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Observation of Directional Storybook Reading Influences Young Children’s Counting Direction

Silke M. Göbel1, Koleen McCrink2, Martin H. Fischer3 and Samuel Shaki4

1 - University of York, United Kingdom

2 – Department of Psychology, Barnard College of Columbia University, New York, United States of America

3- University of Potsdam, Germany

4 - Ariel University Center of Samaria, Israel

Word count (text plus references, without abstract, highlights & figure legends): 10479 words

Accepted by Journal of Experimental Child Psychology on 07/08/2017

Please send correspondence to:

Silke M. Göbel

Department of Psychology, University of York, Heslington, York YO24 1DF, England

Tel.: +44 1904 432872

e-mail: [silke.goebel@york.ac.uk](mailto:silke.goebel@york.ac.uk)

**Acknowledgements:** This research was supported by a British Academy/Leverhulme Small Research Grant to Silke Göbel and Sam Shaki (SG121544), and by R15HD077518-01A1 from the Eunice Kennedy ShriverNational Institutes of Child Health and Human Development to Koleen McCrink. We thank Hiba Abo, Joanne Clark, Beth Edlington, Megan Ettenger, Amarelle Hamo, Lama Manzur, Courtney Poole, Hannah Place, Lamisah Wilkinson and Francesca Wood for help with data collection. We would like to thank Maggie Snowling and Charles Hulme for thoughtful comments on earlier versions of this paper.

**Research Highlights**

* storybooks carry directional cues consistent with the cultural reading direction
* these directional cues influence the counting direction of 3- to 5-year olds
* just observing directional movements does not change preferred counting direction
* reading observation shapes spatial-numerical associations

**Abstract**

Even before formal schooling, children map numbers onto space in a directional manner. The origin of this preliterate spatial-numerical association is still debated. We investigated the role of enculturation for shaping the directionality of the association between numbers and space, focusing on counting behavior in 3-5-year-old preliterate children. Two studies provide evidence that, after observing reading from storybooks (left-to-right or right-to-left) children change their counting direction in line with the direction of observed reading. Just observing visuo-spatial directional movements had no such effect on counting direction. Complementarily, we document that book illustrations, prevalent in children’s cultures, exhibit directionality that conforms to the direction of a culture’s written language. We propose that shared book reading activates spatio-temporal representations of order in young children which in turn affect their spatial representation of numbers. [145]

**Keywords:** counting direction, cross-cultural, mental number line, reading, spatial-numerical association

**Observation of directional storybook reading influences young children’s counting direction**

Cultural differences reflect and reinforce behavioral practices, from social conventions to traffic directions (Berry, Breugelmans, Poortinga, Chasiotis, & Sam, 2011). Our cognitive skills are also shaped by cultural practices, as in the systematic use of physical space for literacy and numeracy. When asked to think about numbers, people often activate a mental number line on which number concepts are represented by increasing magnitude and with systematic direction: In Western cultures, small numbers are associated with left space and larger numbers with right space. Spontaneous associations between number and space were initially described in Western adults (Dehaene, Bossini, & Giraux, 1993; Göbel, Shaki, & Fischer, 2011; Shaki, Fischer, & Göbel, 2012; Wood, Willmes, Nuerk, & Fischer, 2008) and children (Berch, Foley, Hill, & Ryan, 1999; Hoffmann, Hornung, Martin, & Schiltz, 2013). These associations were initially attributed to a “spill-over” from habitual reading direction (Berch et al., 1999; Dehaene et al., 1993). However, the presence of such an association between numbers and space already in preschoolers who are not yet reading fluently (Opfer, Thompson, & Furlong, 2010; Patro & Haman, 2012; Shaki et al., 2012) demands a different explanation for its origin. The current paper provides evidence for a novel account that explains the directional nature of this early-developing association between numbers and space in preschoolers and how it differs across cultures.

A general preference for an association between numbers of increasing magnitude and left-to-right space has been found in both preverbal infants (Bulf, de Hevia, & Macchi Cassia, 2015; de Hevia, Girelli, Addabbo, & Macchi Cassia, 2014) and non-human animals (Adachi, 2014; Rugani, Kelly, Szelest, Regolin, & Vallortigara, 2010; Rugani, Vallortigara, Priftis, & Regolin, 2015). For example, Bulf, de Hevia, and Macchi Cassia (2015) showed that centrally presented numerosities bias the visual attention of 8-9-months-olds in a directional manner. This shifting of spatial attention was specific for numerical cues and not present for non-numerical cues (small/large shapes). Rugani et al. (2015) reported that 3-day-old chicks trained with an intermediate number of dots subsequently spontaneously associated a smaller numerosity with the left and a larger numerosity with the right side of space (but see Shaki & Fischer, 2015). This suggests a biological contribution to the association between numerical magnitudes and space that is at some point modified by culture.

In humans, the direction of the association between number and space is influenced by how long adults had lived in a left-to-right reading culture (Dehaene et al., 1993; Shaki, Fischer, & Petrusic, 2009). This cultural modulation is also present in other numerical tasks, such as counting: While the majority of British adults count horizontally aligned objects from left to right, most Arab adults – in line with their predominant reading direction – count them from right to left (Shaki et al., 2012). This cultural contribution has often been explained as reflecting the many hours spent actively scanning text with eyes and fingers (Shaki & Fischer, 2008). Specifically, making repeated horizontal eye movements, often accompanied by directional finger movements, might induce a directional bias in line with the acquired, culturally predominant reading direction. However, the presence of a similar association between numbers and space already in pre-literate children requires a modification of this proposed mechanism. An early biologically-driven preference to associate small numerosities with left space might be subsequently shaped by cultural (spatial) experiences such as reading (Bulf et al., 2015; de Hevia et al., 2014; Nuerk et al., 2015). This explanation is appealing and covers the majority of available findings. However, it does not explain exactly *how* cultural experience works to alter the association between numbers and space at such a young age.

Here we test the role of another cultural experience in the emergence of culture-specific spatial-numerical associations: parents and children reading together. Although preliterate children cannot read they experience reading-related activities. They monitor adult reading behavior (Dobel, Diesendruck, & Bölte, 2007), pretend to read or write (Sulzby, 1985; Tolchinsky, 2003) and often possess some rudimentary writing skills (Puranik, Lonigan, & Kim, 2011). Storybook reading is a pervasive activity in the homes, preschools and daycares of literate societies. Surveys in the U.S. A. (Montag, Jones, & Smith, 2015; Raikes et al., 2006) suggest that 30-50% of parents of preliterate children read to their child at least once a day. Even children who do not fully understand reading can be found happily paging through a book (Sulzby, 1985). Thus, both the spatial characteristics of printed materials and the observations of others interacting with such materials are likely influences on the development of the association between numbers and space in preliterate children. This cluster of activities surrounding reading –referred to as *reading observation* - might shape the direction of an early association between numbers and space. The present studies test this hypothesis.

Reading observation is beginning to receive attention as a likely mechanism shaping the association between numbers and space in preliterate children (McCrink, Caldera, & Shaki, in press; McCrink & Opfer, 2014; Nuerk et al., 2015). So far, however, no study has directly tested whether the spatial layout of books, or the observation of others interacting with books, can influence the direction of the association between numerical magnitudes and space in preliterate children. In adults, several studies have shown that the direction of this association can be changed by activating different spatial reference frames (e.g., Bächtold, Baumüller, & Brugger, 1998; Fischer, Shaki, & Cruise, 2009; Göbel, Maier, & Shaki, 2015). For example, Shaki & Fischer (2008; see also Fischer et al., 2009) showed that the strength of the left-to-right association between number and space in bilingual Russian-Hebrew adults varied in line with their recent text reading experience: the association was significantly reduced after reading a Hebrew text (right-to-left reading) in comparison to reading a Russian text (left-to-right reading).

The current studies test whether two components of reading observation (the culture-specific spatial layout of books and the observation of adults’ interactions with books) shape the directionality of the association between numbers and space in preliterate British and Arab children. In Study 1 we document that the orientation of illustrations shown to infants and young children in commercially available children’s books is highly directional and reflects the written language of the book: English-language books portray actions going from left to right on the page while Hebrew-language books portray events developing from right to left. In studies 2 and 3 we experimentally demonstrate that the directional cues children receive when parents read a storybook to them modify children’s association between numbers and space. Specifically, we carefully created two version of a counting storybook (‘The Very Hungry Caterpillar’), differing only in directionality: a left-to-right and a right-to-left version. We then compared counting direction in preschool children before and after reading observation of the left-to-right versus right-to-left version of the storybook. In both studies we found significant changes in children’s association of numbers with space. While the picture books used in study 2 contained a counting activity, we removed any counting from the books for study 3. Reading observation without any counting observation in study 3 also led to systematic changes in counting direction. Study 4 shows that directional spatial-attentional shifts, even when accompanied by adult-led gestures, do not systematically modulate the association between number and space. In sum, our results clearly establish reading observation as one mechanism underlying the cultural sensitivity of the preliterate association between number and space.

**Study 1: Directionality in children’s books from two reading cultures**

We have reviewed above that culture-specific directional spatial mappings for stimuli are present before reading and writing acquisition [(Opfer & Furlong, 2011; Shaki et al., 2012)](https://paperpile.com/c/NjZkDR/HxZn+0c0H). One plausible explanation for these biases is that extensive implicit directional structuring exists throughout the preliterate child’s environment. The purpose of our first study was to document the degree of such spatial directionality in children’s books. Thus, we selected an extensive collection of English-language illustrated children’s books with a targeted reader age range of infancy to 8 years. We also collected a set of children’s books written in Hebrew to study whether the reading direction of the language used in the book altered the directionality of the illustrations within. Based on the culture-specificity of action schemata (e.g., Maass, Suitner, & Deconchy, 2014), we predicted that the directional orientation of the main characters will be consistent with the language of the book (e.g., the primary actor in a scene will be oriented mainly left-to-right for English-language books, and mainly right-to-left for Hebrew-language books).

***Method***

*Stimuli*. We examined 89 English-language books, with 16 Level 1 (target age 0-2 years), 22 Level 2 (target age 3-4 years), 28 Level 3 (target age 5-6 years), and 23 Level 4 (target age 7-8 years) books. The 18 Hebrew-language books included three Level 1, seven Level 2, six Level 3, and two Level 4 books (average number of words per page was calculated (Level 1 = 7.2, Level 2 = 13.7, Level 3 = 29.7, Level 4 = 51.1).

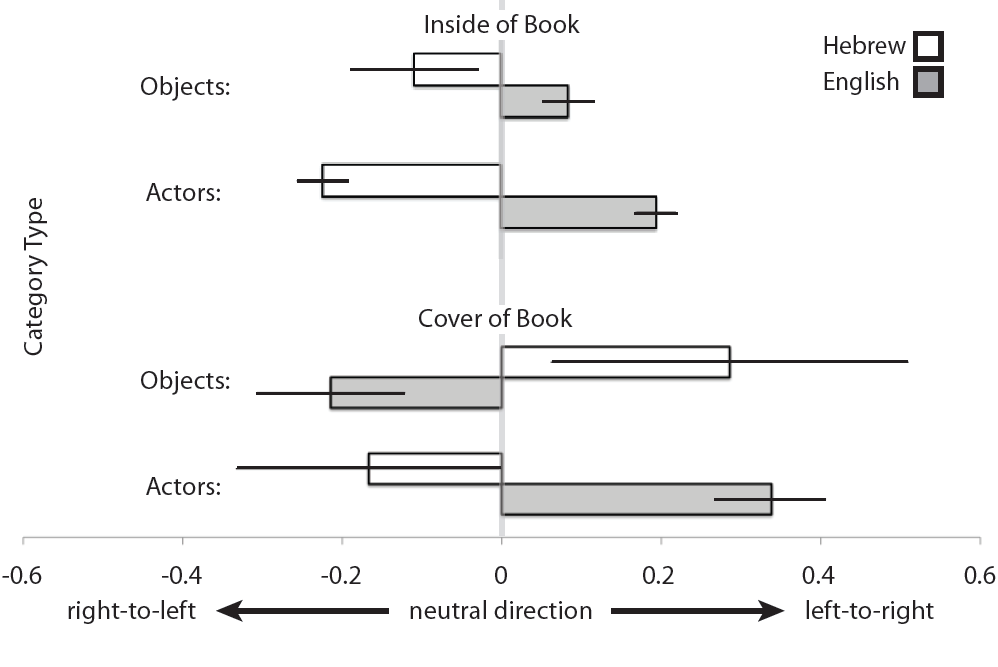
*Coding.* Two coders examined each book separately for the cover and the internal contents. Two “planes” were noted for each page: the action plane where the storyline is carried out in illustrations, and the background plane against which the action took place. The action plane reflected the overarching, unfolding narrative relevant to that scene. For example, a book in which a little girl must shoo away birds from the second floor of a building has the action of the shooing and the main characters on the action plane, and the sky with clouds and an open window on the background plane. The objects on the page were separated into four types: (1) Primary actor(s) (PA): main animate being of the scene; (2) Secondary actor(s) (SA): any animate being in the action plane that is important to the illustration; (3) Primary object(s) (PO): main inanimate object in the action plane of the actors/action of the scene; (4) Secondary object(s) (SO): any other inanimate object in the action plane.

Any illustration without a clear actor or object in their own action plane against the background (a collage, for example) was excluded from analysis. The relevant parts of the illustration were coded as left-to-right (+1), right-to-left (-1), or indiscriminate (0). The orientation of the character or object determined the coding; for example, if a character was gazing towards the right side of the page this was coded left-to-right, and if an object being acted upon by the character was oriented with its primary features pointing left this was coded right-to-left. Any disagreements between the two coders were resolved through discussion and the values across all of the illustrations in a book were averaged for each category. An additional coder who was blind to the hypotheses of the study coded 12 of the books for reliability. This reliability coder also noted the -1 to +1 directionality of each actor and object; the correlation between the original coding scores and reliability coding scores was *r*(12) = .80.

This gives each book a score for each category (Primary Actors, Secondary Actors, Primary Objects and Secondary Objects) that ranges from -1 to +1, with a score above 0 reflective of LR orientation and a score below 0 reflective of RL orientation. Consistent with our hypothesis about the orientation of main characters, we will only report results for the action plane.

***Results and Discussion***

*Cover scene*. For the cover score, the primary and secondary actor scores were averaged and the primary and secondary object scores were averaged to form an overall actor score and object score (Figure 1). These scores were entered into a repeated-measures ANOVA with category type (Actor, Object) as a within-book variable and reading level of book (1, 2, 3, 4) and language (English, Hebrew) as the between-book variables. There was a significant category type x language interaction, *F*(1,28) = 6.44, *p* = .017, *partial η2*= .19.



*Figure 1:* Directionality of illustrations in picture books. The horizontal orientation scores for each category type (the actors and objects in the scene, collapsing over primary and secondary) are plotted for each language. Error bars represent +/- 1 SEM.

Planned analyses corrected for multiple comparisons revealed a significant difference between English and Hebrew language books for the Actor (MEnglish = .39 [SEMEnglish = .14] vs. MHebrew = -.56 [SEMHebrew.= .32]), *F*(1,28) = 7.59*,* *p* = .010, *partial η2*= .21, but not the Object (MEnglish = -.23 [SEMEnglish = .18] vs. MHebrew = .22 [SEMHebrew = .40]), *F*(1,28) = 1.05, *p* > .250, *partial η2*= .04. In English books there was a significant directional difference between category types, *F*(1,28) = 7.53, *p* = .010, *partial η2*= .21, with the Actor (.39) significantly more LR than the Object (-.23), which tended to be oriented RL. This is likely due to the complementarity of the actors and objects on the covers (e.g., a girl picking up a ball). There was no difference for the Hebrew language books for the directionality of the Actor (-.56) and Object (.22), *F*(1,28) = 2.32, *p* = .139, *partial η2*= .08. Post-hoc one-sample tests against a test value of 0 were conducted for the actor and object scores for each language: for English books, the Actor score, *t*(88) = 4.94, *p* < .001, *Cohen’s d* = .52, but not the Object score, *t*(27) = - 1.30, *p* = .206, *Cohen’s d* = - .24, was significantly different from 0, and for Hebrew language books neither category was significantly different from 0, Actor: *t*(17) = - 1.00, *p* > .250, *Cohen’s d* = - .24, Object: *t*(6) = 0.80, *p* > .250, *Cohen’s d* = .30.

*Internal scenes.*  PA and PO scores were entered into a repeated-measures ANOVA with category (actor, object) as a within-book variable and reading level (1, 2, 3, 4) and language (English, Hebrew) as between-book variables. There was a significant overall effect of language, *F*(1,94) = 38.27, *p* < .001, *partial η2*= .29. English-language books were overall oriented LR (MEnglish = .13 [SEMEnglish = .02]) and the Hebrew-language books RL (MHebrew = -.18 [SEMHebrew = .05]). There was a significant interaction between category type and language, *F*(1, 94) = 9.06, *p* = .003, *partial η2*= .09. Post-hoc comparisons corrected for multiple comparisons indicate a significant effect of language on the Actor category (MEnglish = .19 [SEMEnglish = .02] vs. MHebrew = -.26 [SEMHebrew =.05]), *F*(1,94) = 79.20, *p* < .001, *partial η2*= .46, and a marginally significant effect of language on the Object category (MEnglish = .06 [SEMEnglish =.03] vs. MHebrew = -.09 [SEMHebrew -= .08]), *F*(1,94) = 3.54, *p* = .063, *partial η2*= .04. For the English-language books the Actor and Object categories differed significantly, *F*(1,94) = 12.01, *p* = .001, *partial η2*= .11, and for Hebrew-language books the category types were marginally different, *F*(1,94) = 3.30, *p* = .073, *partial η2*= .03. There was a marginally-significant three-way interaction of category type with reading level and language, *F*(3,94) = 2.25, *p* = .09, *partial η2*= .07. Post-hoc comparisons, corrected for multiple comparisons, reveal this interaction was driven by a significantly higher score (e.g., more LR directionality) for the Actor category in the Level 1 books geared towards infants (MLevel1 = .28 [SEMLevel1 = .05]) relative to the Level 2 books geared towards pre-schoolers (MLevel2 = .11 [SEMLevel2 = .04]), *p* = .03, in the English sample. Post-hoc one-sample tests against a test value of 0 were conducted for the actor and object scores for each language. For both languages, the primary actor score significantly differed from zero, English: *t*(87) = 7.62, *p* < .001, *Cohen’s d* = .81; Hebrew: *t*(17) = -7.03, p < .001, *Cohen’s d* = - 1.66, as did the primary object score for the English books, *t*(84) = 2.53, *p* = .013, *Cohen’s d* = .55, but not Hebrew books, *t*(17) = -1.37, *p* = .188, *Cohen’s d* = -.66.

In this analysis we find that the orientation of illustrations in children’s books differs as a function of character category and the language the book was written in. The actors depicted on the covers of books and in the primary action scenes of these books – features that are highly salient objects of focus to the child during reading observation - are significantly more likely to be depicted in a culturally-consistent spatial orientation relative to an object in the scene. This probably reflects the spatial agency bias, in which adult readers (and, presumably, illustrators) position agents and objects in positions that are linguistically-congruent with their culture [(Maass, Suitner, & Deconchy, 2014)](https://paperpile.com/c/NjZkDR/Wg8y+Gkdu+BFm2). The resulting materials are the focus of preliterate children’s attention. Children are frequently exposed to this directional spatial information, both on their own as they pick up books (DeLoache, Uttal, & Pierroutsakos, 2000), and alongside caregivers who provide additional linguistic context in the form of a narrative [(Montag, Jones, & Smith, 2015; Raikes et al., 2006)](https://paperpile.com/c/NjZkDR/vAZg+jrTN+Y8Jd). Therefore, reading observation is a candidate process for how directional associations between number and space emerge in preliterate children.

**Study 2: Reading observation and children’s counting direction**

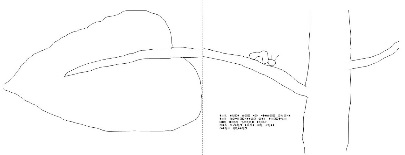
The aim of our second study was to test directly whether reading observation modulates subsequent counting direction. We tested preliterate children from two cultures who differed in terms of their culturally predominant reading direction: left-to-right (British) versus right-to-left (Arab) reading. If reading observation is a driver of spatial directionality, we predict that the manner of reading will modulate the way in which children map number to space in their counting routines. If only longstanding cultural experience (e.g., many hours of reading observation in one’s home environment) has the power to influence associations between number and space, then a short directional storybook experience might not lead to any changes in counting direction. British children would then show a preference, unaltered by reading observation, to count from left to right and Arab children from right to left. If, however, children’s associations between number and space are influenced by the immediate linguistic context (as in adults: Fischer, Shaki & Cruise, 2009; Shaki & Fischer, 2008), then we would expect an effect of reading observation: children would be more likely to count left-to-right after having observed the left-to-right storybook, and more likely to count right-to-left after having observed the right-to-left storybook.

***Method***

Participants. Eighty-seven British (mean age 3.8 years, SD = 0.75, 44 girls) and sixty Arab (mean age 4.1 years, SD = 0.77, 31 girls) right-handed children were tested individually in a single session. Based on Shaki et al. (2012) at least 61 children per group are required to have an 85% chance of detecting a significant difference in counting preference at the 5% level. For this study and subsequent studies, written informed consent was obtained from all nursery managers. Caregivers were informed and gave opt-out consent before the testing session. All children gave verbal consent on the day of testing. All studies had ethical approval from the Department of Psychology, York, UK. This study also had approval from the Faculty Ethics Committee of Ariel University, Ariel, Israel.

Procedure. Children sat at a table with the experimenter sitting either to their right or left side. To establish children’s initial counting bias, children covered their eyes with both hands and then the experimenter placed four golden plastic coins (diameter = 3.2 cm) equidistantly in a horizontal line on a mat (42.5 cm by 30.5 cm, landscape orientation) which was positioned centrally in front of each child. Children were then asked to open their eyes and to point to each coin and count aloud how many they saw. Counting is one of the earliest exact numerical activities children engage in, and thus has a high degree of ecological validity.

Next, all children engaged in a reading-related spatial experience – our reading observation. For this, we prepared two modified versions of a children’s storybook ‘The Very Hungry Caterpillar’ [(Carle, 1969; with the publisher’s permission)](https://paperpile.com/c/NjZkDR/68cu). Each book was presented in landscape format (18.6 cm by 11.2 cm) with 12 double-sided pages. In the Left-book all text was left-aligned, the book was bound on the left and pages were turned right-to-left. For the Right-book we used mirror-images of the pages in the Left-book, all text was right-aligned, the book was bound on the right and pages were turned left-to-right. All letters were replaced with meaningless pseudo-font symbols. Half the children from each culture received the Left-book and the other half the Right-book.



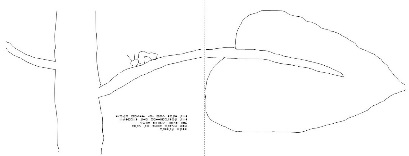
The next day was Sunday again.

The caterpillar ate through

one nice green leaf,

and after that he felt

much better.



The next day was Sunday again.

The caterpillar ate through

one nice green leaf,

and after that he felt

much better.

child

child

adult

adult

A

B

Left-book

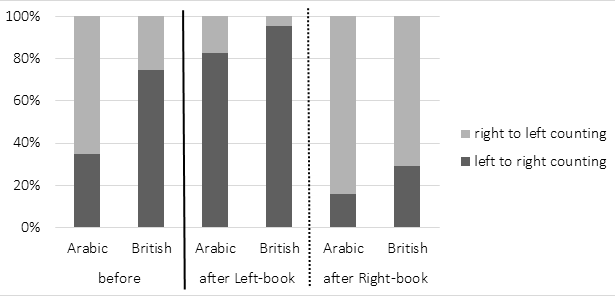
Right-book

*Figure 2:* Schematic illustration of the reading observation in study; A: for the Left-book reading observation, B: for the Right-book reading observation.

The book was placed in front of the child and the experimenter told the story verbatim from memory (in English or Arabic, respectively) while pointing left-to-right (for the Left-book) or right-to-left (for the Right-book) to the symbols for each individual word and turning the pages (see Figure 2). In the story a hungry caterpillar comes out of an egg, looks for food and eats one apple, two pears, three plums, four strawberries and finally five oranges. The experimenter stated those verbal numerals explicitly while pointing to one apple, two pears, three plums etc. The children were asked to attend and point to objects on each page (e.g., “where is the caterpillar?”). This reading observation activity took only 2 – 3 min. Afterwards, we determined post-reading counting bias by asking all children to count four plastic strawberries (object size roughly 3.5 cm by 3.0 cm by 2.5 cm), using the same procedure as with coins.

***Results and Discussion***

*Initial counting bias* varied with cultural reading direction (Figure 3, Table 1): significantly more children from the left-to-right reading culture (British children) counted left-to-right (74.7%) compared to children from the right-to-left reading culture (Arab children; 35.0%), *χ²*(1, *N* = 147) = 23.07, *p* < .001, *φ* = .40.

*Figure 3:* Counting direction in pre-schoolers and reading observation. Percentage of children from cultures with different reading habits (Arab: right-to-left; British: left-to-right) who counted left-to-right (dark grey) or right-to-left (light grey) before shared book reading and after shared book reading (Left-book: book followed left-to-right reading direction, Right-book: book followed left-to-right reading direction).

*Post-reading counting bias:* Overall, 66.7 % of children whose initial counting bias was opposite to their reading experience changed their counting direction (22 children from the Left- book condition and 24 children from the Right-book condition), compared to only 1.3% of children whose initial counting bias was in the same direction as their reading experience (one child from the Right-book condition, Figure 3), *χ²*(1, *N* = 147) = 71.96, *p* < .001, *φ* = .70. A McNemar’s test for repeated measures showed that children from the right-to-left reading culture showed a significant pattern of change in their counting direction after left-to-right reading experience, *N* = 29, *p* < .001, but not after the right-to-left reading experience, *N* = 31, *p* = .29. For children from the left-to-right reading culture the McNemar’s test showed a significant change of counting direction for both, left-to-right reading experience: *N* = 46, *p* = .002, right-to-left reading experience: *N* = 41, *p* = .019 (Table 2).

*Table 1:* Percentage of children counting left to right versus right to left before and after reading observation/video band percentage of changes in counting direction from before to after by study

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Initial counting bias | |  | Post-activity counting bias | |  | Changes in counting direction | | |
| Study | Reading culture | N | Left to right | Right to left |  | Left to right | Right to left |  | Predicted direction | Opposite direction | No change |
| 2 | Right-to-left | 60 | 35.0% | 65.0% |  | 48.3% | 51.7% |  | 28.3% | 1.7% | 70.0% |
|  | Left-to-right | 87 | 74.7% | 25.3% |  | 64.4% | 35.6% |  | 33.3% | 0% | 66.7% |
| 3 | Left-to-right | 87 | 86.2% | 13.8% |  | 73.6% | 26.4% |  | 17.2% | 2.3% | 80.5% |
| Follow-up | Left-to-right | 68 | (85.3%) | (14.7%) |  | 88.2% | 11.8% |  | 11.8% | 8.8% | 79.4% |
| 4 | Left-to-right | 168 | 65.5% | 34.5% |  | 66.7% | 33.3% |  | 7.7% | 4.8% | 87.5% |

*Table 2:* Percentage of children counting left to right versus right to left before and after reading observation/video by book/video condition separately for each study

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Initial counting direction | | | | | | |  | Post-activity counting direction | | | | | |
|  |  | Left book/video | | | | Right book/video | | |  | Left book/video | | | Right book/video | | |
| Study | Reading culture | N | Left to right | Right to left | N | | Left to right | Right to left |  | N | Left to right | Right to left | N | Left to right | Right to left |
| 2 | Right-to-left | 29 | 41.4% | 58.6% | 31 | | 29.0% | 71.0% |  | 29 | 82.8% | 17.2% | 31 | 16.1% | 83.9% |
|  | Left-to-right | 46 | 73.9% | 26.1% | 41 | | 75.6% | 24.4% |  | 46 | 95.7% | 4.3% | 41 | 29.3% | 70.7% |
| 3 | Left-to-right | 42 | 81.0% | 19.0% | 45 | | 91.1% | 8.9% |  | 42 | 83.3% | 16.7% | 45 | 64.4% | 35.6% |
| Follow-up | Left-to-right | 31 | 80.6% | 19.4% | 37 | | 89.2% | 10.8% |  | 31 | 90.3% | 9.7% | 37 | 86.5% | 13.5% |
| 4 | Left-to-right | 87 | 69.0% | 31.0% | 81 | | 61.7% | 38.3% |  | 87 | 73.6% | 26.4% | 81 | 59.3% | 40.7% |

Irrespective of their initial counting direction, 82.8% of children who participated in the left-to-right reading experience now counted left-to-right, compared to only 16.1% of children who participated in the right-to-left reading experience. Similarly, 83.9% of children who participated in the right-to-left reading experience now counted right-to-left, compared to only 17.2% of children who participated in the left-to-right reading experience (Figure 3, table 2). Post-reading counting bias was significantly influence by reading observation, *χ²*(1, *N* = 147) = 67.73, *p* < .001, *φ* = .68.

Children’s initial counting direction reflected the cultural reading direction in both left-to-right and right-to-left reading cultures. This bias is already present when children are just three years old and well before formal reading acquisition. Furthermore, this culturally shaped counting bias was easily changed for both groups by a short reading observation scenario, in particular when the reading observation was opposite to the culturally predominant reading direction. This suggests that children’s associations between number and space are strongly influenced by recent spatial cues that violate their expectations.

**Study 3: Follow-up test of counting direction**

Children adapted their counting direction directly after reading observation in study 2. However, we were concerned that the reading observation in study 2 contained a counting activity: The book had discrete objects arranged in a line and the sense of magnitude growing both throughout the storyline as well as within each page (e.g., the caterpillar ate 1 apple, then on the next page 2 pears, then 3 plums, etc.). The change in counting direction observed in study 2 could thus have been a consequence of observing an adult counting in the direction of the book (left-to-right for the Left-book, right-to-left for the Right-book), in other words an instance of adult modelling [(Bandura, 1986; Meltzoff & Williamson, 2013)](https://paperpile.com/c/NjZkDR/5jpX+vM59) of the target outcome behaviour. In order to test our hypothesis that the change in counting direction was related to the reading observation independently of counting observation, we replicated study 2 with all counting removed from the books.

In addition, it is unclear how stable the induced counting bias observed in study 2 is, and how long this change persists. Thus in order to examine the durability of any changes that occur, we tested British children on their counting direction directly after the reading observation and again four weeks later. During those four weeks children will have had ample exposure to their culturally predominant reading direction (left-to-right), but little or no exposure to the opposite reading direction (right-to-left). We thus expected that four weeks after the experimental reading observation the majority of children would have returned to the counting direction in line with their culturally predominant reading direction; i.e. the reading observation will no longer show an effect on the counting direction.

***Methods***

Participants. Eighty-seven right-handed British 3-5-year-old children (mean age 3.9 years, SD = 0.74, 42 girls) were tested. None of these children had received any formal reading instruction or had participated in study 2.

Procedure. Children were tested exactly as described in study 2 with two differences: first, the five counting pages in both the Left- and the Right-book were replaced by five pages containing five objects each and the text was changed to “the caterpillar ate through apples, pears, plums, strawberries and oranges.” Second, 68 of those children (mean age 3.9 years, SD = 0.75, 34 girls) were retested after four weeks (the remaining 19 children were not available for retesting). We determined the follow-up counting bias by asking all children to count four plastic frogs (3.5 cm length, 3.5 cm width, 2 cm height), using the same procedure as in study 2.

***Results and Discussion***

*Initial counting bias*: significantly more children from the left-to-right reading culture counted left-to-right (86.2 %) than right-to-left (13.8 %), *χ²*(1, *N* = 87) = 45.62, *p* < .001, *φ* = .721 (Figure 4, Table 1).

*Post-reading counting bias:* Overall, 30.6 % of children whose initial counting bias was opposite to their reading observation changed their counting direction (2 children from the Left- book condition and 13 children from the Right-book condition), compared to only 5.3% of children whose initial counting bias was in the same direction as their reading experience (one child in each group), *χ²*(1, *N* = 87) = 8.75, *p* = .003, *φ* = .32. A McNemar’s test for repeated measures showed that children showed a significant pattern of change in their counting direction after the right-to-left reading observation, *N* = 45, *p* = .002, but not after the left-to-right reading experience, *N* = 42, *p* = 1.00. Post-reading counting bias showed a significant difference related to reading experience, *χ²*(1, *N* = 87) = 3.99, *p* = .046, *φ* = .21. Irrespective of the initial counting direction, 83.3% of children who participated in the left-to-right reading experience now counted left-to-right, compared to only 64.4% of children who participated in the right-to-left reading experience. Similarly, 35.6% of children who participated in the right-to-left reading experience now counted right-to-left, compared to only 16.7% of children who participated in the left-to-right reading experience (Figure 4, Table 2).



*Figure 4:*Stability of counting direction in preschoolers. Percentage of children from a left-to-right reading culture who counted left-to-right (dark grey) or right-to-left (light grey) before shared book reading, directly after shared book reading (Left-book: book followed left-to-right reading direction, Right-book: book followed left-to-right reading direction) and 4 weeks later.

*Follow-up counting bias:* 88.2% of those 68 children who were available for retesting four weeks later counted left-to-right (Table 1). The counting bias did no longer significantly differ as a function of the book used during the reading experience four weeks earlier, *χ²*(1, *N* = 68) = 0.24, *p* > .250, *φ* = .06. Of all children who were retested, 90.3% of those who had participated in the left-to-right reading experience counted left to right and 86.5% of those who had participated in the right-to-left reading experience counted left to right (Table 2).

*Comparison of study 2 and study 3:* there was no significant difference between the number of children from the left-to-right reading culture who changed their counting direction after the right-to-left reading experience in study 2 and 3, study 2: 46.3%, study 3: 31.1%, *χ²*(1, *N* = 86) = 2.10, *p* = .147, *φ* = .16. However, there was trend for children from the left-to-right reading culture in study 3 to be less likely to change their counting direction after the left-to-right reading experience than in study 2 (study 2: 21.7%, study 3: 7.1%), *χ²*(1, *N* = 88) = 3.72, *p* = .054, *φ* = .21. This is not surprising given that in study 2 as part of the reading observation the experimenters modelled counting direction. The power of adult modelling on children’s behaviour is well-documented. While imitation of adult behaviour might play a role in the generation of counting biases, results from Shaki et al. (2012) suggest that for preschool children cultural reading direction is more influential than adult counting direction. In this study Israeli adults and children were tested. The majority of Israeli adults counted left-to-right while the majority of Israeli preschool children counted right-to-left. These findings are contrary to what would be expected if children were simply copying adult counting behaviour and thus provide evidence against a pure imitation account for counting direction.

In line with this, results from study 3 clearly establish that reading observation still significantly influenced the counting direction of preschool children, even when adult modelling of counting was not present in the storybook. This shows that children are sensitive and respond quickly to task-irrelevant spatial cues when they are in contrast to their regular reading experience. This adaptive change in counting direction, however, was not stable over time. Four weeks after the reading observation there was no longer any significant difference in the frequency of counting directions between children who took part in the left-to-right reading observation versus those who took part in the right-to-left reading observation. Most children’s counting direction was again in line with the culturally predominant reading direction.

**Study 4: Visuo-spatial attention and counting direction**

The results of studies 2 and 3 have established that children’s counting is temporarily influenced by their most recent reading observation. This leads us to the question about the way in which reading observation influences counting direction. Reading observation involves a large number of directional cues, such as overt eye-movements and associated covert attentional shifts driven by the words on the page, but also the results of joint attention from observing another person looking and pointing at the words and images on the page (Moore & Dunham, 1995). These spatial cues, plus the modelling of directional motor actions by an adult model, might have led to high engagement of the child and increased the tendency for behavior-matching [(Csibra & Gergely, 2009)](https://paperpile.com/c/NjZkDR/qYWY). Finally, the narrative itself includes a directional progression in the form of a sequence of events across space and time. All these components of reading observation are potential sources of the adaptation of the association between number and space. Although a large number of studies will be required to isolate and identify the underlying mechanism of changes in the association between number and space during naturalistic and multi-component reading observation, we test in Study 4 whether the non-linguistic, directional visuo-spatial engagement of attention is driving the reading observation effect.

***Methods***

Participants. 171 right-handed British children (mean age = 4.08 years, SD = 0.75, 96 females) were tested. None of these children had received any formal reading instruction or participated in studies 2 or 3.

Procedure. Children sat at a table with the experimenter sitting either to their right or to their left side (counterbalanced across participants). To establish their initial counting bias, children covered their eyes with both hands and then the experimenter placed four plastic gold coins (diameter = 3.2 cm) equidistantly in a horizontal line on a mat (42.5 cm by 30.5 cm, landscape orientation) that was positioned centrally in front of each child. Children were then asked to open their eyes, point to each coin and count aloud how many coins they saw.

Next, all children watched a 3 min video in which animals moved across the screen either from left to right (Left-video) or right to left (Right-video). Importantly, the duration of the video was roughly as long (if not longer) as the duration of the reading observation in studies 2 and 3. The videos were created in E-Studio Professional 2.0 and presented on a 15 x 17 inch laptop screen. In both videos, 11 sequences with a different animal in each sequence (e.g., sheep, duck, fish) were presented. Each animal-moving sequence consisted of four different, subsequently presented slides, with the same animal picture. The four slides only differed in the location of the animal picture: the center of the same picture was placed at either 3.4 inches (position 1), 6.8 inches (position 2), 10.2 inches (position 3) or 13.6 inches (position 4) from the left side of the screen (and always at 6.5 inches from the bottom of the screen). Each slide was presented for 1000 ms. Sound clips (from<http://soundbible.com> and [www.freesfx.co.uk](http://www.freesfx.co.uk)) chosen to represent the prototypical sound associated with each animal accompanied each picture presentation. Sound onset was synchronised with slide presentation. A blank slide appeared for 1000 ms between each animal moving sequence. The sequence was repeated twice, thus resulting in 22 spatial shifts compared to 12 spatial shifts in studies 2 and 3.

In the Left-video, each animal started at position 1 and ended at position 4, moving left-to-right across the screen. In the Right-video, animals began at position 4 and ended at position 1, moving right-to-left across the screen. The Left- and Right-videos contained exactly the same pictures of animals and sounds in the same order, only the order of animal positions differed between the videos. During the display of the Left- or the Right-video the experimenter, sitting next to the child, used her right hand to point to each animal appearing on the screen while looking onto the screen and remaining silent. Children were told to concentrate on the screen and listen to the sounds. Afterwards, children were asked to count four plastic strawberries (object size roughly 3.5 cm by 3.0 cm by 2.5 cm), using the same procedure as described above. Finally, children were invited to choose a sticker as their reward. Three children (2 girls, 1 boy) changed counting direction within one counting trial and their data were excluded from further analyses.

***Results and Discussion***

*Initial counting bias*: As expected, significantly more of these British children counted left to right (65.5%) than right to left (34.5%), χ²(1, *N* = 168) = 16.1, *p* < .001, *φ* = .31 (see Figure 5, Table 1).



*Figure 5:*Effect of visuo-spatial attention shifts on counting direction in preschoolers. Percentage of children from a left-to-right reading culture who counted left-to-right (dark grey) or right-to-left (light grey) before watching a directional video and after watching a directional video accompanied by experimenter pointing (Left-video: left-to-right motion direction, Right-video: left-to-right motion direction).

*Post-video counting:* A McNemar’s test for repeated measures showed that children showed no significant pattern of change in their counting direction neither after the right-to-left video, *N* = 81, *p* > .250, nor after the left-to-right video, *N* = 87, *p* > .250.

*Comparison of study 4 to study 3:* Children from a left-to-right reading culture were significantly more likely to change their counting direction after the right-to-left reading experience in study 3 than after the right-to-left video experience in study 4 (study 3: 31.1%, study 4: 7.4%), *χ²*(1, *N* = 126) = 12.17, *p* < .001, *φ* = .31. However, there was no significant difference between the number of children from the left-to-right reading culture who changed their counting direction after the left-to-right reading experience in study 3 and those who changed their counting direction after the left-to-right video experience in study 4 (study 3: 7.1%, study 4: 17.2%), *χ²*(1, *N* = 129) = 2.41, *p* = .121, *φ* = .14.

In study 4, children showed again an initial preference for a counting bias in line with the culturally predominant reading direction. However, after a visuo-spatial motor engagement, there was no significant change in their counting behaviour. Children were equally likely to change their counting direction in line with the direction of the video as into the opposite direction. These data are in contrast with studies 2 and 3, where children showing a systematic and significant shift into the direction of book observation.

The aim of study 4 was to test the most plausible alternative explanation, i.e. that the repeated systematic movement of visuo-spatial attention caused the effects observed in study 2 and 3. We carefully matched the duration of the video intervention to the average duration of the book reading intervention. Because the main variable of interest was shifting of visuo-spatial attention we increased the number of stimulus-induced visuo-spatial shifts in study 4 to 22 visuo-spatial shifts for each child (in comparison to 12 spatial shifts in studies 2 and 3). If shifts in visuo-spatial attention alone were the key factors behind the effects in study 2 and 3 we should have observed an effect in study 4 given the larger number of directional visuo-spatial shifts.

In summary, the results of study 4 show that spatial-attentional cues alone – even when coupled with a motor and social component - cannot explain the systematic effect of reading observation seen in study 2 and 3.

**General discussion**

Children’s observations of adults reading to them transmits cultural skills. At least two factors contribute to this transmission. First, observing directional interactions with printed materials induces spatial biases in children’s spatial-numerical activities. Second, the illustrations in picture books themselves are culturally shaped and echo the directionality of the written language of a culture.

Children’s spatial-numerical biases reflect their recent directional reading observation. In studies 2 and 3 children’s choice of counting direction was significantly modified by their recent reading observation. This modification was sensitive to the child’s previous experience; it occurred only when children observed an adult reading in a manner inconsistent with what they previously knew. Thus, children can learn to count in a manner inconsistent with their culture, and they are selectively responsive to information that disconfirms their previous experience. These findings are in line with predictive coding theory (see Clark, 2013). According to this theory, the brain predicts outcomes based on previous information and tries to minimize the prediction error by preferentially processing information that does not match the predictions it made based on previous experience.

Our experiments document that systematic cultural practices shape the preliterate association between number and space, and make a unique contribution by showing a direct effect of reading observation - and not merely visuo-spatial attention – on counting direction in preliterate children. Additionally, in study 1 we documented that the directional cues we varied in our experimental manipulations in studies 2 and 3 are present in commercially available picture books used in everyday life. We thus find evidence for a strong natural candidate pathway for shaping spatial-numerical associations in children who cannot yet read themselves: reading observation.

This leads us to an important question: through which mechanism/s does reading observation lead to changes in counting direction? The current studies were not designed to investigate in detail all aspects of reading observation that might modulate counting direction, but study 4 tested one candidate: shifts of visual attention accompanied by pointing. This mechanism seemed plausible because not only does eye movement behaviour in reading differ significantly across different writing systems [(Deutsch & Rayner, 1999)](https://paperpile.com/c/NjZkDR/n2ZA), reading direction also influences preferred visual scanning direction of non-text material [(Abed, 1991; Rinaldi, Di Luca, Henik, & Girelli, 2014)](https://paperpile.com/c/NjZkDR/ImP1+Xxat). Furthermore, the culturally predominant reading direction has been shown to modulate spatial biases in line bisection, both in adults [(Kazandjian, Cavézian, Zivotofsky, & Chokron, 2010)](https://paperpile.com/c/NjZkDR/bUBS+BZmU+GruL) and in pre-school children: [Chokron and De Agostini (1995)](https://paperpile.com/c/NjZkDR/Ua97) found a significant effect of cultural reading direction on line bisection already in their youngest group of participants (mean age 4.5 years). In adults there is a close link between visuo-spatial attention and numerical tasks [(Fischer et al., 2003; Göbel, Calabria, Farnè, & Rossetti, 2006; Knops, Thirion, Hubbard, Michel, & Dehaene, 2009)](https://paperpile.com/c/NjZkDR/2XTL+wZwe), with some evidence for a neural association between directional eye movements and arithmetic number-space associations [(Knops et al., 2009)](https://paperpile.com/c/NjZkDR/wZwe). Thus there are reasons to propose that reading observation can lead to directional biases in visuo-spatial attention, even in preliterate children, and that these directional biases are altering their association between number and space.

However, in clear contrast to studies 2 and 3, in study 4 children were not more likely to change their counting direction *in the direction of the observed cues* than changing in the direction opposite to the observed cues. This suggests that shifts of visuo-spatial attention alone cannot account for the association between number and space. Recent results by [Patro, Fischer, et al. (2015)](https://paperpile.com/c/NjZkDR/t9RJ) suggest that different types of associations between number and space might be modulated by different spatial mechanisms. In line with our findings, their visuo-spatial motor training, while it affected a task measuring an association between number and response side, did not lead to a change in explicit counting direction. Thus, despite considerable evidence linking shifts in visuo-spatial attention to spatial-numerical associations [(Bächtold et al., 1998; Fischer et al., 2003; Stoianov, Kramer, Umiltà, & Zorzi, 2008; Zorzi et al., 2002)](https://paperpile.com/c/NjZkDR/7FTy+xYI1+Giu0+RmUg), the current series of experiments does not provide clear evidence for a causal role of attentional shifts leading to directional biases for explicit counting in preliterate children.

Currently, the most plausible mechanism underlying this reading observation effect is the activation of a *mental time line*. The nature of reading observation (as opposed to visual shifts of attention without a narrative, as in study 4) means that children experience events that unfold, one after the other, in a temporal narrative. Adults [(Bonato, Zorzi, & Umiltà, 2012)](https://paperpile.com/c/NjZkDR/uULV) and children (Bottini & Casasanto, 2013; Koerber & Sodian, 2008; Tversky et al., 1991) represent time as space, and do so with a directionality that is culture-specific [(Bonato et al., 2012; Ouellet, Santiago, Israeli, & Gabay, 2010)](https://paperpile.com/c/NjZkDR/uULV+j7s8). Furthermore, several studies have established a causal role of reading direction in determining spatial representations of time [(Ariel, Harthy, Was, & Dunlosky, 2011; Casasanto & Bottini, 2010)](https://paperpile.com/c/NjZkDR/obaT+7j6G). [Casasanto and Bottini (2014)](https://paperpile.com/c/NjZkDR/8lfo), for example, showed that after reading mirror-reversed text for as little as 5 minutes the direction of participants’ mental time lines changed from the initial left-to-right orientation to a right-to-left orientation. Thus, we speculate that left-to-right reading observation increases the probability and strength of an association of time and space along a left-to-right mental time line while right-to-left reading observation leads to a stronger tendency to associate movements in time from right to left space (and thus to favour a right-to-left mental time line).

How, then, could the direction of children’s mental time line affect counting direction? There are at least two possible pathways. First, counting objects in order might have been perceived by the children as a temporal ordering task. Thus, the direction of their mental time line could directly influence the direction of their counting. This would predict that any pointing task irrespective of the involvement of a numerical element should be affected by reading direction. Future studies will have to investigate this idea, but we think this is highly unlikely. Study 4 much more explicitly manipulated spatio-temporal order than studies 2 and 3: children observed the experimenter explicitly pointing to animals appearing one after the other on different positions on the screen, thus highlighting the spatio-temporal order and modelling spatio-temporal properties of the pointing behavior for them. However, there was no significant effect of this specific spatio-temporal order manipulation on counting direction in study 4. We thus suggest that the mental time line affects counting direction in a more indirect way. There is increasing evidence that time, space, and number are represented with a common magnitude system (Walsh, 2003), even in infancy (Lourenco & Longo, 2010). Directional changes in the association between space and time by reading observation could thus lead to changes in the direction of space-number associations, because representations of time, space and number are being simultaneously activated. Future studies will have to test this hypothesis, for example by testing whether training on directional spatial-numerical associations influences the orientation of space-time mappings.

While the mental time line explanation is appealing, would this explanation not predict even stronger directional changes in the association between space and time after the video observation in study 4, because there the association between space and time was more explicitly and systematically manipulated? There are at least two possible reasons for why reading observation might have influenced the mental time line representation more strongly than video observation. First, while there is a clear association between space and time in both activities, in the video condition this association is only present within each animal sequence. In contrast, during reading observation, in addition to the order of events on each page, there is a longer-term development of a storyline, a narrative arc, that is progressing from the first to the last page. This narrative development is missing in the video condition. Here, different animals appear and move across the screen making animal noises, but there is no sense of a development from the beginning of the video observation to the end. It is thus likely that the association of start with left for the Left-book (or right for the Right-book) and a development from left to right (or right to left) is much more firmly established during the reading observation than during video observation. Secondly, there is a linguistic component in the story telling during reading observation which is absent in the video condition. Like many stories in picture books for young children, the linguistic component of the book we used emphasises temporal development. For example temporal markers are used on nearly every page (On Sunday…He started....the next day). Those markers connect pages temporally, again with an overarching order from beginning to end. It is possible that temporal markers automatically activate a mental time line. Future studies will have to investigate which aspects of reading observation (e.g. the development of a narrative or the temporal markers of a story) contribute significantly towards the orientation of space-time and thus space-number mappings.

Alternatively, given that spatial-numerical associations can be manipulated by serial order in working memory, is it possible that directional reading observation could have affected the ordinal position of numbers in working memory? Van Dijck and Fias (2011) showed that when participants from a left-to-right reading culture had to keep a sequence of numbers in working memory that numbers that came earlier in the sequence were responded to faster with a left response and numbers later in the sequence were responded to faster with a right response. A similar phenomenon occurs in toddlers from left-to-right reading cultures, who spontaneously map initial information from a sequence to the left side of a set, and final information to the right (McCrink, Perez, & Baruch, 2017). Based on this and similar findings the working memory account (van Dijck & Fias, 2011; van Dijck, Ginsburg, Girelli & Gevers, 2015) proposes that the ordinal position of numbers in working memory is spatially coded and affects associations between numbers and space. Could this working memory account also explain our findings? Children might have encoded the events happening in the book in an ordered sequence in (working) memory. Depending on which book condition they were in they might have associated the beginning of the events with the left side of space (in the Left-book condition) or the right side of space (in the Right-book condition). Our two book conditions would thus result in the opposite order of events in (working) memory. However, in order to explain how the order of non-numerical events in (working) memory then subsequently affected counting direction this account also needs to propose a shared representation between space, time and numbers.

Assuming this shared representation, the working memory account might also be able to explain the effect of the reading observation. However, we do favour the mental time line account, because working memory account in itself cannot explain the baseline differences in counting preference between cultures that we clearly observed in study 2 and in previous studies (e.g., Shaki et al., 2012). The assumption of the working memory account is that numbers are stored in working memory in their canonical sequence, e.g. ordered by size starting with the smallest number, unless the order has been manipulated by task or context. This working memory account however does not explain why numbers at the beginning of the sequence are associated with left in Western participants and with right in participants from right-to-left reading cultures and why there is no directional bias in illiterates. To account for all our data the working memory account would need to be combined with a shared representation between space, time and numbers that is influences by reading direction.

Focusing on the initial counting preference, all studies reported here show a significant preference in 3-5 year-old children from a left-to-right reading culture to count from left-to-right. However, the amount of children showing this preference varies in our studies from around 66% in study 4 to around 86 % in study 3. This is in line with a range of percentages reported in the literature for this age range: in a sample of 429 British preschool children Shaki et al. (2012) reported left-to-right counting for 61%, and Knudsen et al. (2014) in German pre-schoolers reported an even lower percentage. Opfer and Thomson (2006) and Opfer and Furlong (2011) in American preschoolers reported 98% and 76% of left-to-right counters, and McCrink et al. (2017) reported 55% in American toddlers. Future studies will have to investigate which factors influence the strength of the initial counting bias seen in a particular sample. Our results suggest that the amount of reading experience and reading observation the participating children had will be a crucial factor.

***Conclusion***

In sum, the current studies provide evidence that everyday, early-occurring cultural experiences of children with storybooks shape the nature of their quantity representations. Even before formal schooling children have a propensity to map numbers onto space and we have shown that – as with adults - the precise form of that mapping depends on long-standing as well as recent reading observation. Therefore we propose that one way by which the preliterate association between number and space is shaped is by reading observation. Storybook reading is a common, often daily activity for young children and we have shown that commercially available storybooks carry directional cues that are in line with the culturally dominant reading direction. We hypothesize that reading observation is an attractive and pleasurable activity for young children that, by the temporal nature of a story line paired with the directional use of space in reading, activates spatial representations of time, which in turn affect the spatial representations of number.

**Acknowledgements**

This research was supported by a British Academy/Leverhulme Small Research Grant to X and Y (SG121544), and by R15HD077518-01A1 from the Eunice Kennedy Shriver

National Institutes of Child Health and Human Development to Z. We thank Hiba Abo, Joanne Clark, Beth Edlington, Megan Ettenger, Amarelle Hamo, Lama Manzur, Courtney Poole, Hannah Place, Lamisah Wilkinson and Francesca Wood for help with data collection. We would like to thank Maggie Snowling and Charles Hulme for thoughtful comments on earlier versions of this paper.

**Open Practices**

All data have been made publicly available via Open Science Framework and can be accessed at https://osf.io/fy6ec/.

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***Figure Legends***

*Figure 1:* Directionality of illustrations in picture books. The horizontal orientation scores for each category type (the actors and objects in the scene, collapsing over primary and secondary) are plotted for each language. Error bars represent +/- 1 SEM.

*Figure 2:* Schematic illustration of the reading observation in study; A: for the Left-book reading observation, B: for the Right-book reading observation.

*Figure 3:* Counting direction in pre-schoolers and reading observation. Percentage of children from cultures with different reading habits (Arab: right-to-left; British: left-to-right) who counted left-to-right (dark grey) or right-to-left (light grey) before shared book reading and after shared book reading (Left-book: book followed left-to-right reading direction, Right-book: book followed left-to-right reading direction).

*Figure 4:*Stability of counting direction in preschoolers. Percentage of children from a left-to-right reading culture who counted left-to-right (dark grey) or right-to-left (light grey) before shared book reading, directly after shared book reading (Left-book: book followed left-to-right reading direction, Right-book: book followed left-to-right reading direction) and 4 weeks later.

*Figure 5:*Effect of visuo-spatial attention shifts on counting direction in preschoolers. Percentage of children from a left-to-right reading culture who counted left-to-right (dark grey) or right-to-left (light grey) before watching a directional video and after watching a directional video accompanied by experimenter pointing (Left-video: left-to-right motion direction, Right-video: left-to-right motion direction).