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# Elementary school children's attentional biases in physical and numerical space

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Numbers are conceptualized spatially along a horizontal mental line. This view is supported by mounting evidence from healthy adults and patients with unilateral spatial neglect. Little is known about children's representation of numbers with respect to space. This study investigated elementary school children's directional biases in physical and numerical space to better understand the relation between space and number. We also examined the nature of spatial organization in numerical space. In two separate tasks, children ($n = 57$) were asked to bisect a physical line and verbally estimate the midpoint of number pairs. In general, results indicated leftward biases in both tasks, but the degree of deviation did not correlate between the tasks. In the number bisection task, leftward bias (underestimating the midpoint) increased as a function of numerical magnitude and interval between number pairs. In contrast, a rightward deviation was found for smaller number pairs. These findings suggest that different underlying spatial attentional mechanisms might

be directed in physical and numerical space in young school children, which would be integrated in adulthood.

***Keywords:*** Mental number line; Physical line bisection; Directional asymmetry; Space and number.

A left-to-right directional asymmetry is common across several cognitive domains, particularly in cultures that read and write from left to right. This left-to-right axis forms a basis for systems that represent time, number, and even the conception of events (Chatterjee, 2011). In this framework of directional asymmetries, the representation of numbers is notable. There are no a priori reasons to think that numbers or symbolic representations of quantity should be represented along a horizontal axis. Yet, the evidence for a *mental number line,* with smaller numbers placed on the left and larger numbers on the right, is robust (Dehaene, Bossini, & Giraux, 1993). In left-to-right reading cultures, adults are faster to respond to smaller numbers with the left hand and larger numbers with the right hand, supporting the left-to-right spatial representation of numbers (so-called spatial-numerical representation of response codes—the SNARC effect; Dehaene et al., 1993; Fias, 2001; Fisher, Castel, Dodd, & Pratt, 2003).

Even though research with adults demonstrates the left-to-right directional asymmetry of numbers (e.g., Dehaene et al., 1993; Gobel, Calabria, Farne, & Rossetti, 2006; Longo & Lourenco, 2007), less is known about children's representation of numbers with respect to space (e.g., de Hevia & Spelke, 2009; Opfer, Thompson, & Furlong, 2010). The goal of this study was to examine young school children's directional biases in both physical and numerical space. A secondary goal was to characterize the nature of spatial organization in numerical space.

In the following sections, we will first review literature on adults' attentional biases in physical and numerical space. We will then discuss the research on how children represent physical and numerical space and describe the current study.

## Adults' spatial attention in physical and numerical space

Spatial asymmetries are a significant part of human nature. We read and write from left-to-right or right-to-left. Most people are either right- or left-handed. Our brains and some of our internal organs are also influenced by left—right asymmetries (Chatterjee, 2011). The directional asymmetries are not only apparent in our constructed environment and in our body, but also operate in our internal representations of space and number. In left-to-right

reading cultures, adults' representations of space and number have spatial biases. Two common tasks, paper line bisection and number line bisection, are used to identify these biases in both clinical and healthy populations.

Paper line bisection was initially used to diagnose hemispatial (visuospatial) neglect in patients with unilateral brain lesions. Patients who suffer from left hemispatial neglect show a rightward bias when asked to bisect a physical line (e.g., Marshall & Halligan, 1989; Schenkenberg, Bradford, & Ajax, 1980). Similar to the responses in physical line bisection, patients with right parietal lesions accompanied by persistent left neglect show a rightward bias in the mental number line task when asked to find the midpoint between two numbers. That is, these patients overestimate the midpoint in a given number pair (Rosetti et al., 2004; Zorzi, Priftis, & Umilta, 2002; see also Vuilleumier, Ortigue, & Brugger, 2004). A recent case study from a patient with right neglect indicated parallel results, suggesting that the same spatial attention system deployed across physical lines might also be deployed across mental number lines (Pia, Corazzini, Folegatti, Gindri, & Cauda, 2009; but see Ashkenazi & Henik, 2010; Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Tian et al., 2011).

In contrast to patients with unilateral right brain lesions, healthy young adults display a minor leftward bias in line bisection tasks. This systematic leftward bias has been called *pseudoneglect* (Bowers & Heilman, 1980; Jewell & McCourt, 2000). An analogous *pseudoneglect* is also found in mental number bisection. Healthy adults demonstrate a leftward bias when they estimate the midpoint of number pairs (Gobel et al., 2006; Loftus, Nicholls, Mattingley, Chapman, & Bradshaw, 2009; Longo & Lourenco, 2007; Lourenco & Longo, 2009).

In a recent study, Longo and Lourenco (2007) compared healthy adults' spatial attentional biases in both bisection tasks. Individuals with a stronger leftward bias in paper line bisection also demonstrated larger leftward bias in number line bisection. The authors proposed that similar hemispheric asymmetries in spatial attention occur in both physical and numerical space. Additionally, after transcranial magnetic stimulation (TMS) of the right posterior parietal cortex, healthy adults err toward the right in both the paper line and mental number bisection tasks (Fierro, Brighina, Piazza, Oliveri, & Bisiach, 2001; Gobel et al., 2006). These findings are consistent with the hypothesis that both tasks share common attentional mechanism presumably mediated by parietal activation in the brain. Together, studies from clinical and healthy populations suggest that the same attentional mechanisms operate on physical lines extended in external space as well as number lines extended in mental space.

An intriguing finding from Longo and Lourenco (2007) was that in number bisection the leftward bias (underestimation of midnumber) in healthy adults increased as a function of the magnitude of the numbers

bisected (e.g., Longo & Lourenco, 2007). The mental number line also seems scaled in a logarithmic fashion—as the numbers to be bisected get larger the mental representation of numbers is compressed (Dehaene, 2001; Dehaene & Mehler, 1992). Thus, according to compressive scaling the subjective distance between 10 and 20 is larger than the distance between 90 and 100. Another view suggests that numbers lie on a linear scale where the subjective distance between two numbers remains constant regardless of the absolute magnitude of these numbers (Gallistel & Gelman, 1992, 2000).[1] In a recent study, Lourenco and Longo (2009) showed that, based on the numerical context, the same bisection task may elicit logarithmic or linear representation of numbers (see also Calabria & Rosetti, 2005; Fischer, 2001).

As already pointed out, healthy adults display directional asymmetries in both physical and numerical space. Leftward bias in both spaces supports the position that adults consider numbers along a spatial mental number line. Additionally, the compressive scaling of numbers results in differences in the directional biases; a greater leftward bias is observed with an increase in numerical magnitude (but see Calabria & Rosetti, 2005; Fischer, 2001; Lourenco & Longo, 2009). However, less is known about children's spatial directional asymmetries that are seen in adults in physical and numerical space (de Hevia & Spelke, 2009, 2010; Lourenco & Longo, 2010; Opfer et al., 2010). These systems could develop in concert, or they could have distinct developmental trajectories that converge later in adulthood.

## Children's spatial attention in physical and numerical space

Studies with children have mostly focused on the attentional biases in physical space (Smith & Chatterjee, 2008). In a detailed assessment of paper line bisection performances of 650 children aged 7–12 years, van Vugt, Fransen, Creten, and Paquier (2000) found that directional biases on the horizontal axes change as a function of gender, age, and handedness. Girls erred toward the right and boys toward the left. Left-handed and younger children exhibit more leftward attentional biases than right-handed and older children (van Vugt et al., 2000). Even before 8 years of age, children bisected the lines toward the left when using the left hand and toward the right when using the right hand (Bradshaw, Spataro, Harris, Nettleton, &

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[1]Although the distance does not vary in linear scaling, linear models that use scalar variability would also predict an increase in error rate as a function of numerical magnitude. However, Longo and Lourenco (2007) argued that only a compressive model predicts increased bias on number bisection tasks. Yet, both of these accounts suggest that the representation of numbers should overlap more with an increase in numerical magnitude that leads to an increase in directional bias. Thus, both compressive and linear accounts might predict similar results on these types of tasks due to scalar variability (see Longo & Lourenco, 2007, for further discussion).

Bradshaw, 1988). In a more recent study, the same patterns were found with 10- to 12-year-olds. After age 13, children's attentional biases resemble young adults' responses, showing leftward bias when they used either hand (Hausmann, Waldie, & Corballis, 2003). The difference in the directional biases between young adults and children is attributed to the maturation of the corpus callosum, as callosal connectivity might be crucial for the integration of motor and perceptual processes (Hausmann et al., 2003). However, the overall leftward bias in adults might be related to more activation in the right hemisphere (particularly in the right posterior parietal lobe) during this spatial task (Fierro et al., 2001).

Developmental studies on children's representation of numbers have suggested that children map numbers onto space (Berch, Foley, Hill, & Ryan, 1999; de Hevia & Spelke, 2009; Opfer & Furlong, 2011; Opfer et al., 2010; van Galen & Reitsma, 2008). Some argue that number-space mapping develops after children begin schooling and learn to count (Berch et al., 1999; van Galen & Reitsma, 2008). However, preschool children raised in Western cultures spontaneously map numbers onto space in visuospatial task (de Hevia & Spelke, 2009) and they use left-to-right numeric information in spatial search (Opfer & Furlong, 2011; Opfer et al., 2010). Moreover, de Hevia and Spelke (2010) provided evidence that infants as young as 8 months old are sensitive to the relation between numerical magnitude and spatial length. Additionally, a recent study showed that 9-month-old infants represent a general magnitude system for space, number, and time (Lourenco & Longo, 2010). Thus, these studies demonstrate that space and number associations (the SNARC effect) develop early in life even before children learn language, receive formal education, or learn to count.

Prior research has mainly examined children's representation of numbers with respect to space using a "number-to-position" task, in which children are asked to position a number on a physical line (e.g., Barth & Paladino, 2011; Booth & Siegler, 2006, 2008; Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Moeller, Pixner, Kaufmann, & Nuerk, 2009; Opfer & Siegler, 2007; Siegler & Booth, 2004; Siegler & Opfer, 2003). The main goal of these number-line tasks is to test the estimation of numerical magnitudes. Overall, results suggest a gradual shift from logarithmic (compressive) to linear representation of numbers with age (but see Ebersbach et al., 2008). In contrast to this dominant view, Barth and Paladino (2011) provided a proportion judgement account for testing the number-line estimation tasks. This model argues that to position "40" on a line with endpoints of "0" and "100," children need to estimate the size of a part (the numerical magnitude of 40) relative to the size of the whole (the numerical magnitude of 100).

In log-to-linear shift model, Siegler and Opfer (2003) found an interaction between the representation of numbers (logarithmic vs. linear) and the size of the interval between two numbers. For example, when smaller intervals

(0–100) were marked at the ends of a line, second-graders' estimations were consistent with a linear scaling. With the larger intervals (0–1000) children at the same age had a logarithmic scaling (e.g., 30 was placed toward the middle of the line). Thus, the shift from linear to logarithmic scaling might be related to children's familiarity and exposure to numbers in different number ranges. Further studies indicate that the accuracy of estimations is positively correlated with math knowledge (Booth & Siegler, 2006) and children's familiarity with numbers (Ebersbach et al., 2008).

In sum, research on the representation of numbers in childhood provides strong evidence of the mapping of space and number as well as a left-to-right directional bias of the mental number line. Nevertheless, in these developmental studies, numbers are always placed on a physical line or presented spatially. Thus, the estimation of a number on a physical line would elicit an explicit left-to-right directional representation as representations of space and number are conflated in this task. In particular, the argument for a spatial representation of numbers would be stronger if numbers were presented without a spatial context and if similar directional biases occurred on separate physical and numerical bisection tasks as found in adults (Longo & Lourenco, 2007).

## The present study

In this study, we investigated elementary school children's directional asymmetries in physical and numerical space. Our goals were twofold. First, we asked whether similar left-to-right directional biases occur in both physical and numerical space. To better understand children's representations of space, number and their interactions, following Longo and Lourenco (2007), children were exposed to two separate tasks: paper line and mental number line bisection. Then, we compared the attentional biases in these tasks. Second, we aimed to characterize the nature of spatial organization in numerical space. Different from the previous studies, to decrease the explicit mapping of space and number in the mental number line task, children were verbally asked to estimate the midpoint of number pairs without seeing the numbers.

First, we predicted that if common spatial mechanisms similar to those evidenced in adults were available at this age, children would exhibit similar directional biases in both tasks (e.g., Longo & Lourenco, 2007). In particular, children who showed a larger leftward bias in physical line bisection would also present a larger leftward bias in the mental number line. Second, if spatial-numeric associations were evident even when children were presented with the mental number line verbally and if children at this age have compressive scaling, a consistent directional bias (i.e., leftward bias) would be found in the number line bisection task. Last, we hypothesized that the

directional biases might be contingent on the magnitude of numbers and the interval size between number pairs, in which with larger numbers and larger interval sizes, children would demonstrate larger leftward bias.

## METHOD

### Participants

The participants were 57 children, of two age groups: 7- to 9-year-olds ($n = 29$, 14 females, $M = 8.66$, $SD = 0.89$, range 7.15 to 9.92) and 10- to 12-year-olds ($n = 28$, 15 females, $M = 11.53$, $SD = 0.79$, range 10.14 to 12.89). These age groups were chosen to represent the complete developmental trajectory during the elementary school period. The grouping of the children was based on the previous research on the line bisection task (e.g., Hausmann et al., 2003). The sample was recruited from paediatricians' offices in Philadelphia and the surrounding area. Most children were African American (51%) and White (36%), with the rest (13%) of Asian American and Hispanic ethnicity.

### Stimuli and procedure

The participants were presented with two tasks: paper line bisection and mental number line bisection. In the paper line bisection task, children bisected 20 lines of 200 mm in length, presented in the centre of a horizontally oriented letter size sheet of paper. Children were instructed to draw a vertical line at the midpoint of the line. To be consistent with previous studies (Haussmann et al., 2003; van Vugt et al., 2000), in half of the trials children used their right hands and in the other half they used their left hands, regardless of their dominant hand. The hand use was blocked rather than randomly varied across trials. Deviation from the midpoint was measured to the nearest half millimetre. Negative values represent leftward biases, and positive values rightward biases.

In mental number line bisection, the stimuli and procedure follow those of Zorzi et al. (2002; Zorzi, Priftis, Meneghello, Marenzi, & Umilta, 2006). Children were given 48 different pairs of numbers and bisected them verbally without seeing them on paper. The numerical interval between the number pairs was 3, 5, 7 or 9 inclusive (12 trials each). The order of intervals was randomized. The numbers ranged from 1 to 32, and the smaller number was always presented first. For each interval the number pairs were sampled randomly across 1 and 32. For example, for interval 5, the number pair could be either 11–15 or 23–27. Before starting the task, two sample trials were given with the two most extreme intervals. In each trial, the experimenter verbally asked the child, "What number is halfway between (first number) and (second number)?" Children were instructed to perform

the task as quickly as possible without calculating. Two dependent variables were obtained from this task: the accuracy of the estimations and the bias in the errors. The mean accuracy was computed for children's responses to all trials. Bisection errors were calculated by subtracting the arithmetical midpoint (correct answer) from the child's subjective midpoint (child's answer). Negative errors indicated that the child's answer was smaller than the arithmetical midpoint (leftward bias), and positive errors showed that the answer was larger than the arithmetical midpoint (rightward bias).

Each child was tested individually in a quiet room for a single 30-minute session. Number bisection was always done first so as not to create a spatial bias. The presentation of the line bisection task first would increase the spatial bias on the subsequent number bisection task. At the end of the session, each child received a gift card for participation.

## RESULTS

Four outliers were excluded from the analyses, because their overall mean deviations from the midpoint in one or both tasks were 2.5 standard deviations or more above/below the mean (for the paper line: $M = -2.48$ mm, $SD = 3.55$ and for the mental number line: $M = -0.63$, $SD = 2.04$). The final sample consisted of 53 children.

### Paper line bisection

A univariate analysis of variance (ANOVA) with Age Group (7–9, 10–12), Gender, Hand Use (left hand first vs. right hand first) as the between-subject variables and the mean deviation from the midpoint as the dependent variable revealed no main effects of Age Group, Gender, or any interactions among them, $ps > .05$. As shown in Figure 1, almost all children (45/53) showed a leftward bias ($M = -2.91$ mm, $SD = 2.97$; $p < .0001$, binomial test, two-tailed), $t(52) = -7.11$, $p < .0001$. Furthermore, deviation did not differ based on the order of hand use (left hand first vs. right hand first) or children's handedness, $ps > .05$.

### Mental number line bisection

The 10- to 12-year-olds were more accurate than the 7- to 9-year-olds in the mental number line task, $F(1, 51) = 20.98$, $p < .0001$, $\eta^2 = .29$ ($M_{7-9 \text{ years}} = 46\%$ and $M_{10-12 \text{ years}} = 72\%$). A univariate ANOVA with Age Group (7–9, 10–12) and Gender as the between-subject variables and the mean deviation from the midpoint as the dependent variable did not show any main effects or interactions between these variables, $ps > .05$. Children in both age groups mostly (39/53) had a leftward bias in finding the midpoint of number pairs,

(a)



(b)
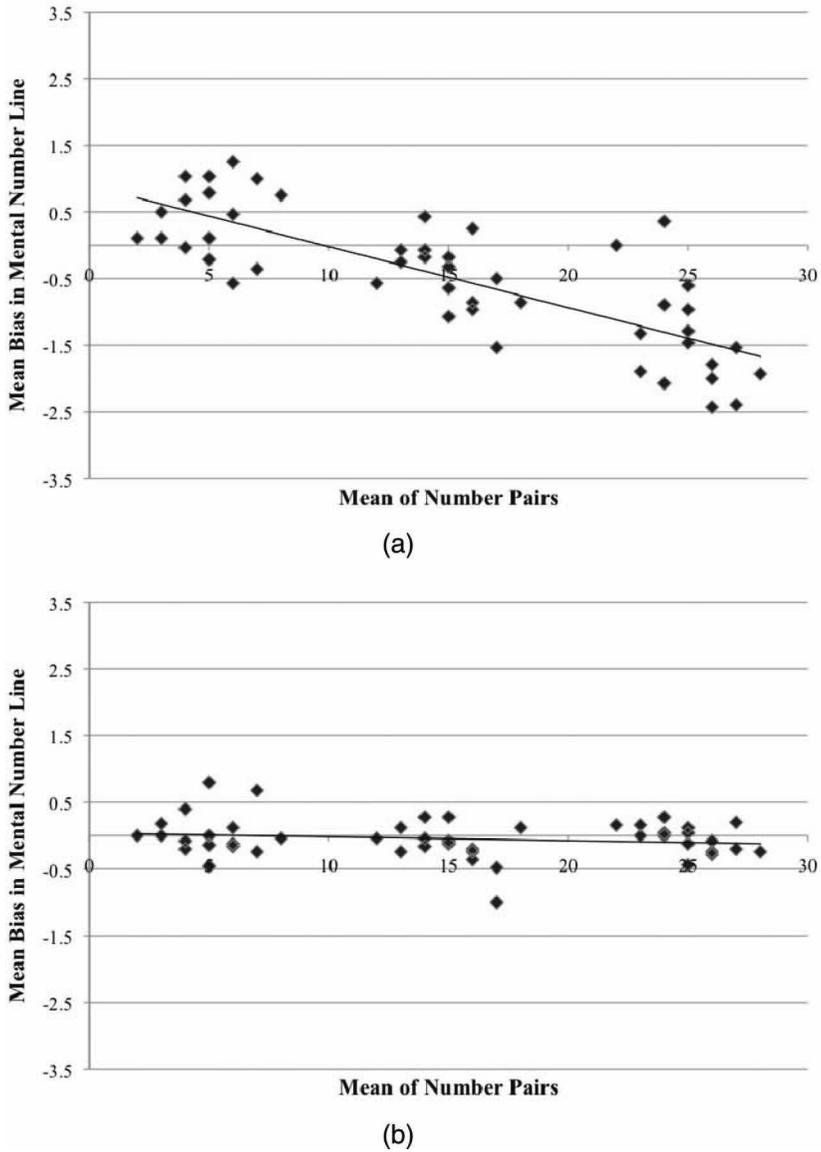
**Figure 1.** (A) Mean deviation from the midpoint in the mental number line bisection task as a function of the magnitude of number for younger children (7- to 9-year-olds). The leftward bias increased with the magnitude of number. (B) Mean deviation from the midpoint in the mental number line bisection task as a function of the magnitude of number for older children (10- to 12-year-olds). No significant relationship was found between numerical magnitude and leftward bias.

meaning that they underestimated the midpoint ($p < .001$, binomial test, two-tailed). The average reported midpoint ($M = -0.36$, $SD = 1.37$) was deviated toward the left, though this did not reach statistical significance, $p = .06$.

Second, we analysed the effect of the numerical magnitude (i.e., whether the bisected numbers were small or large) by correlating the mean bias for each number with the mean of the number pairs. For example, the average of the number pair 22 to 30 (i.e., 26) was correlated with the mean directional bias for that number pair (i.e., $-1.04$). A negative correlation was found between children's bias and the mean of the number pairs, $r(48) = -1.768$, $p < .0001$, showing that underestimation bias increased as the number pairs got larger (see Figure 1). As we hypothesized differences between age groups based on the magnitude of numbers, we correlated the directional bias and the numerical magnitude for each age group. Results showed that the correlation between the mean bias for each number and the mean of the number pairs was significant only for the younger group, $r(48) = -1.793$, $p < .0001$ and $r(48) = -1.164$, $p > .05$.

Last, we examined the effect of interval between number pairs (3, 5, 7, and 9) on the children's biases. No main effect of interval or an interval by age group interaction was found. In a subsequent analysis, we divided the number pairs into smaller and larger number pairs. The number pairs between 1 and 16 were assigned to the smaller number pairs category and larger number pairs category consisted of the number pairs between 17 and 32. Results indicated an interaction between interval size and the numerical magnitude, $F(1, 47) = 3.87$, $p < .02$, $\eta^2 = .23$. Except for the lowest interval size, children displayed leftward biases for the higher number pairs in each interval. For example, children showed a rightward attentional bias when asked to bisect 1 and 7 (interval of 7), but the same interval led to a leftward bias when asked to bisect 21 and 27 (Figure 2). Results on the numerical magnitude and the interval size suggest that a greater leftward directional bias occurs with larger numbers and larger intervals.

## The relationship between physical line bisection and mental number line bisection

Children's attentional biases were shifted toward the left in both tasks. Twenty-eight children (out of 53) presented leftward biases in both tasks. Given that 39 children had a leftward bias in number bisection, most children who showed a leftward bias in this task also presented a leftward bias in line bisection (72%). The correlation between the two tasks was not significant, $r = -1.261$, $p > .05$. Moreover, the correlation between the directional bias in line bisection and in each numerical interval was not significant, $rs < -1.24$ and $ps > .09$.

Following Longo and Lourenco (2007), we divided participants into low and high pseudoneglect groups by a median split based on their
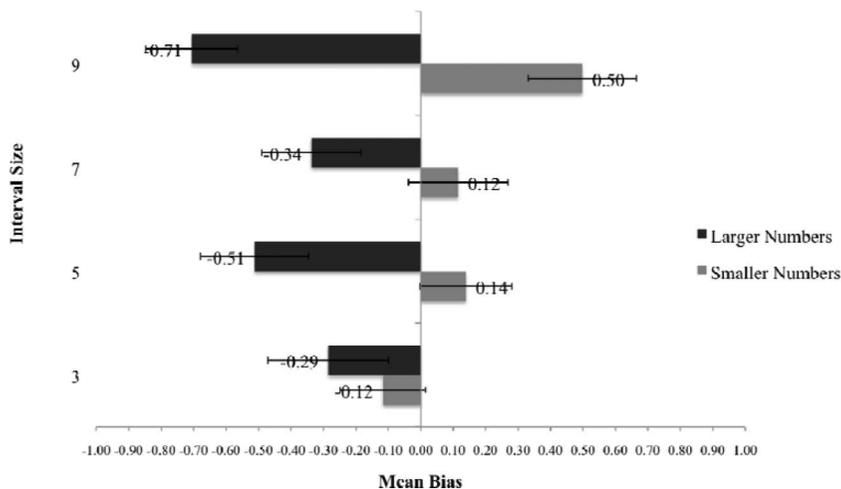
**Figure 2.** Mean deviation from the midpoint in the mental number bisection task as a function of interval and numerical magnitude. The error bars represent the standard deviation from the mean.

performance on paper line bisection. Both low ($M_{low} = -1.66$ mm) and high ($M_{high} = -5.68$ mm) groups were significantly deviated towards left in the paper line bisection task, $ts > 9.715$, $ps < .001$. There was no difference between low and high pseudoneglect groups in terms of mental number line bisection, $p > .05$. Thus, the degree of leftward deviation in paper line bisection did not influence the bias in number bisection.

## DISCUSSION

The purpose of this study was to assess elementary school children's directional biases in physical and numerical space. The physical line and the mental number line bisection tasks were used to investigate whether space and number develop with similar spatial attention underpinnings. First, we found that leftward biases (underestimation of midpoint) in numerical space increased with numerical magnitude. When children bisected larger numbers and larger intervals, they shifted further to the left. In contrast, smaller numbers with larger intervals resulted in a rightward deviation. Although both age groups presented leftward deviation for larger numbers, the correlation between the directional bias and the numerical magnitude was significant only for the younger children. Despite having similar directional asymmetries in both tasks, in general, the extent of leftward bias in these tasks was not correlated and the degree of leftward deviation in paper line bisection did not influence the bias in number bisection.

Consistent with the previous studies with children and adults, elementary school children demonstrate a leftward bias in bisecting physical space (Haussmann et al., 2003; Longo & Lourenco, 2007). In our study, handedness or the hand used during line bisection did not influence the direction of children's attentional biases. One reason for this inconsistency with other studies (Haussmann et al., 2003; van Vugt et al., 2000) could be the specific procedures of the task itself. Previous studies typically used different line lengths to evaluate spatial attentional biases in children and adults. Instead, we used the same line length in all trials. Jewell and McCourt (2000) suggested that leftward biases might increase with the length of the physical line. Thus, using the same length in all trials would lead to a consistent leftward bias across age groups, handedness, and hand use.

One of the main contributions of the current study is testing of mental number bisection in elementary school children. The results of the directional biases from the number bisection task are mixed. Overall, most children demonstrate an underestimation on the mental number line, like adults (Loftus et al., 2009; Longo & Lourenco, 2007; but see Zorzi et al., 2002). However, the direction of the bias is determined by the interaction between the interval size and the numerical magnitude. With larger numbers and larger intervals, children in both age groups display leftward biases. In contrast, children had rightward biases with smaller numbers and with intervals larger than five. Longo and Lourenco (2007) argued that increased leftward bias with numerical magnitude of number pairs reflects logarithmic scaling processes. In the current study with a verbal mental number line task, regardless of age, the compression of numbers is based on the bisected number pairs rather than a general directional asymmetry.

Two factors might have influenced the results on number bisection and could account for differences between this study and previous research. First, our number bisection task was verbally presented as opposed to being shown visually on a line. This difference could have modulated the spatial attentional bias on the mental number line. However, the same directional bias was found in both line bisection and number line bisection (although the extent was different), even though the numerical line bisection task was performed verbally. Siegler and Booth (2004) suggested that there is a logarithmic representation of the mental number line only with numbers that are larger than 100 for second graders. In the current study, all of the numbers were below 100, which could be another factor leading to inconsistency in the direction of bias.[2] Even though we followed the intervals

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[2]One reviewer suggested that because only larger numbers are underestimated (a leftward bias), there might not be spatialization of numbers involved. This might be a possibility since we used a *verbal* mental number line task. A comparison of verbally and visually presented mental number lines might address number and space mapping in this task.

and stimuli used by Zorzi et al. (2002), future research should use bigger number pairs and bigger intervals with a verbal presentation to examine whether children have the shift to linear representation around the same age as in the previous research (see Barth & Paladino, 2011, for an alternative account). Second, older children could have a calculation strategy when they estimate the midpoint of number pairs. In addition, using a similar task, Zorzi et al. (2002) did not find a logarithmic representation of mental number line with healthy adults—perhaps the task was easier for adults and led to fewer errors. Thus, small intervals and small number pairs can encourage adults and older children to calculate rather than estimate.

Even though most children who show a leftward bias in number bisection also present a leftward bias in the physical bisection (28 out of 39 children who showed a leftward bias in number bisection), the *degree of deviation* in each task differs. Further analyses show that the degree of leftward deviation in paper line bisection does not influence the bias in number bisection.[3] That is, there was no difference between children who showed a larger or smaller leftward bias in line bisection on their directional biases in number bisection. This could be a result of differences between the two tasks. In physical line bisection, children bisected the same line length in all trials; they bisected four different intervals in the number bisection task. However, the lack of correlation between line bisection and bisection of numbers at any interval range suggests that the directional bias in line bisection is not predictive of degree of errors at any of the number ranges tested.

Some recent studies also provide evidence for dissociation between physical line bisection and number bisection tasks (Ashkenazi & Henik, 2010; Doricchi et al., 2005; Tian et al., 2011). For example, in schizophrenia, individuals have leftward bias in only one task, suggesting a clear dissociation between physical and numerical space (Tian et al., 2011). These findings suggest that directional biases in numerical and physical spaces might share different visuospatial operations and brain networks (Doricchi et al., 2005). In particular, physical line bisection is related to the structures of the striate cortex, the extrastriate visual cortex, and the parietal lobe whereas number bisection is related to the right parietal lobe and prefrontal cortex (Doricchi et al., 2005; Gobel et al., 2006; Pia et al., 2009). Because we obtain similar leftward biases in each task (at least for larger numbers in the number bisection), our study cannot speak to separate neural networks underlying the processing of each task in childhood. Future studies are required to examine whether there is a double dissociation in spatial attention to physical and numerical space in

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[3]Although it is hard to compare numerical units (for number bisection) with mm (for physical bisection), we followed the analyses conducted by previous studies with adults (Ashkenazi & Henik, 2010; Longo & Lourenco, 2007; Tian et al., 2011).

early childhood. In addition, children with parietal lobe injuries would be a candidate group to investigate the existence of parallel mechanisms underlying spatial attention in physical and numerical space.

In summary, this study suggests that elementary school children have left-to-right directional biases in both line bisection and number bisection tasks. For the number bisection, the directional bias is contingent on the magnitude of numbers and the interval size between number pairs. The bias is stronger in physical space. The *degree of deviation* in each task is different and no correlation is found between the two tasks. This is suggestive of differing spatial attentional mechanisms underlying physical and numerical space in childhood that might integrate in adulthood.

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