



# Children perform better on left than right targets in an ordinal task

Rosa Rugani<sup>a,b,\*</sup>, Yujia Zhang<sup>c</sup>, Nuwar Ahmed<sup>b</sup>, Elizabeth Brannon<sup>b</sup>

<sup>a</sup> Department of General Psychology, University of Padova, Padova, Italy

<sup>b</sup> Department of Psychology, University of Pennsylvania, Philadelphia, PA, United States

<sup>c</sup> Department of Developmental Psychology and Socialization, University of Padova, Padova, Italy

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## ABSTRACT

Francis Galton first reported that humans mentally organize numbers from left to right on a mental number line (1880). This spatial-numerical association was long considered to result from writing and reading habits. More recently though, newborns and animals showed a left-to-right oriented spatial numerical association challenging the primary role assigned to culture in determining the link between number and space. Despite growing evidence supporting the intrinsic association between number and space in different species, its adaptive value is still largely unknown.

Here we tested for an advantage in identification of left versus right target positions in 3- to 6-year-old children. Children watched as a toy was hidden under one of 10 linearly arranged identical cups and were then asked to help a stuffed animal retrieve the toy. On each trial, the toy was hidden in the 2nd, 3rd, or 4th cup, from the left or right. To prevent children from staring at the target cup, they were asked to pick up the stuffed animal from under their chair after witnessing the hiding of the toy and then to help the stuffed animal find the toy. Older children were more accurate than younger children. Children exhibited a serial position effect, with performance higher for more exterior targets. Remarkably, children also showed a left bias: they remembered the left targets better than the right targets. Only the youngest children were dramatically influenced by the location of the experimenter during search. Additional analyses support the hypothesis that children used a left-to-right oriented searching strategy in this spatial/ordinal task.

## 1. Introduction

The ability to represent precise numbers and numerical concepts, such as logarithms, and square roots, is only mastered by a subset of humans who have received mathematical education. However, uniquely human mathematical competence did not emerge de novo in linguistic/symbolic adult humans, but was likely built on cognitive precursors available soon after birth (Dehaene, 2011). Numerical abilities are present prelinguistically in infancy (Izard et al., 2009) and a prelinguistic approximate representation of number can be accessed in adult humans whenever the use of language is prevented (e.g., Cordes et al., 2001). Qualitatively and quantitatively similar performance, observed at different ages (Cantlon & Brannon, 2007), suggests that non-symbolic number sense can be considered a developmental building block for uniquely human mathematical abilities (Dehaene, 2011).

A peculiar characteristic of numbers is their intrinsic association with space. Numbers are represented along a left-right oriented Mental Number Line (MNL), with smaller numbers located on the left and larger

ones on the right (Galton, 1880). When given a parity judgment task that requires indicating whether an Arabic numeral is odd or even, adults are faster in responding to small numbers presented on the left and to large numbers presented on the right demonstrating a spatial-numerical association of response codes, SNARC effect (Casarotti et al., 2007; Dehaene et al., 1993; Mapelli et al., 2003). The spatial layout of small and large numbers does not only affect response times but also action planning. Precision grips to manipulate small objects are initiated faster in response to small numbers while power grips are initiated faster in response to large numbers (Lindemann et al., 2007; Namdar et al., 2014). Hand grip aperture is greater when people grasp blocks that depict larger numbers compared to when they grasp identical sized blocks that depict smaller numbers (Andres et al., 2008). Thus numerical magnitude, even when task-irrelevant, affects the kinematics of motion. Nevertheless, number processing also affects action execution. While performing a dual task, which required simultaneously making a numerical discrimination to decide whether a number was smaller or larger than five and moving a block in peripersonal space, adults

\* Corresponding author at: University of Padova, Department of General Psychology, Via Venezia 8, 35100, Padova, Italy.

E-mail addresses: [rosa.rugani@unipd.it](mailto:rosa.rugani@unipd.it), [rugani@sas.upenn.edu](mailto:rugani@sas.upenn.edu) (R. Rugani).

spontaneously moved the cube leftward while they were processing a small number and rightward when evaluating a large number (Gianelli et al., 2012). In performing an unusual action, like kicking a ball with their index finger toward one of two lateral goals upon detecting a visual stimulus, participants performed more left kicks in responding to small numbers and more right kicks in responding to large ones. Moreover, the kinematics of movement differed: participants were faster to finalize the action when responding to small numbers toward the left and to large numbers toward the right (Rugani et al., 2018). Overall, these studies show that number processing modulates action selection and affects more subtle and automatic temporal and spatial components of movement, providing new insights on the mechanisms that drive the SNARC effect. Therefore, number representation does not seem to be limited to abstract conceptualization, instead it seems to be strongly connected with sensorimotor transformations related to motor control (Lindemann et al., 2007; Rugani et al., 2018).

There is substantial evidence that culture influences the left-to-right orientation of the MNL. While people who read from left to right show strong SNARC effects, Arabic speakers and Palestinians, who read words and numbers from right to left, show an inverted SNARC effect (Shaki et al., 2009; Zebian, 2005). Israelis, who read words from right to left but numbers from left to right do not show any reliable SNARC effect (Shaki et al., 2009). However, a growing number of studies support the idea that the MNL may have strong phylogenetic origins and not be entirely driven by culture (Rugani & de Hevia, 2017). Recent evidence from preschoolers (Hoffmann et al., 2013; Opfer et al., 2010; Patro & Haman, 2012; Shaki et al., 2012; West & McCrink, 2021), infants (Bulf et al., 2016; de Hevia & Spelke, 2010) and newborns (de Hevia et al., 2017; Di Giorgio et al., 2019) rule out a primary influence of verbal culture in MNL orientation. Children looked longer at leftward but not rightward displays that matched the number of sounds they heard (West & McCrink, 2021). Seven-month-olds, presented with subsequent arrays of dots arranged along a left-to-right oriented spatial display which could either increase (e.g. 1-2-3) or decrease (e.g. 3-2-1) in numerical magnitudes, looked longer at the increasing, compared to the decreasing sequence (de Hevia et al., 2014). Eight-month-olds shifted their attention toward the left after the presentation of a small number of dots, while they shifted their attention toward the right when presented with a large number of dots (Bulf et al., 2016). Three-day-old newborns habituated to an array of 12 items, spontaneously associated a smaller number, 4, with the left and a larger number, 36, with the right side. Moreover, the same number, 12, was associated with the left after habituation with 36 items, but with the right after habituation with 4 items (Di Giorgio et al., 2019). This evidence indicates that a predisposition to associate numbers onto a left-to-right-oriented mental number line exists independently of cultural factors and with little, if any, early exposure to directional cues. This supports the hypothesis that numbers, together with their spatial organization, would be biologically predisposed in the brain (Brugger, 2015; Rugani et al., 2020; Vallortigara, 2018), even if how neural representation of number (Harvey et al., 2013; Harvey & Dumoulin, 2017; Hubbard et al., 2005; Piazza et al., 2004) can sustain the MNL is still unknown.

Likewise, comparative research shows a spatial numerical association in non-human animals (Adachi, 2014; Drucker & Brannon, 2014; Gazes et al., 2017; Rugani et al., 2010; Rugani et al., 2015), which supports the non-learned hypothesis of the MNL being mainly based on action selection (Rugani & Regolin, 2021). Day-old domestic chicks, adult Clark's nutcrackers, and adult monkeys, trained to identify a target element, for example the 4th, in a sagittally-oriented series of identical elements, when faced an identical series but rotated by 90°, responded to the left target and neglected the right one (Drucker & Brannon, 2014; Rugani et al., 2010).

The association of numerical magnitudes, in their symbolic or non-symbolic form, with space thus seems to have ancient roots. Yet, the developmental trajectory and functional significance of a spatial numerical association remains unclear (Aulet & Lourenco, 2018). One

proposal is that the spatial numerical association supports numerical comprehension and mathematical development and understanding (Fischer & Shaki, 2014; Opfer et al., 2010). On this view, a stronger spatial numerical association would be associated with more advanced or mature math development. Yet, existing evidence of a connection between a strong directional MNL and abstract mathematical competence in adults are inconclusive. Some studies suggest an inverse correlation: mathematically impaired university students showed stronger SNARC effects than students with high math ability in a parity judgment task (Hoffmann et al., 2014). Similarly, professional mathematicians, who use advanced math in their work, did not show a SNARC effect, while non-mathematicians, mostly engineers, did (Cipora et al., 2016). Other studies have found no relation between the strength of left-to-right spatial-numerical orientation, as indexed by the SNARC effect, and math competence in adulthood (Bull et al., 2013; Cipora & Nuerk, 2013). The influence of the SNARC effect on mathematical school achievement is also negligible when compared to the influences of conceptual knowledge and numerical intelligence in 11-year-old children (Schneider et al., 2009). Five- to seven-year-old children did not show any relation between a directional mental number line and mathematical ability. A stronger SNARC effect, as indexed by a non-symbolic magnitude comparison task (Patro & Haman, 2012), was associated with inferior performance in mathematical tasks, which consisted in non-symbolic numerical discrimination or approximate or exact symbolic arithmetic calculation (Aulet & Lourenco, 2018). This finding indicates that acquisition of abstract concepts is more predictive than SNARC for math skill. Alternately, the measures to detect the direction of the MNL throughout the SNARC effect may not be the most reliable to study an eventual presence of a link. The lack of correlation between the SNARC effect, measured by the mean response times in parity judgments tasks, and math achievement emphasizes the role of speed but ignore the direction of choices. Nevertheless, it is likely that the direction of choices can better describe the relation between the MNL and mathematical achievement.

Another approach to provide precise indications of individuals' numerical representations is the number line estimation task, which requires participants to locate numbers on a line that includes starting and ending values, such as 0 to 10 (Friso-van den Bos et al., 2015; Geary et al., 2008; Siegler & Opfer, 2003; Simms et al., 2013). The number line estimation task is positively correlated with mathematical achievement: children who have more precise and linear numerical representations showed better mathematical achievement (Booth & Siegler, 2008; Friso-van den Bos et al., 2015; Muldoon et al., 2013; Siegler & Opfer, 2003; Simms et al., 2013). This task provides more direct and reliable measures of the internal representation of numbers and mathematical achievements, yet number knowledge can affect these kinds of evaluations. Age-appropriate scales, based on the upper value of the scale (0 to 20 or 100; Muldoon et al., 2013), have been used to test different ages, nevertheless the confound of symbolic number knowledge on MNL cannot be excluded. This evidence sustains the hypothesis that the MNL can be seen as a specific groundwork upon which children built the acquisition of more advanced numerical concepts and operations (Case et al., 1996; de Hevia, 2021; Schneider et al., 2009). A major limitation of this approach is that it requires understanding symbolic numbers, whereas the spatial numerical association initiated in the very first day of life is non-symbolic. The latter may pave the way to a deeper understanding of the mechanisms at the roots of the relation between space and number comprehension. These results, together with the evidence which demonstrated that early number-space association does not appear in speed of responses, but on action selection, suggest that possibly the answer to this question can be obtained from a different and innovative perspective. To get to the roots of the number space association, we developed a task which embedded a numerical-ordinal component with a spatial searching task, that allows studying at the same time a rudimental numerical comprehension of serial ordinal magnitudes and lateral bias.

Here we implemented a non-symbolic task to study spatial/ordinal representation in children ranging from three to six years old. Children participated in an engaging task, which required helping a stuffed animal find a toy that was hidden under one of ten identical and horizontally aligned plastic cups. The hidden location changed from trial to trial, and could be the 2nd, 3rd or 4th cup from the left or from the right. We expected a serial position effect with higher performance with exterior positions, and an age effect with higher performance for older children. The main question was whether there would be a laterality effect, with performance better when the toy was hidden on the left, and how a laterality effect would interact with age.

## 2. General methods

### 2.1. Participants

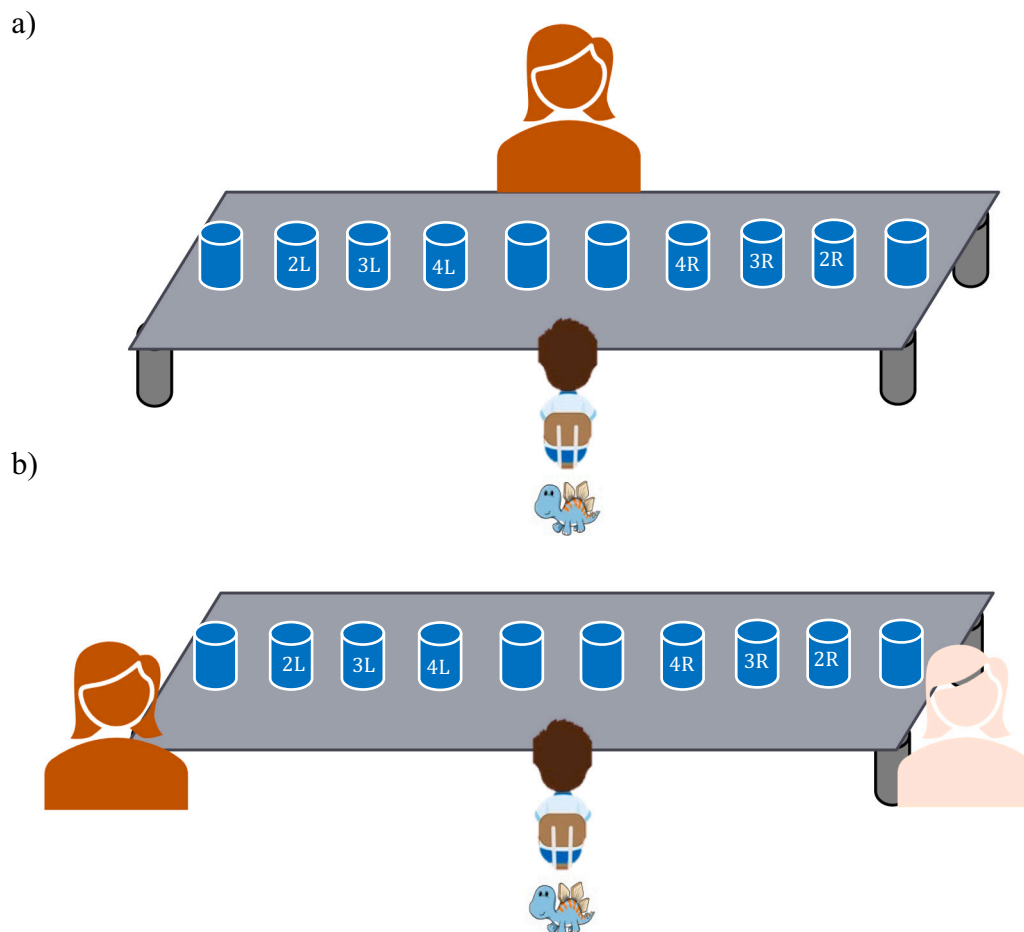
Participants were 167 children aged three to six years old (80 female). We tested children in Brightside Academy pre-schools and after-care centers, and the Academy of Natural Sciences of Drexel University. Seventy-nine children (44 female) were tested in the Lateral Condition (LC) where the experimenter who hid the toy was located on the same side as the hidden toy. Eighty-eight children (36 female) were tested in the Middle Condition (MC) where the experimenter who hid the toy was located centrally. We tested 23 three-year-olds (12 in LC), 71 four-year-olds (35 in LC), 43 five-year-olds (21 in LC) and 30 six-year-olds (11 in LC). The majority of participants were right-handed, while 13.92% in LC and 13.64% in MC, were left-handed. Informed consent was obtained

from children's parents or guardians prior to the study. We conducted a power analysis on Wilcoxon signed rank test (one sample) in G-Power 3.1 and used the default values (Effect size  $d = 0.5$ ,  $\alpha = 0.05$ , Power = 0.8), since there were no previous studies to rely on. Thirty-five participants were needed for each age group in each experimental condition to reach a medium effect. Even though we were unable to complete the planned number of participants due to COVID closures, our effect sizes ranged from medium to large which supports the replicability of our findings.

### 2.2. Materials and procedures

Before the experiment, participants were told that they would be helping a stuffed animal, Dani the dinosaur, find a toy. On each trial, ten identical blue Solo cups (Fig. 1a) were placed face down in a horizontal series along the length of the table (243.84 cm) covered with a solid gray fabric. On either side, the first cup was placed 7.5 cm from the edge of the table and the cups were 5 cm apart from each other, so that the series was centered along the length of the table. The 10 cups were labeled as 1 L, 2 L, 3 L, 4 L, 5 L, 5R, 4R, 3R, 2R and 1R, on the experimenter side for scoring purposes, but they looked identical from the children's perspective. A child-sized chair was centered in front of the table (which was always the starting location for the child), at 60 cm from it. A basket, under the chair, served as Dani's nest.

At the beginning of each trial, the participant sat in the chair, and Dani the dinosaur was in her nest. The experimenter hid the toy underneath one of the cups while the child watched. The child was then



**Fig. 1.** An illustration of the experimental setup, the target cups looked identical from the child's perspective. Here they are labeled for the reader's convenience. a) The position of the experimenter in the Middle Condition, MC; b) The position of the experimenter in the Lateral Condition, LC. In the LC the experimenter stood on the side congruent with the target side and thus functioned as a landmark.

asked to stand up, walk around the chair, and retrieve Dani the dinosaur. We intentionally located Dani under the chair at the start of each trial to create a 5-s distraction period and to prevent children from continuously staring at the target cup. The child was then asked to point Dani the dinosaur's nose at the cup that contained the hidden toy. On each trial, the child was allowed to repeatedly choose cups until they found the hidden toy. The experiment consisted of two consecutive blocks, each comprising 6 trials. The toy was hidden under the 2nd, 3rd, or 4th positioned cup on either the left or right side of the series (2 L, 2R, 3 L, 3R, 4 L, or 4R). The order of trials within each block was randomly predetermined and identical for every participant.

In the Middle Condition, MC, the experimenter stood across the table in its longitudinal center, in front of the participant's starting position (seated in the chair, Fig. 1a). In the Lateral Condition, LC, the experimenter stood on the table side, consistently with the hidden location: whenever the toy was hidden on the left side (2 L, 3 L, or 4 L), the experimenter stood on the left, whenever the toy was hidden on the right side (2R, 3R, or 4R) the experimenter stood on the right (Fig. 1b). Thus, in the LC the experimenter provided a side landmark for where the object was hidden. The task concluded with an attention-control test, to explore whether children were paying attention to the location where the toy was hidden. This consisted of two consecutive trials where children were asked to point to the target cup (4 L or 4R) immediately after the toy was hidden instead of engaging in the distraction task. The whole experiment lasted for approximately 12 min per participant.

### 2.3. Analyses

For each trial we recorded the specific sequence of cup locations chosen by each child and then computed two measures: accuracy on the first choice (0 or 1) and the number of errors before the hidden object was retrieved (0–9).

Accuracy on the first choice for each target location was calculated as the percentage of correct first responses each child made on the two trials at each of the 6 target locations. Accuracy was therefore 0, 50% or 100% at each location for each child.

Number of errors: we calculated the number of incorrect choices the child made before selecting the correct cup and averaged them for each target location. The number of errors on any given trial could range from 0 to 9.

Since the data were not normally distributed, we used the One-sample Wilcoxon Test to analyze departures from chance level (10%) on the Accuracy on the first choice and Bonferroni's correction for multiple comparisons. Wilcoxon signed-rank test was used to test the effect of condition and side on Accuracy and Number of errors. Kruskal-Wallis test was conducted to examine the effects of age and serial position. We conducted all analyses using R 4.0.3.

## 3. Results

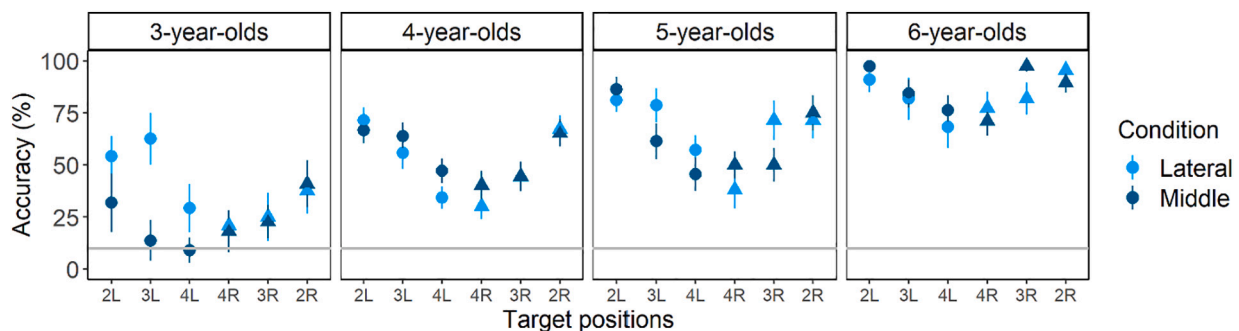
### 3.1. Accuracy on the first choice

There was a significant effect of age on accuracy (3 years old: Mean = 30.797, SE = 3.184; 4 years old: Mean = 52.582, SE = 1.976; 5 years old: Mean = 63.760, SE = 2.421; 6 years old: Mean = 84.722, SE = 1.934;  $\chi^2 = 150.23$ ,  $df = 3$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.150$ ), indicating that older children were more likely to accurately find the toy on their first choice.

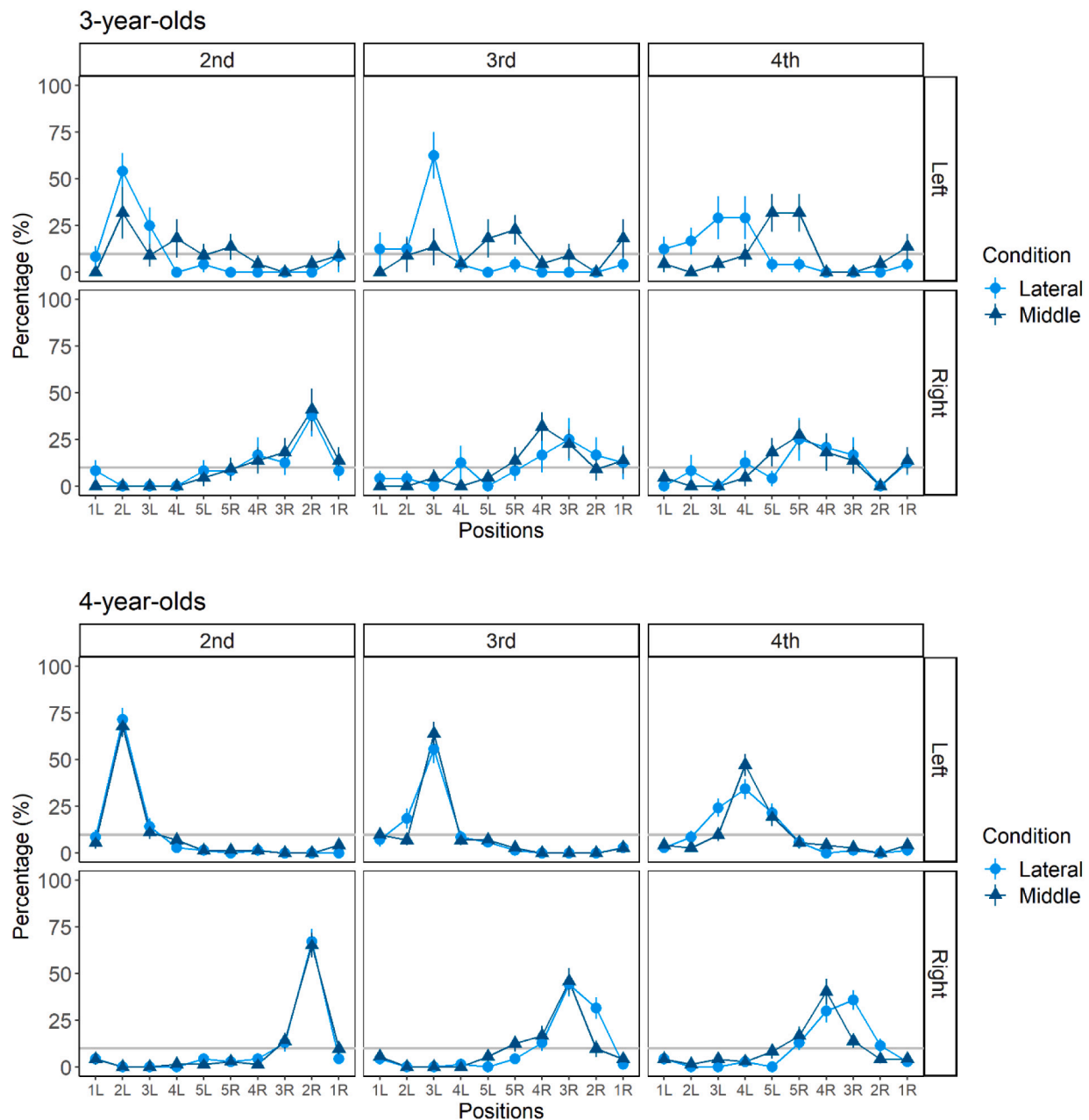
Fig. 2 shows accuracy on the first choice as a function of condition, age and target location. Three-year-old children showed a strong effect of condition with higher accuracy in the Lateral Condition (Lateral: Mean = 38.194, SE = 4.585; Middle: Mean = 22.727, SE = 4.206,  $W = 2900.5$ ,  $p = 0.013$ ,  $r = 0.212$ ). There was no effect of condition (Lateral vs. Middle) on first choice accuracy for 4-, 5-, and 6-year-olds (4-year-olds. Lateral: Mean = 50.476, SE = 2.844; Middle: Mean = 54.630, SE = 2.747;  $W = 21,435$ ,  $p = 0.298$ ,  $r = 0.050$ ; 5-year-olds. Lateral: Mean = 66.270, SE = 3.511; Middle: Mean = 61.364, SE = 3.340;  $W = 8953.5$ ,  $p = 0.249$ ,  $r = 0.072$ ; 6-year-olds. Lateral: Mean = 82.576, SE = 3.326; Middle: Mean = 85.965, SE = 2.373;  $W = 3524.5$ ,  $p = 0.367$ ,  $r = 0.067$ ). Overall, the location of the experimenter had a strong effect on 3-year-old children's search behavior while older children seemed to ignore the external landmark and focus on their internal representations.

As illustrated in Fig. 2, 4-, 5- and 6-year-old children remembered the location of all targets with above chance accuracy (all  $p$  values were  $< 0.001$  and  $r$  values ranged from 0.45 to 0.96; see Fig. 3 for the distribution of the choices on every position for each target cup, respectively for three-, four-, five- and six- year-old children). However, in Lateral Condition, three-year-old children were only above chance when the toy was hidden at 2 L or 3 L but not 4 L, and selected all right targets at chance (2 L: Mean = 54.167, SE = 9.650;  $V = 75$ ,  $p = 0.013$ ,  $r = 0.834$ ; 2R: Mean = 37.500, SE = 10.880;  $V = 63$ ,  $p = 0.183$ ,  $r = 0.551$ ; 3 L: Mean = 62.500, SE = 12.500;  $V = 72$ ,  $p = 0.029$ ,  $r = 0.759$ ; 3R: Mean = 25.000, SE = 11.514;  $V = 42$ ,  $p = 1.000$ ,  $r = 0.070$ ; 4 L: Mean = 29.167, SE = 11.445;  $V = 50$ ,  $p = 1.000$ ,  $r = 0.255$ ; 4R: Mean = 20.833, SE = 7.432;  $V = 50$ ,  $p = 1.000$ ,  $r = 0.257$ ). In the Middle Condition, when there was no landmark to direct attention to the side that the toy was hidden, three-year-olds did not perform with above chance expectations ( $p$  values ranged from 0.127 to 1).

Four-, 5-, and 6-year-old children showed strong a serial position effect. For all three age groups accuracy was best for target positions 2 L and 2R, and worst for 4R and 4 L (4-year-olds. 2nd targets: Mean = 67.606, SE = 3.207, 3rd targets: Mean = 52.113, SE = 3.529, 4th targets: Mean = 38.028, SE = 3.078;  $\chi^2 = 37.808$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.089$ ; 5-year-olds. 2nd targets: Mean = 78.488, SE = 3.656, 3rd



**Fig. 2.** Accuracy on first choices as a function of target location for each age group and each condition. In the Lateral Condition but not the Middle Condition the experimenter's location could serve as an efficient landmark. Error bars indicate standard errors. The gray line represents the chance level ( $y = 10$ ). Three-year-old children performed above chance only with the 2nd and the 3rd left targets in the Lateral Condition ( $ps < 0.05$ ), older children performed above chance for all targets.



**Fig. 3.** Distribution of first choices (mean percentage  $\pm$  SE) for each target (2nd, 3rd or 4th cup) and experimental condition for three-year-olds, four-year olds, five-year olds, six-year olds. The gray line represents the chance level ( $y = 10$ ).

targets: Mean = 65.116, SE = 4.381, 4th targets: Mean = 47.674, SE = 3.871,  $\chi^2 = 30.136$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.117$ ; 6-year-olds: 2nd targets: Mean = 93.333, SE = 2.213, 3rd targets: Mean = 87.500, SE = 3.282, 4th targets: Mean = 73.333, SE = 3.845,  $\chi^2 = 19.955$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.111$ ; Fig. 2). Three-year-olds did not show a serial position effect in either condition (Lateral: 2nd targets: Mean = 45.833, SE = 7.321; 3rd targets: Mean = 43.750, SE = 9.184; 4th targets: Mean = 25.000, SE = 6.730;  $\chi^2 = 4.141$ ,  $df = 2$ ,  $p = 0.126$ ,  $\epsilon^2 = 0.058$ ; 3-year-olds. Middle: 2nd targets: Mean = 36.364, SE = 8.816; 3rd targets: Mean = 18.182, SE = 6.194; 4th targets: Mean = 13.636, SE = 5.868;  $\chi^2 = 4.651$ ,  $df = 2$ ,  $p = 0.098$ ,  $\epsilon^2 = 0.072$ ).

We next asked whether there was a laterality effect with better performance when the toy was hidden on the left than the right. Since three-year-old children showed a strong effect of condition we examined the laterality effect separately for the two conditions. Accuracy on left

and right cups did not differ in the Middle Condition (Left: Mean = 18.182 SE = 6.084; Right: Mean = 27.273, SE = 5.794;  $V = 22$ ,  $p = 0.166$ ,  $r = 0.249$ ). However, three-year-old children performed with much higher accuracy on the left than on the right in the Lateral Condition (Left: Mean = 48.611, SE = 6.751; Right: Mean = 27.778, SE = 5.789;  $V = 183$ ,  $p = 0.015$ ,  $r = 0.410$ ).

Given that 4, 5, and 6-year-old children did not show an effect of condition we collapsed across condition to examine the effect of laterality for these age groups. Four and five, but not six-year-old children showed higher first choice accuracy when the toy was hidden on the left than the right side (4-year-olds. Left: Mean = 56.573, SE = 2.707; Right: Mean = 48.592, SE = 2.861;  $V = 4926.5$ ,  $p = 0.027$ ,  $r = 0.151$ ; 5-year-olds. Left: Mean = 68.217, SE = 3.206; Right: Mean = 59.302, SE = 3.599;  $V = 1475.5$ ,  $p = 0.026$ ,  $r = 0.196$ ; 6-year-olds. Left: Mean = 83.889, SE = 2.938; Right: Mean = 85.556, SE = 2.529;



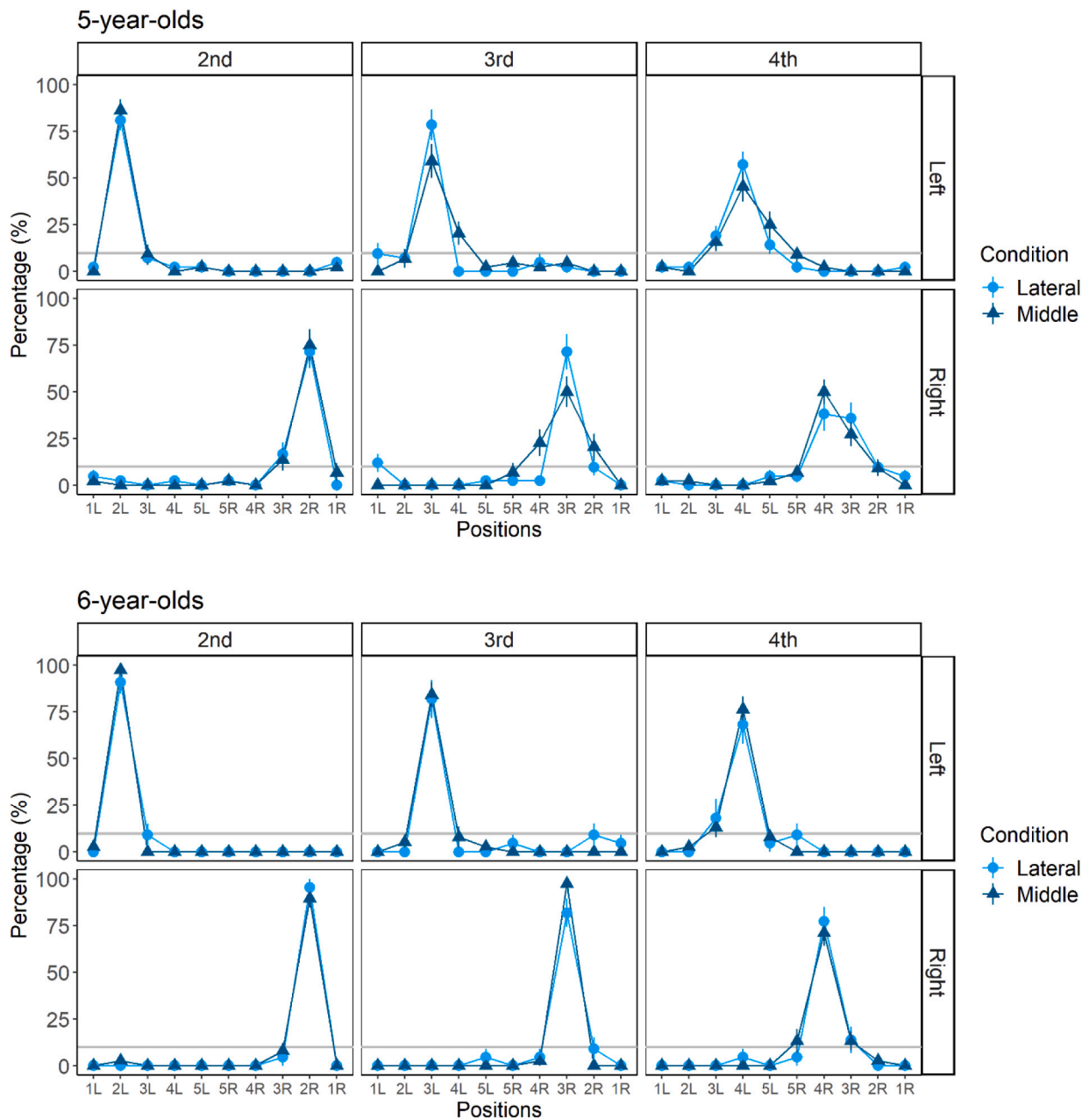


Fig. 3. (continued).

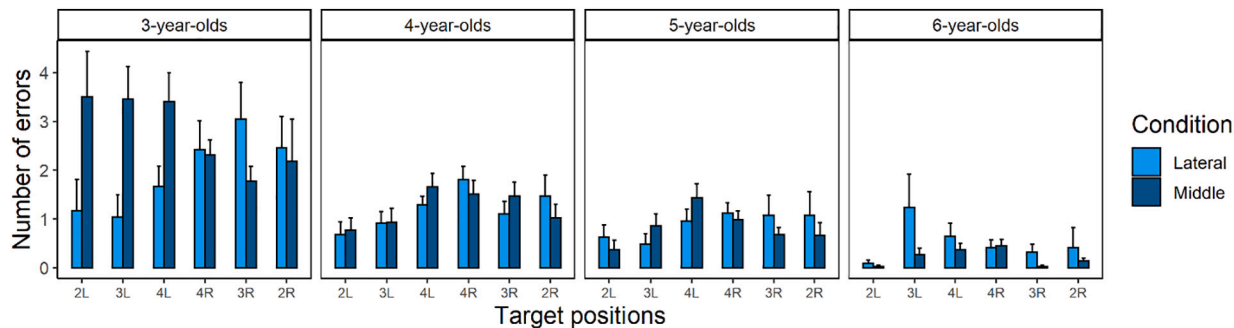


Fig. 4. Number of errors. The graph represents the mean with SE of choices for each target position in two (Lateral/Middle) Conditions separated by age groups.

$V = 324$ ,  $p = 0.648$ ,  $r = 0.049$ ; Fig. 2), indicating an advantage in identifying the left targets.

Further evidence that 3-year-olds were influenced by the location of the experimenter comes from the location of their first-choice errors in the Middle Condition. Three-year-old children selected the 5th cups (5 L and 5R) in the Middle Condition significantly more often than in the Lateral Condition (LC: Mean = 11.806, SE = 2.983; MC: Mean = 34.091, SE = 5.205;  $W = 19$ ,  $p = 0.004$ ,  $r = -0.613$ ), suggesting that these young children were anchoring their starting point to the location of the experimenter.

### 3.2. Number of errors

Fig. 4 shows the number of errors children made before finding the toy as a function of condition for each age group. As expected, the number of errors made decreased with age (3 years old: Mean = 2.351, SE = 0.187; 4 years old: Mean = 1.218, SE = 0.081; 5 years old: Mean = 0.857, SE = 0.080; 6 years old: Mean = 0.322, SE = 0.061;  $\chi^2 = 147.91$ ,  $df = 3$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.148$ ).

Three-year-old children made significantly fewer errors before finding the toy in the Lateral compared to the Middle Condition (3-year-olds. Lateral: Mean = 1.965, SE = 0.250, Middle = 2.773, SE = 0.273,  $W = 1789$ ,  $p = 0.012$ ,  $r = 0.215$ ). In contrast, there was no effect of condition on the number of errors for the older groups (4-year-olds. Lateral: Mean = 1.210, SE = 0.116; Middle: Mean = 1.227, SE = 0.113;  $W = 22,910$ ,  $p = 0.853$ ,  $r = 0.009$ ; 5-year-olds. Lateral: Mean = 0.885, SE = 0.131; Middle: Mean = 0.830, SE = 0.095,  $W = 7763$ ,  $p = 0.327$ ,  $r = 0.061$ ; 6-year-olds. Lateral: Mean = 0.515, SE = 0.149, Middle: Mean = 0.211, SE = 0.042;  $W = 4086$ ,  $p = 0.223$ ,  $r = 0.091$ ).

We next evaluated the effect of right vs left on the number of errors for each age group. Since 3-year-old children showed a significant effect of condition, we analyzed the two conditions separately for this age group but collapsed across condition for 4, 5, and 6-year-olds. Four-year-olds, showed a significant laterality effect with more errors when the toy was hidden on the right than left (four-year-olds. Left: Mean = 1.040, SE = 0.103, Right: Mean = 1.397, SE = 0.123;  $V = 4616$ ,  $p = 0.004$ ,  $r = 0.199$ ). Five and six-year-olds showed no laterality effects (five-year-olds. Left: Mean = 0.787, SE = 0.103, Right: Mean = 0.926, SE = 0.123;  $V = 1501.5$ ,  $p = 0.452$ ,  $r = 0.066$ ; six-year-olds. Left: Mean = 0.378, SE = 0.104, Right: Mean = 0.267, SE = 0.065;  $V = 418.5$ ,  $p = 0.691$ ,  $r = 0.043$ ).

In the Lateral condition, 3-year-old children made fewer errors with left targets than right targets (Left: Mean = 1.292, SE = 0.290, Right: Mean = 2.639, SE = 0.379;  $V = 94$ ,  $p = 0.004$ ,  $r = 0.477$ ). The error data are thus consistent with the accuracy data and suggests that when the experimenter draws attention to the left in conjunction with an intrinsic left-to-right search strategy this results in more searching on the left and thus fewer errors when the toy is hidden on the left. In contrast, when the experimenter is located directly in the middle of the sequence (Middle Condition), three-year-old children required fewer choices to find right targets than left targets (Left: Mean = 3.455, SE = 0.418; Right: Mean = 2.091, SE = 0.314;  $V = 392.5$ ,  $p = 0.005$ ,  $r = 0.494$ ). We suggest that drawing children's attention to the center of the sequence may anchor children's starting point to the center which in combination with a left to right each strategy would naturally result in more searching on the right and therefore fewer errors when the toy is hidden on the right.

There was a significant effect of serial position on the number of errors for 4-, 5- and 6-year-old children but not the youngest age group (3-year-olds. Lateral: 2nd targets: Mean = 1.813, SE = 0.463; 3rd targets: Mean = 2.042, SE = 0.481; 4th targets: Mean = 2.042, SE = 0.364;  $\chi^2 = 1.788$ ,  $df = 2$ ,  $p = 0.409$ ,  $\epsilon^2 = 0.025$ ; 3-year-olds. Middle: 2nd targets: Mean = 2.841, SE = 0.639; 3rd targets: Mean = 2.614, SE = 0.404; 4th targets: Mean = 2.864, SE = 0.342;  $\chi^2 = 0.924$ ,  $df = 2$ ,  $p = 0.630$ ,  $\epsilon^2 = 0.014$ ; 4-year-olds. 2nd targets: Mean = 0.986, SE = 0.153, 3rd targets: Mean = 1.106, SE = 0.134, 4th targets:

Mean = 1.563, SE = 0.127,  $\chi^2 = 36.670$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.086$ ; 5-year-olds: 2nd targets: Mean = 0.674, SE = 0.157, 3rd targets: Mean = 0.773, SE = 0.133, 4th targets: Mean = 1.122, SE = 0.120,  $\chi^2 = 25.406$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.099$ ; 6-year-olds: 2nd targets: Mean = 0.142, SE = 0.078, 3rd targets: Mean = 0.375, SE = 0.144, 4th targets: Mean = 0.450, SE = 0.081,  $\chi^2 = 19.389$ ,  $df = 2$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.108$ ).

## 4. Discussion

This study was designed to investigate the development of spatial numerical associations using a spatial-ordinal search task. Children played a game in which they helped a stuffed animal find a toy that was hidden under one of 10 horizontally arrayed cups. Performance increased with age and children aged four and older showed a serial position effect with better accuracy on exterior compared to interior cups.

Remarkably, children showed an asymmetry with better accuracy when the toy was hidden in a cup on the left of the array compared to when it was hidden on the right. This effect was most dramatic in the youngest 3-year-old children, tested in the Lateral Condition (LC), but was also present in 4- and 5-year-old children. The fact that 3-, 4- and 5-year-old children showed this asymmetry supports a left attentional bias before schooling that it is not a by-product of reading and writing.

Prior research has demonstrated that both adults and preliterate children have a tendency to start counting from either end of a horizontally oriented array. Specifically, participants who were instructed to count a horizontal series of four aligned coins, counted starting from either the left or the right, depending on their culture, and only a small percentage counted in an idiosyncratic unorganized order (Shaki et al., 2012). The directional counting preferences were shaped by culture specific directional bias in British and Palestinian Children. Such a bias emerged at 3 years in British children, who showed a left-to-right counting and in Palestinian children, who showed a right-to-left counting (Shaki et al., 2012). Yet, other studies show that recent experiences can influence which direction children start counting. For example, three- to five-year-old children changed the anchor of their counting behavior, in line with the direction of observed reading (left-to-right or right-to-left), after having observed directional reading from storybooks (Göbel et al., 2018). We suggest that our participants, exposed to a left-to-right oriented culture, may be biased to attend and begin searching from the left. However, for 6-year-old children observing the action of hiding the toy on the left or the right is sufficient to anchor their search to that side and they are able to ignore the experimenter's location after hiding the toy. In contrast, for 3, 4, and 5 year-old children, accuracy is enhanced when there is a congruency between their leftward attentional bias and the location in which the toy was hidden.

Only three-year-old children were influenced by the position of the experimenter and this influence was asymmetrical. When the landmark was on the left, 3-year-old children were much more accurate than when the landmark was on the right or when there was no external landmark (Middle Condition). The asymmetrical influence of the landmark suggests that the landmark did not similarly attract children's attention. Instead, we suggest that the leftward landmark was successful at boosting performance because of the congruency with children's natural bias to search from left to right.

Three-year-old children also erroneously selected the central cups (5 L and 5R) in the Middle Condition significantly more than in the Lateral Condition, providing further evidence that the experimenter anchored their search strategy. This may have resulted in an inversion of search direction. From the children's perspective, an experimenter standing in between 5 L and 5R was on the left of the right targets and on the right of the left targets. If children relied on the experimenter's central position, this could have induced an inversion of the searching direction, starting from the central landmark. This would explain the

surprising finding that children were better at finding right targets compared to left targets and made fewer errors when the target was hidden on the right in the Middle Condition.

It may also be helpful to understand the asymmetry observed in young children by considering the experimenter as a social cue to attention. Research in adults suggests that social gaze cues reflexively orient attention preferentially when presented in the left visual field whereas reflexive orienting to arrow cues occurs for targets presented in both left and right visual fields (Marotta et al., 2012). A great deal of research also shows that social stimuli such as faces are preferentially processed in the right hemisphere (Grand et al., 2003; Kanwisher et al., 1997; McCarthy et al., 1997; Rossion et al., 2000). Thus, if we consider the experimenter as a social cue this may explain why the cue was more effective when present in the left rather than the right visual field.

Six-year-old children's accuracy was highest for the targets in the extremities (2 L and 2R) and deteriorated for inward locations mirroring a serial position effect however they did not exhibit a laterality effect. The lack of a laterality bias in 6-year old children is at first glance puzzling given that cultural influences of reading direction are generally thought to increase the strength of space number mapping. One possibility is that improved counting and labeling skills led to different strategies for 6-year-olds compared to younger children. For example, 6-year-olds may have relied on semantic encoding of ordinal positions (e.g., "the second cup"). Nevertheless, their symmetric performance suggests that 6-year-old children had no trouble orienting to the left or the right as a function of where the toy was hidden.

In conclusion, our spontaneous search task was designed to explore spatial biases that may influence ordinal numerical coding. We suggest that our paradigm may be useful in unveiling the intrinsic association between numerical processing and spatial representation and pave the way for a better understanding of the developmental trajectory and functional significance of the mental number line.

## Declaration of competing interest

The authors declared that no conflict of interests exist.

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## References

- Adachi, I. (2014). Spontaneous spatial mapping of learned sequence in chimpanzees: evidence for a SNARC-like effect. *PLoS ONE*, 9(3), Article e90373. <https://doi.org/10.1371/journal.pone.0090373>
- Andres, M., Ostry, D., Nicol, F., & Paus, T. (2008). Time course of number magnitude interference during grasping. *Cortex*, 44(4), 414–419. <https://doi.org/10.1016/j.cortex.2007.08.007>
- Aulet, L. S., & Lourenco, S. F. (2018). The developing mental number line: Does its directionality relate to 5- to 7-year-old children's mathematical abilities? *Frontiers in Psychology*, 9, 1142. <https://doi.org/10.3389/fpsyg.2018.01142>
- Booth, J. L., & Siegler, R. S. (2008). Numerical magnitude representations influence arithmetic learning. *Child Development*, 79(4), 1016–1031. <https://doi.org/10.1111/j.1467-8624.2008.01173.x>
- Brugger, P. (2015). Chicks with a number sense. *Science*, 347(6221), 477–478. <https://doi.org/10.1126/science.aaa4854>
- Bulf, H., de Hevia, M. D., & Macchi Cassia, V. (2016). Small on the left, large on the right: Numbers orient visual attention onto space in preverbal infants. *Developmental Science*, 19(3), 394–401. <https://doi.org/10.1111/desc.12315>
- Bull, R., Cleland, A. A., & Mitchell, T. (2013). Sex differences in the spatial representation of number. *Journal of Experimental Psychology: General*, 142(1), 181–192. <https://doi.org/10.1037/a0028387>
- Cantlon, J. F., & Brannon, E. M. (2007). Basic math in monkeys and college students. *PLoS Biology*, 5(12), Article e328. <https://doi.org/10.1371/journal.pbio.0050328>
- Casarotti, M., Michielin, M., Zorzi, M., & Umiltà, C. (2007). Temporal order judgment reveals how number magnitude affects visuospatial attention. *Cognition*, 102(1), 101–117. <https://doi.org/10.1016/j.cognition.2006.09.001>
- Case, R., Okamoto, Y., & Society for Research in Child Development. (1996). *The role of central conceptual structures in the development of children's thought*. University of Chicago Press.
- Cipora, K., Hohol, M., Nuerk, H.-C., Willmes, K., Brożek, B., Kucharzyk, B., & Necka, E. (2016). Professional mathematicians differ from controls in their spatial-numerical associations. *Psychological Research*, 80(4), 710–726. <https://doi.org/10.1007/s00426-015-0677-6>
- Cipora, K., & Nuerk, H.-C. (2013). Is the SNARC effect related to the level of mathematics? No systematic relationship observed despite more power, more repetitions, and more direct assessment of arithmetic skill. *Quarterly Journal of Experimental Psychology*, 66(10), 1974–1991. <https://doi.org/10.1080/17470218.2013.772215>
- Cordes, S., Gelman, R., Gallistel, C. R., & Whalen, J. (2001). Variability signatures distinguish verbal from nonverbal counting for both large and small numbers. *Psychonomic Bulletin & Review*, 8(4), 698–707. <https://doi.org/10.3758/BF03196206>
- de Hevia, M. D. (2021). How the human mind grounds numerical quantities on space. *Child Development Perspectives*, 15(1), 44–50. <https://doi.org/10.1111/cdep.12398>
- de Hevia, M. D., Izard, V., Coubart, A., Spelke, E. S., & Streri, A. (2014). Representations of space, time, and number in neonates. *Proceedings of the National Academy of Sciences*, 111(13), 4809–4813. <https://doi.org/10.1073/pnas.1323628111>
- de Hevia, M. D., & Spelke, E. S. (2010). Number-space mapping in human infants. *Psychological Science*, 21(5), 653–660. <https://doi.org/10.1177/0956797610366091>
- de Hevia, M. D., Veggiotti, L., Streri, A., & Bonn, C. D. (2017). At birth, humans associate "few" with left and "many" with right. *Current Biology*, 27(24), 3879–3884. <https://doi.org/10.1016/j.cub.2017.11.024>
- Dehaene, S. (2011). *The number sense: How the mind creates mathematics* (Rev. and updated ed.). Oxford University Press.
- Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122(3), 371–396. <https://doi.org/10.1037/0096-3445.122.3.371>
- Di Giorgio, E., Lunghi, M., Rugani, R., Regolin, L., Dalla Barba, B., Vallortigara, G., & Simion, F. (2019). A mental number line in human newborns. *Developmental Science*, 22(6). <https://doi.org/10.1111/desc.12801>
- Drucker, C. B., & Brannon, E. M. (2014). Rhesus monkeys (Macaca mulatta) map number onto space. *Cognition*, 132(1), 57–67. <https://doi.org/10.1016/j.cognition.2014.03.011>
- Fischer, M. H., & Shaki, S. (2014). Spatial associations in numerical cognition—from single digits to arithmetic. *Quarterly Journal of Experimental Psychology*, 67(8), 1461–1483. <https://doi.org/10.1080/17470218.2014.927515>
- Friso-van den Bos, I., Kroesbergen, E. H., Van Luit, J. E. H., Xenidou-Dervou, I., Jonkman, L. M., Van der Schoot, M., & Van Lieshout, E. C. D. M. (2015). Longitudinal development of number line estimation and mathematics performance in primary school children. *Journal of Experimental Child Psychology*, 134, 12–29. <https://doi.org/10.1016/j.jecp.2015.02.002>
- Galton, F. (1880). Visualised numerals. *Nature*, 21(533), 252–256. <https://doi.org/10.1038/021252a0>
- Gazes, R. P., Diamond, R. F. L., Hope, J. M., Caillaud, D., Stoinski, T. S., & Hampton, R. R. (2017). Spatial representation of magnitude in gorillas and orangutans. *Cognition*, 168, 312–319. <https://doi.org/10.1016/j.cognition.2017.07.010>
- Geary, D. C., Hoard, M. K., Nugent, L., & Byrd-Craven, J. (2008). Development of number line representations in children with mathematical learning disability. *Developmental Neuropsychology*, 33(3), 277–299. <https://doi.org/10.1080/87565640801982361>
- Gianelli, C., Ranzini, M., Marzocchi, M., Rettore Micheli, L., & Borghi, A. M. (2012). Influence of numerical magnitudes on the free choice of an object position. *Cognitive Processing*, 13(S1), 185–188. <https://doi.org/10.1007/s10339-012-0483-7>
- Göbel, S. M., McCrink, K., Fischer, M. H., & Shaki, S. (2018). Observation of directional storybook reading influences young children's counting direction. *Journal of Experimental Child Psychology*, 166, 49–66. <https://doi.org/10.1016/j.jecp.2017.08.001>
- Grand, R. L., Mondloch, C. J., Maurer, D., & Brent, H. P. (2003). Expert face processing requires visual input to the right hemisphere during infancy. *Nature Neuroscience*, 6(10), 1108–1112. <https://doi.org/10.1038/nn1121>
- Harvey, B. M., & Dumoulin, S. O. (2017). A network of topographic numerosity maps in human association cortex. *Nature Human Behaviour*, 1(2), 0036. <https://doi.org/10.1038/s41562-016-0036>
- Harvey, B. M., Klein, B. P., Petridou, N., & Dumoulin, S. O. (2013). Topographic representation of numerosity in the human parietal cortex. *Science*, 341(6150), 1123–1126. <https://doi.org/10.1126/science.1239052>
- Hoffmann, D., Hornung, C., Martin, R., & Schiltz, C. (2013). Developing number-space associations: SNARC effects using a color discrimination task in 5-year-olds. *Journal of Experimental Child Psychology*, 116(4), 775–791. <https://doi.org/10.1016/j.jecp.2013.07.013>
- Hoffmann, D., Mussolin, C., Martin, R., & Schiltz, C. (2014). The impact of mathematical proficiency on the number-space association. *PLoS ONE*, 9(1), Article e85048. <https://doi.org/10.1371/journal.pone.0085048>
- Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience*, 6(6), 435–448. <https://doi.org/10.1038/nrn1684>
- Izard, V., Sann, C., Spelke, E. S., & Streri, A. (2009). Newborn infants perceive abstract numbers. *Proceedings of the National Academy of Sciences*, 106(25), 10382–10385. <https://doi.org/10.1073/pnas.0812142106>



- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience*, 17(11), 4302–4311. <https://doi.org/10.1523/JNEUROSCI.17-11-04302.1997>
- Lindemann, O., Abolafia, J. M., Girardi, G., & Bekkering, H. (2007). Getting a grip on numbers: Numerical magnitude priming in object grasping. *Journal of Experimental Psychology: Human Perception and Performance*, 33(6), 1400–1409. <https://doi.org/10.1037/0096-1523.33.6.1400>
- Mapelli, D., Rusconi, E., & Umiltà, C. (2003). The SNARC effect: An instance of the Simon effect? *Cognition*, 88(3), B1–B10. [https://doi.org/10.1016/S0010-0277\(03\)00042-8](https://doi.org/10.1016/S0010-0277(03)00042-8)
- Marotta, A., Lupiáñez, J., & Casagrande, M. (2012). Investigating hemispheric lateralization of reflexive attention to gaze and arrow cues. *Brain and Cognition*, 80(3), 361–366. <https://doi.org/10.1016/j.bandc.2012.08.001>
- McCarthy, G., Puce, A., Gore, J. C., & Allison, T. (1997). Face-specific processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, 9(5), 605–610. <https://doi.org/10.1162/jocn.1997.9.5.605>
- Muldoon, K., Towse, J., Simms, V., Perra, O., & Menzies, V. (2013). A longitudinal analysis of estimation, counting skills, and mathematical ability across the first school year. *Developmental Psychology*, 49(2), 250–257. <https://doi.org/10.1037/a0028240>
- Namdar, G., Tzelgov, J., Algom, D., & Ganel, T. (2014). Grasping numbers: Evidence for automatic influence of numerical magnitude on grip aperture. *Psychonomic Bulletin & Review*, 21(3), 830–835. <https://doi.org/10.3758/s13423-013-0550-9>
- Opfer, J. E., Thompson, C. A., & Furlong, E. E. (2010a). Early development of spatial-numeric associations: Evidence from spatial and quantitative performance of preschoolers: Spatial-numeric associations. *Developmental Science*, 13(5), 761–771. <https://doi.org/10.1111/j.1467-7687.2009.00934.x>
- Patro, K., & Haman, M. (2012). The spatial–numerical congruity effect in preschoolers. *Journal of Experimental Child Psychology*, 111(3), 534–542. <https://doi.org/10.1016/j.jecp.2011.09.006>
- Piazza, M., Izard, V., Pinel, P., Le Bihan, D., & Dehaene, S. (2004). Tuning curves for approximate numerosity in the human intraparietal sulcus. *Neuron*, 44(3), 547–555. <https://doi.org/10.1016/j.neuron.2004.10.014>
- Rossion, B., Dricot, L., Devolder, A., Bodart, J.-M., Crommelinck, M., de Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, 12(5), 793–802. <https://doi.org/10.1162/089892900562606>
- Rugani, R., Betti, S., & Sartori, L. (2018). Numerical affordance influences action execution: A kinematic study of finger movement. *Frontiers in Psychology*, 9, 637. <https://doi.org/10.3389/fpsyg.2018.00637>
- Rugani, R., & de Hevia, M.-D. (2017). Number-space associations without language: Evidence from preverbal human infants and non-human animal species. *Psychonomic Bulletin & Review*, 24(2), 352–369. <https://doi.org/10.3758/s13423-016-1126-2>
- Rugani, R., Kelly, D. M., Szelest, I., Regolin, L., & Vallortigara, G. (2010). Is it only humans that count from left to right? *Biology Letters*, 6(3), 290–292. <https://doi.org/10.1098/rsbl.2009.0960>
- Rugani, R., & Regolin, L. (2021). Approach direction and accuracy, but not response times, show spatial-numerical association in chicks. *PLOS ONE*, 16(9), Article e0257764. <https://doi.org/10.1371/journal.pone.0257764>
- Rugani, R., Vallortigara, G., Priftis, K., & Regolin, L. (2015). Number-space mapping in the newborn chick resembles humans' mental number line. *Science*, 347(6221), 534–536. <https://doi.org/10.1126/science.aaa1379>
- Rugani, R., Vallortigara, G., Priftis, K., & Regolin, L. (2020). Numerical magnitude, rather than individual bias, explains spatial numerical association in newborn chicks. *elife*, 9, Article e54662. <https://doi.org/10.7554/eLife.54662>
- Schneider, M., Grabner, R. H., & Paetsch, J. (2009). Mental number line, number line estimation, and mathematical achievement: Their interrelations in grades 5 and 6. *Journal of Educational Psychology*, 101(2), 359–372. <https://doi.org/10.1037/a0013840>
- Shaki, S., Fischer, M. H., & Göbel, S. M. (2012a). Direction counts: A comparative study of spatially directional counting biases in cultures with different reading directions. *Journal of Experimental Child Psychology*, 112(2), 275–281. <https://doi.org/10.1016/j.jecp.2011.12.005>
- Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, 16(2), 328–331. <https://doi.org/10.3758/PBR.16.2.328>
- Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, 14(3), 237–250. <https://doi.org/10.1111/1467-9280.02438>
- Simms, V., Muldoon, K., & Towse, J. (2013). Plane thinking: Mental representations in number line estimation as a function of orientation, scale, and counting proficiency. *Journal of Experimental Child Psychology*, 115(3), 468–480. <https://doi.org/10.1016/j.jecp.2013.03.011>
- Vallortigara, G. (2018). Comparative cognition of number and space: The case of geometry and of the mental number line. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 373(1740), 20170120. <https://doi.org/10.1098/rstb.2017.0120>
- West, E., & McCrink, K. (2021). Eye tracking lateralized spatial associations in early childhood. *Journal of Cognition and Development*, 22(5), 678–694. <https://doi.org/10.1080/15248372.2021.1926254>
- Zebian, S. (2005). Linkages between number concepts, spatial thinking, and directionality of writing: The SNARC effect and the REVERSE SNARC effect in English and Arabic Monoliterates, Biliterates, and Illiterate Arabic speakers. *Journal of Cognition and Culture*, 5(1–2), 165–190. <https://doi.org/10.1163/1568537054068660>