Evidence for a Spatial–Numerical Association in Kindergartners Using a Number Line Task

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In Western cultures, small numbers are often associated with the left space and large numbers are often associated with the right space. We investigated whether this association is already present in kindergartners and second graders. Children (N = 59) estimated the position of numbers on a number line that was labeled either with a small number on the left side and a large number on the right side (i.e., left-to-right orientation) or vice versa (i.e., right-to-left orientation). The estimations were less accurate if the number line was oriented from right to left and if the children started with this condition. The results suggest that already kindergartners possess a culture-typical spatial–numerical association that develops before the acquisition of reading and writing skills and significantly affects the accuracy of numerical estimations. The performance of second graders, too, was affected by the orientation of the number line, but to a smaller degree than that of kindergartners.

The mapping of number to space is a fundamental and often spontaneously occurring ability in many contexts, ranging from numerical estimations over measurement to mathematics and science (de Hevia & Spelke, 2009; de Hevia, Vallar, & Girelli, 2008). It is assumed that numerical magnitudes are mentally represented in an ascending order along a mental number line (Dehaene, 1992; Restle, 1970). However, in contrast to the actual numbers, the mental representation appears to be distorted with smaller numbers being overrepresented and larger numbers underrepresented. Accordingly, estimations and the discrimination of smaller numbers are often more accurate compared with larger numbers, which becomes evident in particular in children and numerically less experienced adults (Dehaene, Izard, Spelke, & Pica, 2008; De Smedt, Verschaffel, & Ghesquière, 2009).

Furthermore, it has been assumed that smaller numbers are associated with “left” and larger numbers with “right” in space at least in Western cultures, as illustrated for instance by the SNARC (i.e., the spatial–numerical association of response codes) effect (Dehaene, Bossini, & Giraux, 1993; see also Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005, for reviews). This spatial–numerical association is not only reflected in faster responses with the left hand to smaller numbers and with the right hand to larger numbers, but also by the fact that the mere, task-irrelevant perception of smaller numbers directs visual attention to the left (Fischer, Castel, Dodd, & Pratt, 2003). In addition, numbers affect the performance in line bisection tasks. Adults, who were asked to indicate the midpoint of different lines that were flanked...
by task-irrelevant symbolic numbers, moved the midpoint toward the larger number (de Hevia, Girelli, & Vallar, 2006; Fischer, 2001). A similar effect was revealed in 5- and 7-year-olds, when the lines were flanked by nonsymbolic arrays of dots—but not if they were flanked by symbolic numbers (de Hevia & Spelke, 2009). These results imply that symbolic and nonsymbolic magnitudes are automatically processed and significantly influence the performance in spatial tasks.

The association of small numbers with “left” and large numbers with “right” has originally been ascribed to culture-specific experiences associated with formal schooling, such as reading, writing, and measurement, as they follow usually a left-to-right direction in Western cultures (Shaki & Fischer, 2008). This assumption is supported by findings of a reversed SNARC effect in Arabic cultures where people read from right to left (Dehaene et al., 1993) and by no SNARC effect in illiterate adults (Zebian, 2005). Moreover, the SNARC effect emerges initially in children in the course of primary school (Berch, Foley, Hill, & Ryan, 1999; Van Galen & Reitsma, 2008) and was absent in 6-year-olds (White, Szucs, & Soltész, 2012). Correspondingly, a meta-analysis revealed that the SNARC effect could hardly be found in children younger than 9.5 years of age (Wood, Willmens, Nuerk, & Fischer, 2008), whereas Van Galen and Reitsma (2008) reported a SNARC effect even for 7-year-old children at the end of first grade.

To sum up, demonstrating the SNARC effect only in school children supports, at a first glance, the view that cultural practices like reading and writing might provide the basis for this effect. Moreover, studies with bilinguals have shown that the current reading direction—and therefore the visual scanning direction—and not the usual reading direction in the native language modulates the direction of the SNARC effect (Fischer, Shaki, & Cruise, 2009; Shaki & Fischer, 2008).

However, one might also assume that a spatial–numerical association exists in children before they enter school and that only the usual tasks designed for adults might be inappropriate to uncover the SNARC effect in younger children who still lack a robust understanding of the symbolic number system (de Hevia & Spelke, 2009). As a consequence, they will fail to reliably compare Arabic numerals in magnitude comparison tasks, for instance, that require semantic access to the numerical values of symbolic numerals. Furthermore, they will fail to make parity judgments that additionally require a conceptual understanding of “odd” and “even” (White et al., 2012). Indeed, using simpler tasks, Opfer, Thompson, and Furlong (2010) provided first indications that a spatial–numerical association exists before school and significantly affects performance. Preschoolers in their study expected a left-to-right ordering of numbers in a search task, where they had to match the location of an object that was hidden in one of seven compartments of a sample box with the corresponding location in a matching box. The compartments were labeled either from left to right or vice versa. Children performed better if the compartments in both boxes were labeled in an ascending left-to-right order. In addition, children also counted spontaneously from left to right (see also Opfer & Furlong, 2011; Shaki, Fischer, & Göbel, 2012). Compared with symbolic magnitude comparisons, these tasks required only knowledge of the order of symbolic numerals, but not of their exact numerical value.

The present study strived to extend the evidence for a spatial–numerical association in young children by using a number line estimation task where numerical magnitudes were presented both symbolically and nonsymbolically. Kindergartners were chosen as they lack proficiency with reading and writing and are familiar only with small numbers (e.g., Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Siegler & Booth, 2004). They were compared to second graders, who are literate and familiar with numbers up to 100. The task was to estimate the
position of numbers on a number line ranging from 1 to 100. It was flanked either by the small number on the left end and the large number on the right end, or vice versa. The number line paradigm is a powerful paradigm utilized to not only investigate children’s numerical estimation skills, but also to tap the shape of their mental representation of numbers (e.g., Siegler & Opfer, 2003). Moreover, it is well suited to examine anchoring effects in a task that is similar to many everyday situations: Humans often make estimations of parts in relation to a whole, which occurs in number line estimations too, where the larger anchor corresponds to the whole and the presented number to the part or position to be estimated (Barth & Paladino, 2011). The accuracy of the estimations in both conditions (i.e., left-to-right orientation vs. right-to-left orientation of the number line), varied as a within-subjects factor, was analyzed. In addition, children’s counting skills were examined to check whether they were related to the accuracy of the estimations.

It was expected that if a spatial–numerical association in terms of “left–small” and “right–large” exists, it should interfere with the right-to-left oriented number line yielding less accurate estimations in the incongruent right-to-left condition than in the congruent left-to-right condition. Furthermore, children with more advanced counting skills were expected to have developed a more robust and flexible representation of numbers and thus should be more proficient than children with poorer counting skills in the incongruent right-to-left condition, in particular, yielding more accurate estimations.

**METHOD**

**Participants**

Participants were 30 kindergartners (15 girls, 15 boys; \(M_{\text{age}} = 6;0; SD = 4\) months) and 29 second graders (13 girls, 16 boys; \(M_{\text{age}} = 7;8; SD = 4\) months), who were randomly recruited at their kindergartens and schools and took part voluntarily with informed consent from their parents. The sample mainly consisted of Caucasians from a middle-class socioeconomic background.

**Material**

The children had to estimate the positions of 14 different numbers, evenly distributed between 1 and 100 with a distance between 6 and 8 (i.e., 8, 15, 22, 30, 37, 43, 49, 55, 62, 68, 75, 82, 90, 96), on a number line. A wooden bar (100 cm \(\times\) 5 cm \(\times\) 2 cm) served as number line, presented in front of the child. A movable pointer was attached that served to indicate the estimated positions. The numbers to be estimated were presented on cards (21 cm \(\times\) 14 cm) in the center below the bar. Each card showed the number as a digit and simultaneously as a quantity of red dots (diameter = 4 mm each) that were equally distributed over the card. In addition, two anchor cards, showing the number 1 and 1 dot and the number 100 and 100 dots, respectively, were placed on each end of the bar. Symbolic as well as nonsymbolic magnitudes were presented to ensure that the children grasped the meaning of the numerical values (see Girelli, Lucangeli, & Butterworth, 2000). Previous studies revealed that kindergartners are hardly familiar with symbolic numbers up to 100 (e.g., Ebersbach et al., 2008; Lipton & Spelke, 2005).
Procedure and Design

All children were tested individually in a separate room of their institution on 2 different days within the same week to avoid direct transfer effects and too-long testing sessions. Half of the children started the first session with the small anchor on their left side of the bar (i.e., ‘‘left-to-right’’ orientation), and the other half started with the small anchor on the right side (i.e., ‘‘right-to-left’’ orientation). In the second testing session, the position of the anchors was interchanged. The experiment thus obeyed a 2 (age group: kindergartners vs. second graders) × 2 (orientation: left-to-right vs. right-to-left) × 2 (task order: left-to-right first, right-to-left first) design.

A cover story served to explain the task. A brown bar represented a chocolate cake for a birthday party and the children were to estimate how much cake was needed for certain numbers of guests. Each guest was to get 1 piece of cake and the size of 1 piece was marked on the bar as the small anchor. For 100 guests, 100 pieces of cake would be needed and the pointer had to be moved to the opposite end with the large anchor.

To check whether the children had understood the instruction and the meaning of the anchors, each session started with two test trials with feedback. The children had to indicate how much cake would be needed for 1 guest and how much would be needed for 100 guests. Thereafter, the main test started and no feedback was given. Each of the two sessions of the main test consisted of 28 trials, showing each number twice in pseudorandom order ruling out that the same number was presented successively. The children were told that they would see the number of party guests and should indicate on the bar how much chocolate cake would be needed so that every guest would get one piece. The pointer was replaced after each estimation to end of the bar, where the small number was located.

Assessment of Children’s Counting Skills

Finally, children’s counting skills were assessed (Lipton & Spelke, 2005). They were not just asked to count as far as possible as children can often recite a number list before they truly grasp the meaning of these number words (e.g., Fuson, 1988; Le Corre & Carey, 2007) and before they are able to flexibly provide a successor of a randomly chosen number (Rips, Bloomfield, & Asmuth, 2008). Instead, they were asked to count from a given series of numbers to the next decade change to assess their flexible symbolic number knowledge. The experimenter started to count three numbers (e.g., 16, 17, 18 . . .), and asked the children to count on from there. They were interrupted as soon as they reached the next decade change. The decade changes from 10 to 100 were consecutively tested. If a child failed to complete a decade change, the same series of numbers was repeated, and in case of another failure, the assessment was stopped. The highest decade that was successfully completed by a child was recorded.

RESULTS

Preliminary analyses revealed that the subsamples starting with the left-to-right orientation were comparable to the subsample starting with the right-to-left orientation with regard to gender
distribution (kindergarten, \( \chi^2[1, N = 30] = 0.72, p = 1.00 \); second grade, \( \chi^2[1, N = 29] = 0.58, p = .71 \)), age in months (kindergarten, \( F[1, 28] = 1.09, p = .31 \); second grade, \( F[1, 27] = 0.94, p = .34 \)), and counting skills (kindergarten, \( F[1, 28] = 0.25, p = .62 \); all second graders counted 160 to 100). Kindergartners completed decade ranges on average up to 50 (min = 10, max = 100, \( SD = 39 \)).

To examine the accuracy of the estimations, two measures were calculated: 1) mean deviations of the estimations from the actual values that reflect underestimations and overestimations, respectively; and 2) mean absolute deviations (i.e., averaged absolute values of the deviations) that indicate the general accuracy, irrespectively of the direction of the deviations, and thus prevent the equalizing of underestimations and overestimations.

### Mean Deviations of the Estimations

A general analysis of the mean deviations as dependent variable revealed main effects of orientation, \( F(1, 55) = 6.83, p = .012, \eta^2 = .11 \), and age group, \( F(1, 55) = 31.67, p < .001, \eta^2 = .37 \), as well as interactions between orientation and age group, \( F(1, 55) = 7.54, p = .008, \eta^2 = .12 \), orientation and task order, \( F(1, 55) = 7.88, p = .007, \eta^2 = .13 \), and orientation, age group, and task order, \( F(1, 55) = 9.58, p = .003, \eta^2 = .15 \).

To separate the effects, analyses were conducted separately for each age group. Kindergartners rather overestimated the locations on the number line under both orientations toward the larger anchor. There was an effect of orientation, \( F(1, 28) = 7.86, p = .009, \eta^2 = .22 \), and an interaction between orientation and task order, \( F(1, 28) = 9.54, p = .005, \eta^2 = .25 \). The left-to-right orientation tended to yield more accurate estimations (\( M = 6.52, SD = 13.80 \)) than did the right-to-left orientation (\( M = 13.68, SD = 11.65 \)), \( t(29) = -2.47, p = .06 \) (Bonferroni-corrected). This was in particular the case if the kindergartners started with the right-to-left orientation, \( t(14) = -3.35, p = .015 \), but no such deviation was found when the kindergartners started with the left-to-right orientation, \( p > .76 \). In second graders, who made in general more accurate estimations than did kindergartners that slightly tended to be biased against the smaller anchor, neither the main effects nor the interaction became significant, \( ps > .28 \) (see Figure 1).
Mean Absolute Deviations of the Estimations

The analysis of the mean absolute deviations, reflecting the general accuracy of the estimations, revealed main effects of age group, $F(1, 55)=91.56, p < .001$, and task order, $F(1, 55)=4.12, p = .047$, with neither an effect of orientation nor interactions, $p s > .31$. The general accuracy was higher in older than in younger children. Furthermore, it was higher in children who started with the left-to-right orientation than in children who started with the right-to-left orientation (see Figure 2), which applies to both age groups given the lacking interaction.

Counting Skills and Estimation Performance

A correlational analysis between kindergartners’ counting skills and their estimation accuracy was calculated, separately for each orientation of the number line. Their highest decade changes were significantly negatively correlated with their mean deviations, $r(30) = -.44, p = .014$, and their mean absolute deviations, $r(30) = -.43, p = .018$, respectively, if the number line was oriented from right to left. No such relationships emerged for the accuracy of the estimations in the left-to-right condition ($p > .19$).

Finally, to check whether the results of kindergartners were no artifact of an unsystematic performance, linear regressions were computed for the estimations of each single child to identify “mappers” and “nonmappers” (LeCorre & Carey, 2007). Kindergartners were identified as mappers if the regression model, relating their estimations to the actual values, became significant and thus the slope of the regression line differed significantly from 0. This was true for 26 kindergartners in the left-to-right condition (where 2 children, who had started with the right-to-left condition, had significant negative slopes) and 25 kindergartners in the right-to-left condition. This suggests that most kindergartners were generally able to systematically map the target magnitudes on the number line, independently of the orientation of the number line.
DISCUSSION

We investigated whether children’s estimations in a number line task were affected by the spatial orientation of this line. In accordance with the assumption that the mental representation of numbers exhibits at least in Western cultures a left-to-right orientation—with small numbers associated with the left space and large numbers with the right space—we found that an incongruent right-to-left orientation of the external number line significantly impaired the accuracy of the estimations compared with a congruent left-to-right orientation. This effect became evident in particular in the mean deviations of the estimations of kindergartners, who started with the right-to-left orientation. The poorer performance in the right-to-left condition suggests that an interference occurred between the orientation of the mental representation of numbers and the orientation of the external number line that negatively affected the task performance. Moreover, the performance in the right-to-left condition was impeded in particular in children with poorer counting skills, suggesting that they have not yet developed a stable and flexible mental representation of numbers.

To our knowledge, this is the first study demonstrating that the spatial orientation of the mental number line affects the accuracy of kindergartners’ numerical estimations. It furthermore suggests that the typical association between number and space is not solely a product of formal schooling, including the acquisition of reading and writing skills or the use of rulers (e.g., Chokron & De Agostini, 1995; Fagard & Dahmen, 2003), but that it develops earlier. Early counting routines might serve as a potential foundation for this association. Children typically start to count around the age of 2.5 years (Wynn, 1990, 1992), including finger counting, which is assumed to support the development of a visuospatial representation of number (Butterworth, 1999; Fayol & Seron, 2005). In fact, Western preschoolers exhibit an early left-to-right dominance in mathematical actions as they spontaneously count from left to right and also add and subtract objects to (or from) sets in this manner (Opfer, Thompson, & Furlong, 2010; see also Opfer & Furlong, 2011; Opfer & Thompson, 2006; Tversky, Kugelmass, & Winter, 1991). Moreover, Shaki et al. (2012) have shown in a cross-cultural study that children from the age of 3 years and older exhibit culture-specific counting preferences that correspond to the reading direction in their culture. Thus, the foundation for a spatially oriented representation of magnitudes appears to develop before the acquisition of reading skills and might be supported additionally by culture-specific finger-counting routines (Bender & Beller, 2012). One might thus hypothesize that the effect reported in our study for kindergartners, in particular, might be reversed in children from cultures that show a right-to-left preference—but this still needs to be examined.

At this point, one might ask why other studies failed to detect a spatial–numerical association in young children. Clearly, the method plays an important role as these studies used tasks that required a robust understanding of symbolic numbers and their abstract properties, such as parity (e.g., Berch et al., 1999; Van Galen & Reitsma, 2008; White et al., 2012). In contrast, tasks that provided additional information about the numerical values by involving nonsymbolic magnitudes (e.g., de Hevia & Spelke, 2009; Thompson, Opfer, & Furlong, 2010; the present study) were successful in uncovering a spatial–numerical association in young children. Thus, one might perhaps speak of a nonsymbolic spatial–numerical association (see Ren, Nicholls, Ma, & Chen, 2011) that appears to develop before a symbolic spatial–numerical association. Nevertheless, evidence is accumulating that children are able to map magnitudes with space before
formal instruction and this affects not only the performance in number-related search tasks but also the accuracy of numerical estimations.

However, the general effect of the orientation of the number line on the mean deviations of the estimations became only marginally significant in kindergartners, but was manifest in particular in those kindergartners, who started with the right-to-left orientation, which was assumed to be incongruent with the orientation of the mental number line. Kindergartners who started with the congruent condition (i.e., left-to-right) might have used the correspondence between the orientation of their mental representation of numbers and the number line in the task to calibrate and consolidate their estimations. Thereafter, they might have transferred this calibration to the second session, resulting in similarly accurate estimations in the right-to-left condition. Thus, the compatible condition might have served as a training phase, consolidating not only concrete (i.e., which number belongs to which location?), but also more general properties of the number line (such as the proportional aspect, see Barth & Paladino, 2011). In contrast, kindergartners who started with the incongruent condition must have been confused by the lacking correspondence between their own mental representation and the orientation of the number line. They clearly overestimated the positions in this session, potentially as they tended to transfer at least parts of the properties of their mental representation to the task, such as “small numbers to the left”—even as the linear regressions revealed that they did not completely reverse their estimations in terms of placing smaller numbers generally to the left and larger numbers to the right. However, their estimations became significantly more accurate in the second session, where the orientation of the external number line was in line with their mental representation. This is in line with findings of Thompson and Opfer (2008) showing that transfer might yield negative effects if task requirements are at odds with the mental representation of numbers.

Evidence for the initial calibration in the group that completed the left-to-right orientation first came also from the analyses of the mean absolute deviations. In both age groups, this measure was smaller if the children started with the left-to-right orientation. This effect of task order cannot be assigned to differences between the subsamples in each age group, as they were largely comparable. Thus, first completing a number line estimation task, where larger numbers were counterintuitively located on the left end appeared to impair the general accuracy in terms of mean absolute deviations of kindergartners and second graders. Furthermore, the finding that the mean absolute deviations of the estimations revealed no effect of orientation in neither age group can be assigned to the fact that overestimations and underestimations level each other out in this measure. If the right-to-left orientation yielded rather overestimations and the left-to-right orientation rather underestimations, they would appear similarly accurate if the mean absolute deviations were considered.

The effect sizes also suggest that second graders were less affected by an incongruent number line orientation than were kindergartners, potentially due to their more advanced counting skills that involve a more flexible and robust knowledge of numbers and their corresponding magnitudes. This is in line with the finding that the counting skills of kindergartners were significantly correlated with the accuracy of the estimations, which became evident solely in the right-to-left condition but not in the left-to-right condition. A better knowledge of numbers thus appears to promote more accurate estimations in particular in more complex tasks.

To sum up, we demonstrated a spatial–numerical association already in 6-year-old kindergartners by showing that the spatial orientation of the mental number line interfered with the orientation of the external number line and led to less accurate estimations. This effect was indirectly
found in second graders, too, who made less accurate estimations if they started with the incongruent right-to-left orientation. Further research is required to investigate the origins of this association, potentially by relating finger-counting habits and finger gnosis (e.g., Penner-Wilger et al., 2007) to the performance in the congruent and incongruent number line task. In addition, it remains to be examined whether the described effect emerges to similar degree if pure nonsymbolic or pure symbolic magnitudes are used as anchors on the number line. If the assumption is true that a nonsymbolic spatial–numerical association develops before a symbolic spatial–numerical association, the preliminary nonsymbolic association might be used and strengthened at the transition from kindergarten to elementary school as it might serve as a grounded basis for the acquisition and consolidation of symbolic number knowledge (see Fischer, 2012).

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