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Directionality of number space associations in Hebrew-speaking children: Evidence from number line estimation

It is widely believed that quantity manipulation and understanding is an innate human ability, which is preverbal and based upon the mapping between space and quantities (number-space associations) (Dehaene, 1992, 2009; Dehaene et al., 2003, 1999; de Hevia & Spelke, 2010). Infants are born with preverbal approximate number sense (ANS). Later, with maturation and schooling, an exact symbolic quantity system develops, supported by the preverbal ANS as well as verbal abilities (Halberda et al., 2008; Libertus et al., 2011).

The preverbal representation of quantity (ANS) is believed to be needed across the life span mostly for estimation tasks. During numerical estimation, a quantity (symbolic or non-symbolic) is translated into an abstract code of that quantity in the form of the mental number line (Dehaene, 1992, 2009; Dehaene et al., 2003). The mental number line has a few documented characteristics, including its left to right directionality (Dehaene et al., 1993), as well as its arrangement; it is initially logarithmic, and becomes linear with maturation and schooling (Siegler & Booth, 2004; Siegler & Opfer, 2003). Logarithmic representation of the number line includes overestimation of small numbers and underestimation of larger numbers toward the end of the scale. By contrast, linear representation includes equal distances between quantities, regardless of their size.

1 Number line estimation tasks

One popular estimation task, aimed at examining the averbal numerical representations, is the number line estimation task (or the number to position task) (Siegler & Opfer, 2003). In the number line estimation task, a number is presented above a number line, with 0 at one end and 100 or 1,000 at its other end. The participant is instructed to place a number spatially on the line. Corresponding to

Note: Dr. Yossef Arzuan, of blessed memory, was part of the research team and helped design the experiment and performed analysis of the data.

the development of the mental number line (see the previous section), and with maturation, children's estimation shifts from logarithmic to linear (Siegler & Booth, 2004; Siegler & Opfer, 2003). The shift between logarithmic and linear representations is related to familiarity with the range (i.e., a child can present a linear representation for a small and familiar range, and a logarithmic representation for a larger range) and also to age. Specifically, most second graders will show logarithmic representation in an unfamiliar range (up to 1,000), with linear representation in the familiar range (until 100). However, most sixth graders, like adults, will use linear representation regardless of range (Siegler & Booth, 2004; Siegler & Opfer, 2003). However, logarithmic representation can be found in adults due to cultural invention. For example, the Mundurucu, an Amazonian indigenous tribe with no formal education and with a minimal number word system, who at all ages map symbolic and non-symbolic numbers onto a logarithmic scale (Dehaene et al., 2008). Furthermore, a linear tendency is also related to individual differences in numerical abilities. Participants with better numerical abilities will show preference for linear representation over logarithmic representation (Booth & Siegler, 2006). Hence, even if number line estimations should be based upon averbal spatial representations, they are shaped by educational level, culture, and individual differences.

Most of the studies that used the number line estimation task tested schoolage children or adults (Siegler & Opfer, 2003). Only a few studies have tested preschoolers (Berteletti et al., 2010; Siegler & Booth, 2004). For example, Siegler and Booth (2004) examined 5- to 6-year-old children, in the range between 0 and 100, and found a logarithmic representation of that range. Berteletti et al. (2010) tested even younger preschoolers, beginning from the age of 3.5 years, in the ranges of 1-10, 1-20, and 0-100. They discovered that with development, children's estimates shifted from logarithmic to linear in the smaller number range. Estimation accuracy was correlated with knowledge of Arabic numerals and numerical order.

2 Do number line tasks reflect pure averbal numerical estimations?

Lately, there has been debate about the nature of the number to position task. Barth and colleagues (Barth & Paladino, 2011; Slusser & Barth, 2017; Slusser et al., 2013) suggest that the classical number to position task is based upon proportion-judgment strategies, rather than non-symbolic representations. In the number to position task participants are asked to place a number on a number line, and to do it using a base ten understanding of the number line and the distance between the number and reference point on the line (e.g., beginning, mid-point, and end of the line). Proportion estimation strategies involve focusing on a part of the line, thereby producing an estimation bias that is reflected in more precise estimations closer to the reference point, as compared to farther away from it. Accordingly, the shift between logarithmic and linear representation can be explained alternatively by the shift between judgment according to one reference point (the beginning of the line), to judgment according to two reference points (beginning and end of the line), and later on judgment according to three reference points (beginning, mid-point, and end point) (Slusser et al., 2013). Specifically, the first graders used the beginning of the line as a single reference point, while the second graders used both endpoints, and typically by the third grade children's strategy was similar to adults, as they used multiple reference points, including both endpoints and the midpoint. One major support for that view is that across age groups, 1 cycle function and 2 cycle function functions explain the data better (in relation to percentage of explained variance), compared to logarithmic and linear functions (Barth & Paladino, 2011).

3 Number space associations: Are they culturally driven or innate?

A variety of evidence, aside from the number line task, supports number space associations (de Hevia & Spelke, 2010; Hubbard et al., 2005; Wood et al., 2008). For example, in the parity judgment task, participants make their responses more quickly on the right for larger numbers and on the left for smaller numbers (Dehaene et al., 1993). This effect is called Spatial Numerical Association of Response Codes (SNARC). The SNARC effect is the main support for the assumption that the mental number line orients from left (small numbers) to right (large numbers) (Hubbard et al., 2005; Wood et al., 2008).

While the SNARC effect can be found in various tasks and situations (Wood et al., 2008), there is cultural variation in its direction and even its appearance (for review, see Göbel et al., 2011). For example, Dehaene et al. (1993) described an absence or even reversed SNARC effect in Iranian subjects, who read and write Farsi from right to left. Shaki et al. (2009) tested three groups of participants that differed in number and reading directions. (1) Hebrew-speaking participants, who read numbers from left to right, and Hebrew words from right to left; (2) Canadians (words and numbers are oriented from left to right); and (3) Palestinians (words and numbers are oriented from right to left). As expected, Canadians show associations between left-side space with small numbers, and right-side space with large numbers. By contrast, Palestinians showed reversed associations. Importantly, the Hebrew-speaking participants showed no associations between space and numbers. These results suggest that reading habits, for both words and numbers, contribute to the spatial representation of numbers (Shaki et al., 2009). Like the cultural variation of the SNARC effect, a cultural variation was found in finger counting direction (Lindemann et al., 2011). While most Western individuals started counting with the left hand (from left to right), most Middle Eastern (Iranian) respondents preferred to start counting with the right hand (from right to left) (Lindemann et al., 2011).

Lastly, right to left number space associations were found in English-speaking preschoolers prior to formal reading education. For example, young children showed left to right number space mapping during a non-symbolic numerosity comparison in the form of spatial-numerical congruity (quicker reaction times to smaller sets presented on the left side of the screen, and to larger ones presented on the right side) (Patro & Haman, 2012). Moreover, preschoolers in an implicit, color discrimination task showed the SNARC effect (represent right to left mapping of number to space; see previous paragraphs) (Hoffmann et al., 2013; Patro & Haman, 2012).

Notably, cultural variation in the direction of number space associations can start very early, before the formal acquisition of reading habits (Göbel et al., 2018; McCrink et al., 2018; McCrink & Opfer, 2014; Nuerk et al., 2015). In a recent study, American and Israeli toddler-caregiver dyads were tested in a situation of natural interactions (the infants were 2 years old). In the case of ordering spatial structures English-speaking American caregivers were more likely to use left to right spatial structuring, while Hebrew-speaking Israeli parents were more likely to use right to left spatial structuring. The authors concluded that spatial structure biases exhibited by caregivers are a potential route for the development of spatial biases in early childhood, before experiencing any formal education (McCrink et al., 2018).

4 The current study

The current study tested number space associations using the number line estimation task. We tested a group of young children (4–6 years old), before formal experience with reading. We used a familiar range for this age group, 1–9. In the first step, we verified our assumption that 1-9 was a familiar range for young children. Formal number knowledge was tested. Only children with formal number knowledge for the range of 1–9 were included in our sample.

All the children in our sample are native Hebrew speakers; Hebrew is read from right to left. This was found to modulate the direction of number space associations, in a task that implicitly connects numbers to space (e.g., the parity task), in adults (Göbel et al., 2018; McCrink et al., 2018; Nuerk et al., 2015; Shaki et al., 2009). Hence, the main goal of the present study was to test directionality of number space associations in Hebrew-speaking children. Estimations were to be given on number lines oriented from left to right (as expected in Western society) or right to left (similar to the directionality of number space associations for Hebrewspeaking preschoolers) (Shaki et al., 2012). We expected to find better estimations for right to left orientation of the number line than for left to right orientation. This effect should be modulated by children's age. Hence, younger children will show greater preference for right to left orientation than older children.

An additional goal of the present study was to test the effect of presentation on estimations. Magnitudes were presented as symbolic (Arabic numeral) or non-symbolic (dots). We expected that estimations would be modified by presentation. This effect should be modulated by children's age. It was suggested that younger children possess two separate representations for symbolic and non-symbolic quantities, while older children possess a united representation (Kolkman et al., 2013). Hence, we expected that the effect of presentation on estimation should be greater in younger children than in older children.

5 Method

5.1 Participants

Fifty-three subjects from three kindergartens in the central district of Israel participated in the study. The children's mean age was 51.43 months, SD 5.78 months, ranging between 41 and 60 months. All subjects were native Hebrew speakers and did not know how to read (an alphabet); 21 of the participants were female and 32 were male.

5.2 Procedure

Prior to conducting the study, the required approvals were obtained from the Ministry of Education and from the parents of the children for their participation in the study.

Each of the subjects was examined individually in a separate room. The tests were conducted in two sessions, each session lasting about 20 min. All subjects started the test with the pre-knowledge tasks. The order of tasks for each subject was randomly selected. As for the number line tasks, subjects were divided randomly into two groups. One group started with a symbolic number line, and the other group with a non-symbolic number line. Each group was divided into subgroups.

5.3 Task

The study consisted of three parts: (1) pre-knowledge tasks; (2) formal knowledge tasks; and (3) number line tasks. The aim of the pre-knowledge tasks was to test the required knowledge as a pre-condition for participating in the number line tasks.

5.3.1 Pre-knowledge tasks

The coding of tasks was done on a trial-by-trial basis. The score of 1 was given if the child performed with no errors, and a 0 was given for error trial. We averaged each of the repetitions in every task. Each of the tasks was tested four times.

5.3.1.1 Counting

The children were instructed to count freely up to ten.

5.3.1.2 Matching

The children were instructed to match between cards with quantities, and cards with numbers from 1 to 10. The numbers were selected randomly for each child.

5.3.1.3 Ordering

The children were instructed to arrange cards with numbers from 1 to 10.

5.3.1.4 Size ratio

The children were presented with two cards with consecutive numbers. They were asked to indicate which was the larger or the smaller number.

5.3.1.5 Concepts

5.3.1.5.1 Size

Big - small, bigger - smaller.

5.3.1.5.2 Quantity

Much – few, more – less.

5.3.1.5.3 Space

Close – far. For the absolute concepts, two pictures were presented to the children, and for the relational concepts three pictures were presented. The children were asked to point out the picture that fits the concept about which they were asked. The cards contained images of fruits (grapes or bananas) animals (dogs and horses) and objects (houses).

5.3.2 Formal knowledge tasks

5.3.2.1 Cardinality

5.3.2.1.1 The "How many" task

A brown rabbit doll was presented on a table. The experimenter said: "The rabbit likes cucumbers, so I'll give him some.

Please tell me how many cucumbers I should give him?" The amounts were varied randomly from 1 to 5.

5.3.2.1.2 "Give -N" task

A gray rabbit doll was presented on a table. The experimenter said: "The rabbit likes carrots very much. Please give him X carrots." The amounts were varied randomly from 1 to 5.

5.3.2.2 Adding one and subtracting one

The purpose of the next two tasks was to test whether the child knows the principle of a constant difference of 1 between consecutive numbers. The experimenter placed cards with pictures of carrots next to the rabbit and asks the child to count how many carrots the rabbit has. The experimenter repeated the

question several times until he was sure the child remembered how many carrots the rabbit has. Then the experimenter covered the cards and asked the child: "Do you remember how many carrots the rabbit has?" If the child didn't remember, the experimenter allows him to count again. Then he said: "now I give/take one carrot from the rabbit." Then, he added or subtracted one carrot. Then he asked the child without allowing him to count: "How many carrots will he left for the rabbit now?"

5.3.2.3 Order relations

Two rabbits are on the table, one brown and one gray. The experimenter gave one of the rabbits a quantity of cards with pictures of cucumbers (from 1 to 5). The other rabbit got a smaller (-1) or larger (+1) amount of cucumbers than the first rabbit. The experimenter asked the child to count and say how many carrots each rabbit has. Then he asked the child: "What can you do to make the gray rabbit have the same number of cucumbers as the brown rabbit, and vice versa." The child could see and count the quantities of the cucumbers for the two rabbits.

5.3.3 Number line estimation task

Included four subtasks: (1) symbolic orientation from left to right; (2) symbolic orientation from right to left; (3) non-symbolic orientation from left to right; and (4) non-symbolic orientation from right to left. The order of subtasks was selected randomly. Each trial was given on separate sheets of paper with a 13.5 cm. line on it, with one end labeled as 1 or () and the other end labeled as 9 or (). The children got four cards with numbers 3, 4, 6, and 7, one at a time, for symbolic and non-symbolic presentation and for congruent and incongruent directions. They were requested to locate the number by a vertical hatch mark on each sheet of paper. Before performing the task, the children performed practice trials with the numbers 1 and 8. The experimenter practiced the task with the children until he was sure the child understood what to do.

5.4 Stimuli

5.4.1 Cubes

In the matching, cardinality, adding one, subtracting one, and order relation tasks, we used cubes. In each task different color cubes were selected, to avoid

the possibility of children attaching numerical values to certain colors. All the cubes were about 1 × 1 cm in size.

5.4.2 Tabs

In the Matching and Ordering tasks, numeral tabs from 1 to 10 were used. In the size, quantity, and space tasks, the images on each tab were different and contained vegetables or fruits (lettuce, onions, carrots, potatoes, grapes, and bananas). All tabs were about 10×8 cm. in size.

5.4.3 Dolls

Brown and Gray Rabbit dolls about 10×20 cm. in size.

6 Results

6.1 Pre-knowledge

All the children in the sample were able to count to ten, count objects until 7 (as a minimum), and understood numerical concepts of size, quantity, and space. All of the sample could match quantity to Arabic numerals. Most of our sample could understand ratio relations (98%). Most of the children could order groups by size (94%).

6.2 Number line understanding

The entire sample understood the cardinality principle. However, formal understanding of the adding one principle was found in some of the children (73%). An even smaller proportion of the children were able to understand the subtracting one principle (34%). Similarly, only some of the children understood the role of numbers in representing ordinal relations (82%). Please note that none of the variables were related to age (see Tab. 1).

Tab. 1: Descriptive statistics for: (A) Pre-knowledge and (B) Formal number line understanding. The correlations between scores in these tests and age failed to reach significance (see the last column for the correlations).

Variable	Minimum	Maximum	Mean	Std. Dev	Age correlations
A. Matching	1	1	1	0	
Counting	1	1	1	0	
Ratio	0	1	.98	.14	
Ordering	.40	1	.94	.14	.05
Mathematical concepts	1	1	1	0	
B. Cardinality	1	1	1	0	
Adding one	.04	1	.73	.28	-0.6
Subtracting one	0	1	.35	.28	01
Order relations	.40	1	.82	.26	.04

6.3 Number line

6.3.1 Functions fit

The fit statistics of linear, logarithmic, 1 cycle (0.8), and 2 cycle (0.8) functions were computed to analyze the pattern of estimates. We computed these fit statistics for each individual child. We first aimed to exclude children whose fit statistics were negative or less than 0.55 (see the profile analysis).

6.3.1.1 Profile analysis

We examined the profiles of children related to their function fit statistics. To characterize profiles we used the linear fit, examining whether linear fit for each of the study conditions was greater than 0.55 (symbolic congruent (left to right), symbolic incongruent (right to left), non-symbolic congruent (left to right), nonsymbolic incongruent (right to left)). Children in profile 1 (N = 5) had only 1 condition with fit greater than 0.55. Children in profile 2 (N = 7) had 2 conditions with fit greater than 0.55. Children in profile 3 (N = 12) had 3 conditions with fit greater than 0.55. Children in profile 4 (N = 30) had 4 conditions with fit greater than 0.55. We excluded children from profiles 1 and 2 from the other analysis.

6.3.1.2 ANCOVA for individual level fits

A three-way analysis of covariance (ANCOVA) with a mean r value of fit to power analysis was computed, with function (1 cycle / 2 cycle/ linear / logarithmic), presentation type (symbolic/ non-symbolic), direction (congruent from left to right/incongruent from right to left) and the age of the children serving as a covariant. The effect of presentation reached significance [F(1, 39) = 9.22,partial $\eta^2 = .19$, p < .01]. The fit was better for symbolic (mean = 0.91, SD = 0.18) than for non-symbolic (mean = 0.78, SD = 0.39). The effect of directionality was also significant [F(1, 39) = 5.27, partial $\eta^2 = .12$, p < .05]. The fit was better for incongruent direction (right to left) (mean = 0.86, SD = 0.26) than for congruent (left to right) direction (mean = 0.81, SD = 0.32). The interaction between presentation and direction was also significant $[F(1, 39) = 4.64, partial n^2 = .11, p < .05]$. The differences between congruent and incongruent fit were not significant in the symbolic presentation (mean = 0.90, SD = 0.14, mean = 0.9, SD = 0.13 for congruent and incongruent respectively, t(41) = -.18, p = .86). However, in the non-symbolic presentation, fit for incongruent presentation (mean = 0.83, SD = 0.23) was better than for congruent presentation (mean = 0.71, SD = 0.39), with t(41) = -2.4, p < .05.

The effect of age interacted with presentation [F(1, 39) = 7.6, partial $\eta^2 = .16$, p < .01 and direction [F(1, 39) = 4.43, partial $\eta^2 = .10$, p < .05]. The interaction between age and congruency was also significant $[F(1, 50) = 6.10, partial \eta^2 = .1,$ p < .05]. The correlation between age and congruent (left to right) direction was significant r(40) = .40, p = .009. Fit was better as age increased. However, there were no significant correlations for the incongruent (right to left) direction r(40) = .10, p = .52. Similarly, the correlation between age and non-symbolic direction was significant, r(40) = .41, p = .007. Fit was better as age increased. However, there were no significant correlations for the symbolic representation r(40) = -.09, p = .56. Please note that the effects of function and interaction with function were not significant (see Fig. 1).

6.3.1.3 Percentage of absolute error

Children's estimation accuracy was computed as percentage of absolute error (PE). This was calculated with the following equation (Siegler & Booth, 2004):

$$PE = \frac{estimate - target \ number}{scale \ of \ estimates} \times 100$$

A two-way analysis of covariance (ANCOVA) with mean PE was computed, with presentation type (symbolic/non-symbolic), direction (congruent/incongruent), and the age of the children serving as a covariant. The effect of direction reached significance [F(41) = 7.39, partial $\eta^2 = .15$, p < .05]. PE were larger

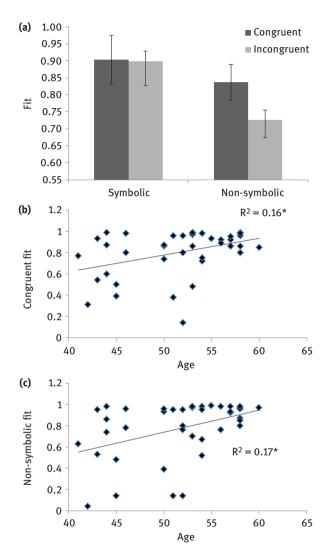


Fig. 1: (a) Function fit as a function of presentation (symbolic or non-symbolic) and direction (congruent from left to right or incongruent from right to left). In the symbolic representation the fit was very large regardless of direction. However, in the non-symbolic representation, fit was larger for incongruent representation than for congruent representation. Correlations between age and function fit in the congruent condition left panel (b) and non-symbolic representation right panel (c). Both are positively correlated, as age increases the fit is better both in the congruent condition and in the non-symbolic presentation. The correlations between incongruent direction and symbolic representation and age were small and non-significant.

in the congruent direction (left to right) (mean = 0.56, SD = 2.04) than the incongruent direction (right to left) (mean = -0.34, SD 2.43). This effect was modulated by age [F(1, 41) = 6.27, partial $\eta^2 = .13$, p < .05]. Age correlated with incongruent direction (right to left) errors, r (41) = .37, p = .015, but not with congruent direction (left to right), r (41) = -.063, p = .69.

The interaction between symbolic presentation and age was marginally significant [F(1, 41) = 3.47, partial $\eta^2 = .08$, p = .07] (see Fig. 2).

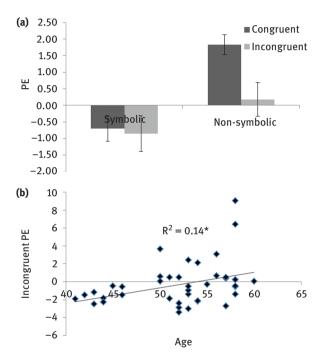


Fig. 2: Children's estimation accuracy was computed as percentage of absolute error (PE). (a) PE as a function of presentation (symbolic or non-symbolic) and direction (congruent from left to right or incongruent from right to left). PE were larger in the congruent direction than the incongruent direction. (b) Age correlated with incongruent direction errors, but did not correlate with congruent direction errors.

7 Discussion

The present study examined a number line estimation task, in a young group of Hebrew-speaking children (starting from 4 years old). Due to the young age of the children, we used a familiar range for that age: 1–9. Two conditions were

manipulated: (1) presentation: symbolic or non-symbolic (Arabic numerals or dots), and (2) directionality: congruent to the mental number line (from left to right), or opposite to the classical number line (from right to left).

We first examined general numerical abilities, as a prerequisite for participation of children in our sample. We found that the entire group had basic understanding of quantities: they were able to count freely, and all of them could count objects and understood mathematical concepts. This finding confirmed our assumption that for all the children in our group, 1–9 was quite a familiar range. However, in relation to the number line estimation task, 23% of the sample had no number line representation (linear, logarithmic, 1 cycle, or 2 cycle) in that familiar range, reflecting the dissociation of formal number knowledge and number space associations in young children.

We calculated functions fit (linear, logarithmic, 1 cycle or 2 cycle) on the individual level. We did not discover any preference (in terms of explained variability) for a specific function or interaction with specific function and the other variables. This finding may possibly be due to the small number of data points to estimate function fits in the present study. Hence, we will not refer to differences between functions fits from now on.

Two variables explained estimations. First, directionality: in the condition of number line orientation from right to left, we found better fits and lower estimation error rates than for orientation of the number line from left to right. Fit of left to right orientation improved with age. There was no such correlation with right to left orientation. In what follows, we suggest that Hebrew-speaking children possess a cultural bias for number space associations. Second, presentation affected estimation. Symbolic presentation had better fits than non-symbolic presentation. Estimations for non-symbolic presentation improved with age. There was no such correlation with symbolic presentation. In what follows, we suggest that young children possess two separate systems for processing of exact symbolic information and approximate non-symbolic information.

7.1 Dissociation of formal number knowledge and number space associations, in young children

Most studies on number line estimation tested children beginning from 5 years old (Siegler & Booth, 2004). To the best of our knowledge, only one other study tested young children (Berteletti et al., 2010), as in the present study. Similar to the present findings, 27% of their sample had no representation of small range (1–10). The present study has shown, for the first time, that children with formal knowledge of numbers could lack number space associations. However, formal

knowledge of (1) order relations and (2) adding and subtracting one rules was not fully developed in our sample, hinting at possible relations between these formal number line abilities and number space associations.

7.2 Directionality of number space associations in Hebrew-speaking children

In the present study, Hebrew-speaking children had better and more accurate fit when the number line orientation was from right to left, compared to the left to right orientation. It has been previously found that Hebrew-speaking adult participants differ from English-speaking participants in their number space associations (Shaki et al., 2009). While English-speaking participants associate small numbers with the left-side space and large number with the right-side space, Hebrew-speaking participants showed reversed associations or no associations (but see Feldman et al., 2019; Zohar-Shai et al., 2017).

This cultural directionality was associated with reading habits (Hebrew words are oriented from right to left). Specifically, the associations between number and space originate from directional counting preference (Göbel et al., 2018). Initially, there is a strong relation between reading direction and directional counting preference (i.e., most of the Hebrew-speaking participants start counting from the right, while most of the English-speaking participants start counting from the left), and later, directional counting preference determines the direction of number space associations (Göbel et al., 2011).

Please note, however, that we tested young children (as young as 4 years old) before formal reading education. How can cultural orientations emerge in young children? (Nuerk et al., 2015). According to Shaki et al. (2012), counting biases exist before reading acquisition in preschoolers, and were found to be modified by early reading experience (Shaki et al., 2012). About 72.9% of the Hebrew-speaking preschoolers started counting from right to left. Importantly, the rates dropped significantly to 55.8% of the Hebrew-speaking children attending school (Shaki et al., 2012). A common explanation for acquiring cultural counting bias, prior to school, is children's observation of adult's actions. Children watch adults reading stories to them, and observe them pointing at words and turning pages (Göbel et al., 2018). Moreover, it has been found that adults present spatial structures from left to right or from right to left according to their culture, demonstrating it to infants as young as 2 years old (McCrink et al., 2018).

Cultural bias for number space associations was found in several implicit number space association tasks, such as parity judgment (Dehaene et al., 1993). This task does not deliberately require participants to present numbers spatially.

However, there are no indications, so far, of cultural bias for number space associations, in a task that requires participants to represent numbers spatially, such as the number line estimation task. Here, for the first time, we revealed a preference for orientation of the number line from right to left in Hebrew-speaking children.

Please note that similar to the present finding, which demonstrates cultural bias in a number line estimation task in young children, the number line estimation task was found to be sensitive to cultural bias due to language structure of multidigit number words. In German, most multi-digit numbers are inverted (e.g., $48 \rightarrow$ "eight-and-forty"). However, there is no inversion in Italian number words. Accordingly, in the first grade, it was found that Italian children were more accurate in number line estimations than German-speaking children (Helmreich et al., 2011).

7.3 Dissociations between symbolic and non-symbolic processing in young children

The current results demonstrated that estimations of spatial locations of number are more precise when numbers are represented as Arabic numerals rather than as dots. This indicates that in young children, two numerical systems exist next to each other: (1) exact symbolic, (2) approximate non-symbolic. Kolkman et al. (2013) have already tested the effect of symbolic and non-symbolic presentation on estimations in a number line task in young children. They tested it, along with other tasks, longitudinally in 4- to 6-year-old children. Specifically, the authors tested whether the data can be explained best by a three-factor model that includes symbolic, non-symbolic, and mapping factors, or one united model. For 4to 5-year-olds, the three-actor model best explained the data, while at the age of 6 the united model best explained the data. Accordingly, the authors concluded that the developmental courses of non-symbolic and symbolic skills are all separate at a younger age and integrated by the first grade.

The finding of more precise estimations when numbers are represented as Arabic numerals instead of dots is not in line with the view that number line estimation reflects activation of the mental number line (Dehaene, 1992; Dehaene et al., 2003, 1999; Halberda & Feigenson, 2008; Halberda et al., 2008). According to the triple code model (Dehaene, 1992), the mental number line is a-modal, and representation of quantity on the mental number line is based upon translation of a specific number representation to an abstract quantity. Hence, contrary to the present results, estimations should not be modulated by presentation notation (symbolic or non-symbolic). Please note, however, that contrary to the triple code model that suggests only an abstract representation of quantity (Dehaene, 1992) Cohen Kadosh et al. (2007) suggested that the right parietal lobe possesses a notation-specific representation of symbolic and nonsymbolic presentations. This view can shed light on the differences between the precise representation of Arabic numerals and the approximate representation of dots that was discovered in the present study.

Lastly, the triple code model (Dehaene, 1992) as well as the findings of Cohen Kadosh et al. (2007) refers to processing by a developed adult brain, rather than a child's developing brain. Hence, it might be only a developmental phase of two numerical systems for processing of exact symbolic and approximate non-symbolic quantities, that will later be united into one system (Kolkman et al., 2013).

8 Conclusions and limitations

The present study tested number line estimation in young Hebrew-speaking children. Innovatively, we found more precise estimations when the number line was orienting from right to left. This finding is in line with the implicit number space association task that found cultural bias of preferences for right to left directions of the number line in Hebrew-speaking adults. This result in Hebrew-speaking adults is associated with reading habits; accordingly, we assumed that the explanation is parallel with the present study. However, we did not directly compare differences between number space associations between Hebrew-speaking children (Hebrew words are oriented from right to left) and English-speaking children (words are oriented from left to right). Hence, it will be important, in future studies, to examine directly number space associations in the number line estimation task of children from different cultures.

We found more precise estimations when numbers are represented as Arabic numerals rather than dots. Accordingly, we suggested that in young children, two numerical systems exist, one next to the other: (1) exact symbolic, (2) approximate non-symbolic. It would be important to see whether preferences for symbolic representation in number line estimation change developmentally, and whether these two systems integrate into one united system in later development.

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