect of either priming condition, $F(2, 26) = 0.65$, $MSE = 0.011$, $p > .05$,

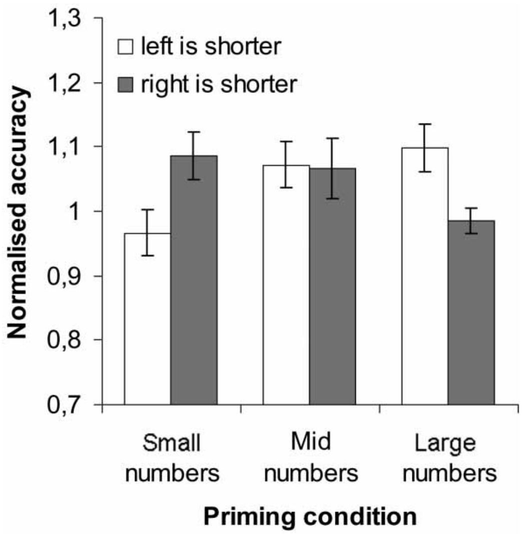

Figure 3. *The mean of participants' (*n *= 14) detection accuracy (in %) on trials on which the left and right sides of the line were of different lengths (i.e., transected trials). Participants' responses were normalized relative to their performance in the baseline condition. The white and grey bars indicate participants' accuracy on trials on which the left and the right side of the line, respectively, was shorter. In the small prime condition (relative to the large prime condition), participants were less accurate to perceive the left side as shorter and more accurate to perceive the right side as longer. The performance in the mid prime condition was intermediate between the two. Error bars depict standard error of the means.*

or trial type, $F(1, 13) = 0.33$, $MSE = 0.061$, $p > .05$. Planned (two-tailed) t tests found no statistical difference in the detection accuracy of "right side shorter" trials between the mid and small prime conditions, $t(13) = 0.788$, $p = .444$, or between mid and large conditions, $t(13) = 1.682$, $p = .116$. Similarly, there was no statistical difference in the detection accuracy of "left side shorter" trials between mid prime and large prime conditions, $t(13) = 0.244$, $p = .811$, or between the mid prime and small prime conditions, $t(13) = 1.833$, $p = .09$.

These comparisons indicate that, in contrast to the bisected trials, on the transected trials priming by mid numbers did not produce a pattern of detection accuracy akin to that observed in the small prime condition and statistically different from that found in the large prime condition. Rather, participants' detection accuracy appears to be intermediate between the small and large prime conditions. As expected on the basis of previous results (Fischer et al., 2003), detection accuracy on "left side shorter" trials was significantly higher in the large prime condition than in the small prime condition, $t(13) = 2.253$, $p = .04$. As can be seen in Figure 3, on "right side shorter" trials, there was a trend towards higher detection accuracy in the small prime condition than in the large prime condition, which did not reach statistical significance, $t(13) = 1.768$, $p = .100$.

No difference was reported between participants that were asked to respond which side of the line was shorter and which side was longer.

EXPERIMENT 2

Experiment 2 had two objectives. The first objective was to investigate more in detail the spatial priming effect induced by the middle-range numbers (46 to 54) used in Experiment 1. Specifically, we investigated whether processing numbers between 51 and 54 induces a similar shift in attention to processing numbers between 46 and 49. This was achieved by presenting participants on each trial with a single number from the "mid" range (rather than with triplets of numbers as was done in Experiment 1). A second objective was to determine whether the attentional effect induced by "mid" numbers in Experiment 1 is also found in a target detection task requiring to respond to a target appearing either on the left or the right side of fixation (cf. Fischer et al., 2003).

Method

Participants

A total of 11 participants (4 males, mean age of 24.6 years) with normal or corrected-to-normal vision took part in the experiment.

Detection task

The detection task was adapted from the experiment by Fischer et al. (2003). The stimuli were presented on a 15-inch (800 × 600 pixels) monitor. Viewing distance was 57 cm. Each trial began with a black fixation point appearing in the middle of the screen for 500 ms on a white background, followed by the number prime (size 0.8 deg of visual angle) that was presented for 300 ms. This was followed by another fixation cross (400 ms) after which a target cross (size 0.8 degrees of visual angle) appeared either on the left or on the right side of fixation at eccentricity of 6 degrees of visual angle. The target stimuli appeared within black boxes (diameter of 1 deg of visual angle) that were present to the left and right of fixation throughout each trial. Participants were asked to report with button presses whether the target appeared to the left or the right side of fixation. Participants responded by pressing one of two buttons with the right index and middle finger for "left" and "right" responses. All participants responded with their right hand. The stimulus remained on the screen until the participant responded. The number primes were taken from the "small", "large", and "mid" range numbers that were used in Experiment 1 (i.e., 16 to 24; 76 to 84; 46 to 54). On each trial, a single number was used as a prime. In addition, a baseline condition was run in which instead of the number participants were presented with two asterisks. Figure 4 shows the timeline of each trial.

The "small", "mid", and "large" number conditions were run in separate blocks. In each block, each of the eight primes in a given range was used eight times preceding a leftward target and eight times preceding a rightward target. In addition, 16 control trials were run in each block (8 for leftward and 8 for rightward targets) in which two asterisks were presented as the prime; this "asterisk" condition was the baseline condition in this experiment. One block consisted of 160 trials. The order of trials in each block was randomized. We ran three blocks for each priming condition. Thus the experiment consisted of a total of nine blocks. The order of the blocks was randomly determined by the computer software.

Procedure

At the beginning of the testing session, approximately 40 practice trials were presented to familiarize participants with the detection task.

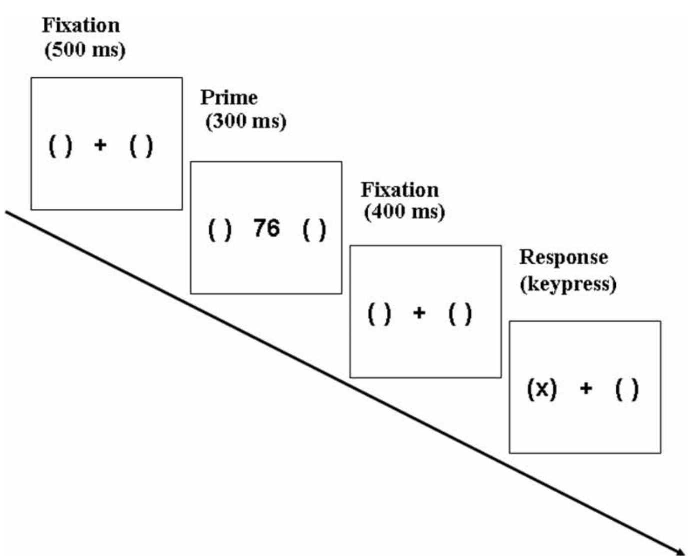

Figure 4. *The timeline of an experimental trial in Experiment 2. Each trial began with a fixation cross appearing at the centre of the screen (500 ms), at which the participants were asked to fixate throughout the trial. The prime was then presented for 300 ms, followed by another 400 ms of fixation, after which the target appeared. Participants were asked to indicate whether the target appeared to the left or right of fixation.*

Before the main experiment participants were instructed that numbers ranging from 0 to 100 would appear on the screen on each trial. Participants were encouraged to respond as quickly as possible. Participants were instructed to pay attention to the numbers but were also informed that numbers were irrelevant to the target detection task.

Results

To obtain a relative measure of participants' reaction times (RTs) in the number prime conditions, their RT in each condition was subtracted from their baseline (asterisk) RT in that condition. The obtained value thus represents any additional benefit or cost induced by the number primes over the baseline RT. Importantly, this procedure also ruled out the role of any possible stimulus–response compatibility effect in determining the pattern of results, given that any advantage of responding with left finger to left stimuli and with right finger to right stimuli (cf. Umiltà & Nicoletti, 1990) was cancelled out by subtracting the RTs obtained in the baseline asterisks' condition.

Figure 5 shows participants' RTs for left- and right-hemifield targets as a function of the priming condition. This figure shows that primes both below and above 50 induced a benefit for targets appearing in the left hemifield relative to targets appearing in the right hemifield. This is confirmed by statistical analyses. For mid numbers, participants' RT benefit was significantly larger for left hemifield than for right hemifield targets, $t(10) = 4.470$, $p = .001$. This was also found for numbers between 46 and 49, $t(10) = 2.582$, $p = .027$, and numbers between 51 and 54, $t(10) = 3.268$, $p = .008$. This pattern of results demonstrates that the "mid" range of numbers on the 0–100 mental number line biases attention to the left side of visual space.

For the large prime condition, as expected on the basis of previous studies (e.g., Fischer et al., 2003), there was a significant RT benefit for right-hemifield targets relative to left-hemifield targets, $t(10) = 2.598$, $p = .027$, indicating that

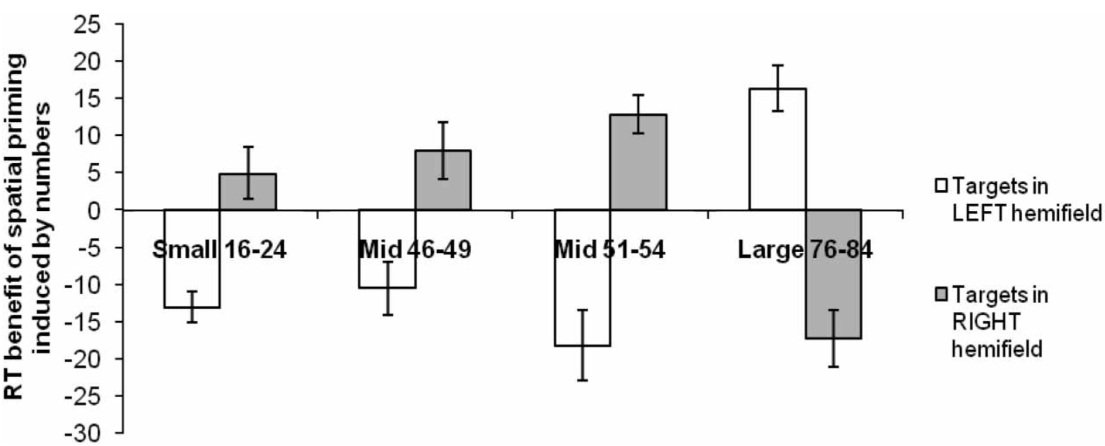

Figure 5. *The mean reaction time benefit (or cost) induced by number processing in Experiment 2 (error bars depict standard error of the means). Participants' mean reaction time (RT) in the control (asterisk prime) condition was subtracted from their RT in each of the number prime conditions. The obtained value represents any additional cost or benefit induced by the number prime, with negative values indicating a benefit and positive values indicating a cost. In the small prime condition, the priming induced a statistically significant benefit for targets appearing in the left hemifield relative to targets appearing in the right hemifield, indicating that attention was allocated to the left side of space. The opposite pattern was observed for the large prime condition, indicating that attention was allocated to the right side of space. For the mid number prime condition, the pattern of results was the same as that observed for the small prime, with a benefit for targets appearing in the left hemifield. This was found for primes in the range of 46–49 as well as in the range of 51–54.*

attention was biased to the right side of space. Conversely, for the small prime condition, as expected, there was a benefit for left-hemifield targets relative to right-hemifield targets, although this effect did not quite reach statistical significance, $t(10) = 2.598$, $p = .076$.

DISCUSSION

Our results show that, after priming to the middle range of numbers, attention is shifted to the left side of space. This was confirmed in two different experiments. In Experiment 1, the perceived asymmetry in the length of the left and right sides of a bisected line was similar to the asymmetry observed after priming to small numbers. Specifically, the proportion of trials on which the right side of the bisected line was perceived as shorter was significantly higher than that in the large prime condition, and, conversely, the proportion of trials on which the left side of the line was perceived as shorter was significantly lower. A similar leftward bias was also observed in Experiment 2 using a simple target detection paradigm (cf. Fischer et al., 2003): Processing of middle-range numbers caused faster detection of targets appearing in the left than in the right hemifield.

As was discussed above, processing of small or large numbers has been shown to have opposing effects on visual target detection, with processing of small numbers enhancing target detection in the left hemifield, and processing of large number enhancing detection in the right hemifield (Fischer et al., 2003). These findings were explained in terms of allocation of spatial attention, with the to-be-processed number shifting attention to the hemifield corresponding to its location on the mental number line. The findings of Experiment 1 are consistent with these results. In the small prime condition (relative to the large prime condition) more attentional resources are allocated to the left side of space, and thus the right side of the line is perceived as shorter than the primed (left) side; the opposite occurs in the right prime condition. The results of Experiment 1 thus extend the previous findings on the spatial priming effect induced by small and large numbers to visual line bisection.

A key finding of the present study was that processing of the middle range of the number line induced a bias comparable to that induced by processing of small numbers; with attention allocated to the left side of space. This leftward bias induced by the middle numbers was observe in visual line bisection (Experiment 1) as well as in simple target detection (Experiment 2). According to a linear representation of numerical magnitudes on the mental number line (Gallistel & Gelman, 2000; Gibbon & Church, 1981; Verguts, Fias, & Stevens, 2005), numbers around 50 should occupy the midportion of a mental number line extending from 0 to 100 and should therefore bias attention neither to the left nor to the right. Conversely, according to the so-called "logarithmic compression" hypothesis (Dehaene, 1997, 2003), which assumes that the mental number is compressed toward the right side, numbers around 50 should fall to the right of the real mid of the physical visual line. In this view, mid numbers should actually prime attention to the right portion of space as large numbers. Our finding is inconsistent with both of these hypotheses.

In turn, our results can be explained in terms of "anchoring" effects occurring in number processing. Numerical judgement can be influenced by the prior consideration of a numerical anchor (i.e., referent), an effect observed in many different domains (e.g., Janiszewski & Uy, 2008; Oppenheimer, LeBoeuf, & Brewer, 2008). In our experiments, the participants were explicitly instructed that they would be presented with numbers between 0 and 100. It is thus possible that the values 0 and 100 were used as "anchors" to mentally place the different primes on the mental number line. The left end of the number line (i.e., 0) is more likely to be used as the "anchor" for small numbers, and the right end (i.e., 100) is more likely to be used as the "anchor" for high numbers; this is because the small numbers are numerically closer to 0 and the high numbers to 100. Which side is used as the anchor for the number 50, which is an equal distance away from 0 and 100? As we normally count forward (i.e., from left to right on the mental number line) and read from left to right (at least in western cultures), individuals may be more likely to use the left end as the anchor for the middle numbers. It is thus possible that in our tasks the left end of the number line (i.e., 0) was used as a reference for the middle numbers, inducing a corresponding shift of attention to the left. Thus, our findings suggest that it is not the "semantic" meaning of numbers that affects visual perception but, rather, the spatial position assigned to the particular values on the mental number line (e.g., Stoianov, Kramer, Umiltà, & Zorzi, 2008).

There is some support for this explanation. In a task requiring participants to estimate the position occupied by a given number on a physical line or the number corresponding to a marked location on a visual line, Ebersbach and colleagues (Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008) found that variability of responses increased as numbers got more distant from the lower anchor, but that variability again decreased as numbers approached the upper anchor. Cross-modal anchoring effects have also been reported. Oppenheimer and colleagues (Oppenheimer et al., 2008) found that physical anchors (e.g., lines of different lengths) might function cross-modally to bias numerical judgements by priming the notion of their general magnitudes (e.g., "large" vs. "small"). These findings support the view that in our task numbers were likely to be processed according to a referent/anchor that corresponds to the beginning or the end of the mental number line and that this anchoring might have influenced the allocation of visuo-spatial attentional resources.

Interestingly, priming by the middle numbers did not modulate participants' performance on the transected lines (i.e., when the left and right sides of the line were of different lengths) of Experiment 1. Participants' detection accuracy in the mid prime condition appeared to be an intermediate between the small and large prime conditions. This suggests that the sensitivity of the visual task modulates the impact of number processing on visual perception. In the transected lines a real physical difference exists in the length of the two sides of the line, and the effect of priming has to overcome this difference (which participants accurately detected on approximately 70% of the trials) in order to be manifested in participants' responses. This is not the case with the bisected lines, in which it is arguably easier for the prime to modulate participants' responses as there is no real physical difference in the stimuli. Therefore, these data suggest that priming to the middle range of the number line acts like priming to the small numbers only when the visual task is sufficiently sensitive or susceptible for modulation.

There are some novel aspects in our bisection paradigm that are worth discussing. First, a real visual line was used as stimulus. Previous studies have primarily used lines made up by numbers themselves or by words corresponding to the numbers (e.g., De Hevia et al., 2007; De Hevia et al., 2006; Fischer, 2001) whereas only a few studies have used a real visual line (see, for instance, Bonato et al., 2008). Secondly, in our paradigm number primes preceded the line bisection task (i.e., they were used as primes), whereas in previous studies they were presented concurrently with the bisection task (e.g., Bonato et al., 2008; De Hevia et al., 2006). The fact that the prime disappeared before presenting the visual line is important for the attention-orienting account and suggests that the mental number line could affect processing before response (e.g., Fischer et al., 2003). It is important to consider that the mapping between numbers and space can conceivably arise at any stage of processing, from early automatic associations between numbers and space at the encoding level, to late, response-selection-related accounts. Although some recent studies have argued for a late, response selection account of the SNARC (Gevers, Ratinckx, De Baene, & Fias, 2006; Keus, Jenks, & Schwarz, 2005), this is not universally agreed upon (Loftus, Nicholls, Mattingley, & Bradshaw, 2008; Nicholls, Loftus, & Gevers, 2008). In this regard, our findings are consistent with early processing accounts of the SNARC effect.

Finally, the fact that participants were informed that numbers were irrelevant to the main task (line bisection or target detection) but were also asked to pay attention to the numbers while maintaining fixation is likely to be of critical importance. In fact, Bonato and colleagues (Bonato, Priftis, Marenzi, & Zorzi, 2009) found that the degree to which the number is task relevant modulates the strength of the SNARC effect, and Casarotti and colleagues (Casarotti, Michielin, Zorzi, & Umiltà, 2007) demonstrated that numbers modulated the allocation of spatial attention only when participants were explicitly instructed to attend to them (Casarotti et al., 2007; see also Galfano, Rusconi, & Umiltà, 2006).

In conclusion, our findings are consistent with an accumulating body of evidence on the overlap between the mental representations of numbers and visual space (Dehaene et al., 1993; Walsh, 2003; Zorzi et al., 2002). Taken together, these studies suggest that not only are numbers and visual space represented using the same principles, but that the underlying representation itself seems to be shared between the two seemingly distinct cognitive functions. Therefore the link between numbers and space is likely to be an active, culturally acquired mapping between these distinct dimensions (cf. Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005).

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