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Picturing time: Children's preferences for visual representations of events

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Abstract

English-speaking adults recruit a left-to-right "mental timeline" (MTL) when thinking about time. The origins of the MTL are debated, with some arguing that it is a cultural construct and others arguing that it is rooted in innate associations between time and space. Here we ask whether preschoolers, with limited experience with cultural practices thought to shape the MTL, prefer conventional linear representations of temporal events. English-speaking preschoolers and adults were told stories and asked to choose which of two visual representations best illustrated the story. As expected, adults overwhelmingly preferred images that were linearly ordered from left-to-right. Five-year-olds also preferred left-to-right to right-to-left series, but were equally likely choose left-to-right and top-to-bottom. By contrast, 3-year-olds chose at random, apparently insensitive to the spatial ordering of event-denoting images. These results suggest that attention to the ordinal structure of visual representations of time increases across early childhood, and that adults' preference for horizontal space-time mappings results from increased cultural conditioning.

Keywords: time; space; mental timeline; events; abstract concepts

1. Introduction

Time and space are deeply interwoven in human experience and culture. For example, diverse societies use spatial tools to depict, measure, and track time; languages often use the same words to refer to both time and space (e.g., *long* and *short*); and readers repeatedly experience temporal narratives unfolding in a particular spatial direction across the page. Behavioral and neuroscientific studies suggest that adults have implicit linear associations between specific locations in time and positions in space (for a review, Bonato et al., 2012). The nature of the relationship between this "mental timeline" (MTL) and cultural practices that link time and space is debated. On the one hand, systematic cross-cultural differences in the direction of the MTL (e.g., Boroditsky, 2011; Bergen & Lau, 2012) suggest that it is learned. On the other hand, evidence of space-time mappings in infants (e.g., de Hevia et al., 2014; Lourenco & Longo, 2010; Srinivasan & Carey, 2010), and the ubiquity of spatial artifacts and metaphors across cultures (Haspelmath, 1997) suggest that some form of MTL may be intrinsic to human cognition. Do cultural tools linking time and space *create* mental associations across domains, or do they simply capitalize on a low-level, biological predisposition to think about time spatially? Understanding the development of space-time associations in children who cannot yet read or use spatial artifacts for time could shed light on this question. Here, we test whether 3- to 5-year-old preschoolers show adult-like preferences for linear representations of events.

Cross-cultural comparisons involving adults and school-aged children have revealed reliable differences in the orientation and direction of ordinal space-time mappings (e.g., Tversky, Kugelmass, & Winter, 1991). The left-to-right (LR) mental timeline is robust in speakers of English and many other languages using an LR orthography, but speakers of languages that are written from right-to-left (RL), often construe of time in an RL line (e.g., Ouellet et al. 2010; Tversky, Kugelmass, & Winter, 1991). Vertical associations between time and space have also been found in speakers of Chinese, which can be written top-to-bottom (TB) and also contains vertical time-space metaphors (e.g., Boroditsky, 2011). Many cultural and environmental sources of the MTL (and the analogous "mental number-line," MNL) have been posited. These include: reading/writing direction, space-time metaphor in language, exposure to artifacts such as calendars, counting-related practices, early visual experiences, and simply growing up in a community with existing space-time associations.

In contrast to purely cultural accounts, some theories contend that we have an innate predisposition to associate space and time. One such theory posits that space, time, and number rely on a single system for magnitude representation (Walsh, 2003). Consistent with the idea that language and social cues are not the sole sources of the MTL, infants and even neonates appear to make implicit associations between duration and spatial length (e.g., de Hevia et al., 2014; Srinivasan & Carey, 2010). Going beyond a general magnitude account, others have argued that the ordinal structure of the MTL/MNL also has a neurophysiological and evolutionary basis, and may be LR by default (Chatterjee, 2001; Rugani et al., 2015).

Importantly, cross-cultural differences in the direction of the adult MTL indicate that, even if innate ordinal space-time mappings exist, they can be modulated by reading-writing behavior or other types of cultural conditioning. It is therefore difficult to pinpoint the developmental origins of the MTL, or to disentangle its potential biological or environmental causes, in adults populations with many relevant types of cultural knowledge.

Here, we explore when and how time-space mappings develop in a population whose exposure to cultural input is more limited: children. Because formal instruction in reading/writing and spatial tools for time often begins in the early school years, evidence of linear space-time associations in younger children might suggest these abilities are not critical to the formation of the MTL. The purpose of the current study is to test whether preschoolers already have a preference for visual representations of events depicted in conventional ordered lines. If so, this might suggest that the tendency to form mental mappings between time and space is not entirely culturally constructed.

Several prior studies argue that directional space-*number* associations are present in preliterate preschoolers (see Nuerk et al., 2015). For instance, English-speaking preschoolers spontaneously count objects from LR, while Hebrew speakers count from RL. Biases on purely spatial tasks such as line-bisection have also been observed in preschoolers. These effects are generally stronger in older children and adults. To the extent that both the MNL and MTL draw on similar spatial representations, we might expect to observe similarly early biases toward LR representations of time in English-speaking preschoolers.

Relatively few studies have investigated space-time mappings in preschoolers. Timeline tasks indicate that 4-year-olds can place events on an LR line more accurately than chance, but that this ability improves considerably over the next 3+ years (e.g., Hudson & Mayhew, 2011; Tillman et al., 2017). Importantly, tasks in which a single type of timeline is provided for children to use cannot address whether they privilege particular spatial orientations or directions. However, even without a template, a majority of school-aged children place stickers representing events in ordered lines with a culture-specific direction (e.g., LR for English-speakers; Tversky, Kugelmass, & Winter, 1991).

In contrast to older children, preschoolers rarely place event-denoting stickers in lines spontaneously, and those who do so show a much more modest, if any, bias toward LR lines (Tillman, Tulagan, & Barner, 2015). Similarly, older children, but not preschoolers, produce spatial representations of single events in which the agent, object, and recipient are linearly ordered in a culturally-conventional direction (Dobel, Diesendrunk, & Bolte, 2007). Together, these studies suggest that the automatic deployment and the direction-specificity of the MTL develop slowly in early childhood, and may rely on literacy and/or formal schooling to become fully engrained.

Critically, tasks like those discussed above either require children to use sophisticated artifacts or to create visual representations of time, and therefore may require significant visuospatial, motor, and working-memory skills. For instance, the sticker-placement task requires an ability to use non-iconic stickers symbolically, sufficient motor control to put them in specific spatial locations, and memory of what previously-used stickers represent. It is therefore possible that the difficulty of these tasks could have masked existing associations between time and space in preschoolers. To address this concern, the present study employs a forced-choice task with minimal response demands to test whether English-speaking preschoolers prefer conventional linear representations of time. Preschoolers were told brief stories describing three-step event sequences, given a choice between two spatial depictions of each story, and asked which of the two was better. In Experiment 1, to test whether children have direction preferences, they chose between (conventional) LR, RL, TB, and bottom-to-top (BT) representations of events. In Experiment 2, to test whether children were sensitive to the ordinality of the images, they chose between ordered and unordered sequences.

2. Experiment 1

2.1 Methods

2.1.1 Participants. Participants included 62 3-year-old children (*M* age = 3;6), 60 5-year-old children (*M* age = 5;5), and 85 adult controls. They were pseudo-randomly assigned to one of 3 conditions: Horizontal (n = 21 3YO; 21 5YO; 29 adults), Vertical (n = 20 3YO; 20 5YO; 29 adults), and Mixed (n = 21 3YO; 20 5YO; 27 adults). Children were recruited from museums and daycares in the San Diego, CA, area, and adults were workers on Amazon Mechanical Turk. All participants spoke English as their primary language, and none spoke a secondary language with non-LR orthography. Adults and parents of children gave informed consent to participate. Children were awarded a small prize, and adults were compensated $1. An additional 9 children were tested but excluded from analysis because either English was not their primary language (n = 3), they spoke a second language with a non-LR orthography (n = 2), they failed to complete the task (n = 2), developmental delay (n = 1), or clerical error (n = 1). Five adults were excluded from analysis due to speaking a language with non-LR orthography (n = 2) and lack of attention to the task, as indexed by failing a "catch" trial (n = 3).

2.1.2 Procedure. On each of 8 trials, children heard a story involving 3 steps (see Table 1). The experimenter placed two cards on the table in front of the child, and asked: "Which card shows that story? Which one is *better*?"

Table 1. ***Event stories*****.**

Event	*First..*	*Then..*	*And..*	Images (LR)
Egg	there was an egg	the egg cracked	a baby chick came out!	
Ice Cream	there was an ice-cream	it started melting	and it was all gone!	
Drawing	someone started drawing a stem	they added blue petals	it was a flower!	
Caterpillar	there was a caterpillar	it made a cocoon	it turned into a butterfly!	
Baby	a baby was born	he started growing	he was a big kid!	
Apple	there was an apple	someone took a bite	they ate it all!	
Rose	a rose started growing	it opened	it got big and pink!	
Watermelon	there was a watermelon	we cut it all up	everyone ate it!	

After the child pointed to their choice, the cards were removed, and the next trial began.

Participants in the Horizontal condition always chose between one card with three pictures depicting the story in order from left-to-right (LR; see Table 1 and Fig 1A) and another with the same 3 pictures ordered from right-to-left (Fig. 1B). Participants in the Vertical condition chose between cards with images arranged from top-to-bottom (Fig 1C) vs. bottom-to-top (Fig 1D), and, in the Mixed condition, between LR and TB lines (Fig. 1A vs. 1C). The two cards were placed side-by-side in the Vertical and Mixed conditions, but were positioned one above the other in the Horizontal condition. Every child heard the Egg story first. Half the children heard the remaining stories in the order listed in Table 1, and half heard them in the reverse order. The positioning of the two cards was counterbalanced across subjects and items. Adults read the stories on a computer, and clicked the image they thought was better. Data analysis was done using R and the *lme4* package.

2.2 Results

2.2.1 Horizontal condition. Participants in the Horizontal condition chose between LR and RL sets of images (e.g., Fig. 1A vs. 1B). To test for direction preferences, we calculated the percentage of trials on which each subject chose the LR card. As expected, virtually all adults (n = 28 of 29) chose the LR card on every trial (Fig 2A). In contrast, the median percentage of LR choices for 5-year-olds was lower, at 75%, and these children were less consistent across trials than were adults (see Fig 2A). The median percentage of LR picks by 3-year-olds was 50%. Exact Wilcoxon signed-rank tests confirmed that 3-year-olds' performance was consistent with random guessing ($V = 24.5$, $p = 0.5$), but five-year-olds selected the LR card significantly more often than chance ($V = 126.5$, $p = 0.02$).

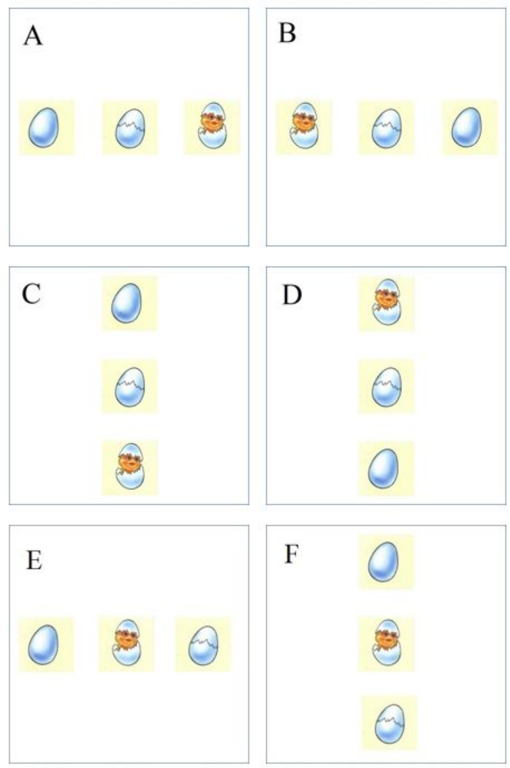

Figure 1: *Example picture cards.* The three images on each card depict the three stages in the Egg story (see Table 1). Cards used in Experiment 1: (**A**) LR, left-to-right, **(B)** RL, right-to-left, (**C**) TB, top-to-bottom, and (**D**) BT, bottom-to-top. Additional cards used in Experiment 2: (**E**) Scrambled Horizontal and (**F**) Scrambled Vertical.

2.2.2 Vertical condition. Participants in the Vertical condition chose between TB and BT images (Fig 1C vs. 1D). As shown in Figure 2B, 90% of adults (n = 26 of 29) chose the TB card on every trial. A subset of 5-year-olds

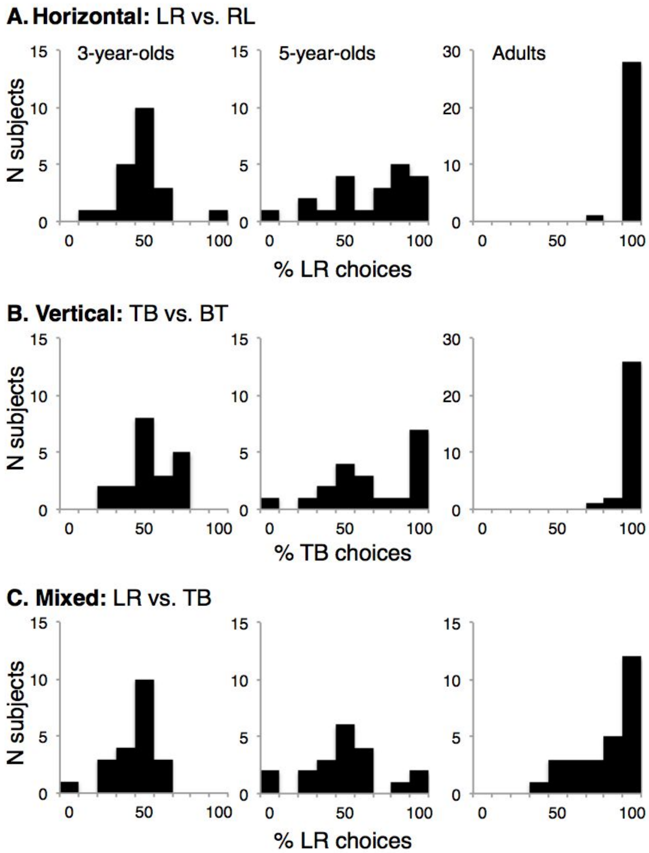

Figure 2: *Direction and orientation preferences*. Histograms showing the number of subjects who picked the more conventional representation of time at each degree of consistency.

(n = 9 of 20) also showed a strong preference for TB cards, bringing the group median to 63.5%, significantly higher than chance (Exact Wilcoxon signed-rank test, V = 111, p = 0.02). The median response among 3-year-olds was 50% TB, consistent with random guessing (Exact Wilcoxon signed-rank test, V = 54, p = 0.3).

We next asked whether children's directional biases were stronger along one spatial axis than the other. In other words, did children have a significantly stronger preference for LR in the Horizontal condition than they had for TB in the Vertical condition? We used mixed-effects logistic regression to model the likelihood of a "conventional" choice (i.e., LR in the Horizontal condition; TB in Vertical) as a function of Age Group (3-year-olds vs. 5-year-olds) and Condition (Horizontal vs. Vertical). The model included the interaction of fixed effects as well as a random effect of subjects[1]. Examining this model, we found only a main effect of Age Group (β = 0.65, p = 0.01; $\chi2(1)$ = 10.1, p = 0.002). The effect of Condition did not reach significance (β = 0.15, p = 0.6; $\chi2(1)$ = 0.4, p = 0.5). Thus, the results indicate that children have equally strong (or weak) directional preferences within the horizontal and vertical axes.

[1] The addition of random intercepts and slopes involving Items (Egg, Rose, etc) did not improve the fit of these models.

2.2.3 Mixed condition. Participants in the Mixed condition chose between (horizontal) LR- and (vertical) TB-ordered images (Fig. 1A vs. 1C). In contrast to their near-perfect consistency in the other conditions, only about half the adult sample (n = 12 of 27) chose the LR card on every trial (n = 12), resulting in a median response of 87.5% LR (Fig. 2C). In contrast, the median percentages of LR picks for both 3- and 5-year-olds were 50%, consistent with random guessing (Exact Wilcoxon signed rank tests, p's > 0.05).

Next, we asked whether children's likelihood of choosing the LR card was impacted by the orientation of the comparison set of images, by fitting a mixed-effects logistic model to data from the Horizontal and Mixed conditions. As predictors, we entered Age Group and Condition, their interaction, and a random effect of subjects. Examining the model, we found significant main effects of both Age Group (β = 0.69, p = 0.01; $\chi2(1)$ = 9.9, p = 0.01) and Condition (β = -0.51, p = 0.02; $\chi2(1)$ = 5.1, p = 0.02), with no interaction. In other words, when given a choice, children chose LR more often than RL, but not more often than TB.

Together, the results of Experiment 1 suggest that directional linear associations of time emerge between 3 and 5 years of age, and that children's biases *within* spatial axes develop earlier than biases *across* axes.

3. Experiment 2.

When given choices between two ordinal representations of a story that had different directions, the majority of 3-year-olds in Experiment 1 did not demonstrate a preference. One explanation for this behavior is that, for 3-year-olds, all ordered series of images are equally compelling illustrations of stories. An alternative explanation is that 3-year-olds simply did not attend to the relative ordering of the images on the cards. Experiment 2 tests this hypothesis.

Rather than choosing between two ordered sets varying in direction, children in Experiment 2 chose between one ordered set (either LR or TB) and one *unordered* set with the same orientation (horizontal or vertical). If children are sensitive to the ordinal relations among images, we would expect them to choose cards showing ordered temporal sequences (e.g., caterpillar-cocoon-butterfly) more often than cards showing scrambled sequences (e.g., caterpillar-butterfly-cocoon). On the other hand, if 3-year-olds do not attend to the order of the pictures (in relation to the order of events in the story), we would expect the same pattern of results found in Experiment 1.

3.1 Methods.

3.1.1 Participants. Thirty-eight 3-year-olds (M age = 3;7) were recruited from daycares and museums in the Comox valley, BC, and San Diego, CA, areas. Nineteen were assigned to the Scrambled Horizontal condition and 19 to the Scrambled Vertical condition. An additional 4 children were excluded because English was not their primary language (n = 1), they spoke a second language with a non-LR orthography (n = 2), and experimenter error (n = 1).

3.1.2 Materials and procedures were identical to those used in the Horizontal and Vertical conditions of Experiment 1, except that each RL card was replaced with a Scrambled Horizontal card (Fig. 1E), and each BT card was replaced with a Scrambled Vertical card (Fig. 1F).

3.2 Results and Discussion.

3.2.1 Horizontal Scrambled condition. Figure 3A plots the distribution of children who chose the ordered (LR) card with each level of consistency across trials. The median percentage of LR choices was 50%, again consistent with random guessing (Exact Wilcoxon signed-rank test, V = 52.5, $p = 0.3$).

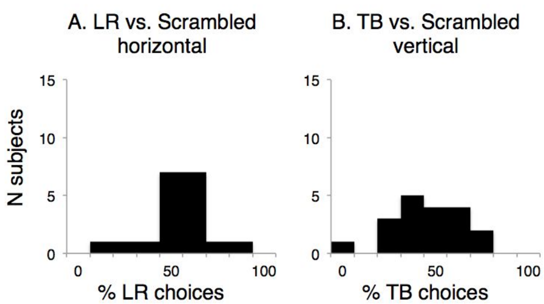

Figure 3. *Spatial ordinality preferences.* Histograms showing the number of 3-year-olds who picked the ordinal representation of time over an unordered one, at each degree of consistency.

To compare 3-year-olds' performance on the Horizontal Scrambled (Exp. 2) and unscrambled Horizontal (Exp. 1) conditions, we used a mixed-effects logistic model predicting the likelihood of an LR choice as a function of Condition (Horizontal vs. Horizontal Scrambled), with a random effect of subjects. The Condition factor did not improve the fit of the model over a null model ($\beta = 0.23$, $p = 0.3$; $\chi2(1) = 1.0$, $p = 0.3$). Children were no better at choosing the LR card over an unordered sequence than they were at choosing LR over RL or TB in Experiment 1.

3.2.2 Vertical Scrambled condition. Results from the Vertical Scrambled condition are shown in Fig 3B. As in the Horizontal Scrambled condition, most 3-year-olds picked the TB card on 50% of trials, consistent with chance (Exact Wilcoxon signed-rank test, V = 44, $p = 0.4$) and the addition of Condition (Vertical vs. Vertical Scrambled) as a factor did not significantly improve the fit of a model predicting children's likelihood of choosing the TB card ($\beta = 0.36$, $p = 0.1$; $\chi2(1) = 2.5$, $p = 0.1$).

Together, the results of Experiment 2 suggest that 3-year-olds are insensitive to the ordinal relationships among images depicting temporal events.

4. General Discussion

We explored the development of mental associations between time and space, by asking whether preschoolers prefer visual representations of events that have a conventional linear structure (i.e., left-to-right for English speakers). Consistent with conventions in their culture, we found that 5-year-olds prefered depictions of events ordered from left-to-right to those ordered right-to-left. Furthermore, even though vertical artifacts for time are rare in their culture, 5-year-olds prefered top-to-bottom representations of events to bottom-to-top ones. However, unlike adults, 5-year-olds showed no preference for horizontal (LR) over vertical (TB) depictions of events. Furthermore, younger preschoolers, 3-year-olds, not only appeared to lack direction or orientation preferences for ordered sequences, but also did not prefer ordered sets of pictures to unordered ones. Together, these findings suggest that children may not initially attend to the ordinal structure of event-depicting images, and that the "mental timeline" is constructed gradually in early childhood.

A substantial body of cross-cultural evidence indicates that the direction of mature linear mappings between time and space varies according to factors such as writing direction (e.g., Ouellet et al., 2015). A smaller number of studies indicate that these differences may emerge in childhood (Dobel, Diesendrunk, & Bolte, 2007; Tillman, Tulagan, & Barner, 2015; Tversky et al., 1991). The present study adds to this existing literature, by providing new evidence that cultural factors shape the direction of the mental timeline during childhood. Specifically, we found that preliterate 3-year-olds did not privilege conventional LR representations of time, and that LR biases appeared around age 5, when literacy often begins to emerge[2]. Going beyond prior work, the current study also suggests that preliterate 3-year-olds may not map sequential temporal events to ordinal lines at all, regardless of the direction of those lines. If so, this suggests that both the directionality *and* the ordinal structure of the "mental timeline" are constructed during childhood, in response to increased environmental input.

The task used here was designed to give children more scaffolding for the formation of space-time mappings than previous studies have provided, while also making fewer response demands. In contrast to the classic sticker-placement task (Tversky, Kugelmass, & Winter, 1991), for example, the present task did not require children to produce a spatial representation, or to recruit an implicit mental timeline "from scratch." Our task provided both the

[2] While we did not assess children's emergent literacy skills here, ongoing studies are employing parent surveys to do so.

temporal stimulus (a verbal story) and the spatial stimulus (images in lines) to be associated. The child simply needed to compare the two alternative mappings afforded by the two cards, and to pick the best match of temporal structure to spatial structure. However, given that 3-year-olds' performance in both experiments did not differ from chance, we cannot rule out the possibility that their failure stemmed from some less theoretically interesting incomprehension of the task. For example, it is possible that these children may have failed to recognize the images, or to remember the ordering of the three parts of the story. We are currently conducting a new experiment to test these possibilities.

Our findings are inconsistent with theories suggesting the LR direction of the MTL is a biological default that must be over-ridden to achieve an RL or TB mental timeline (Chatterjee, 2001; Rugani, 2015). Our findings also suggest that perceptual mappings between duration and length observed in infants cannot account for the ordinal MTL observed in adults and older children, in which positions in space (e.g., on the left) represent locations in time (e.g., in the past, see Winter, Marghetis, & Matlock, 2015, for discussion). Several studies indicate that, if presented with a stimulus that is spatially "long" (e.g., a visual line) and temporally "long" (e.g., an auditory tone), prelinguistic infants associate these two dimensions automatically, and can detect mismatches between duration and length (de Hevia et al, 2014; Srinivasan and Carey). In contrast, preschoolers in the present study did not appear to align 3-part temporal sequences and analogous 3-part spatial representations. It is therefore possible that space-time associations in infancy apply only to temporal properties of single events, not to event sequences.

Our findings in 5-year-olds may also provide a hint into the process by which linear space-time mappings are shaped. In particular, we observed a developmental trajectory in which within-axis direction preferences (LR > RL; TB > BT) emerged prior to a preference for one axis over the other. Can a literacy-based theory of MTL-acquisition account for this? In considering this question, it is interesting to note that English orthography has *both* a horizontal and a vertical component, with text progressing rightward across lines and downward through the page. Indeed, the vertical component of text may be more salient in children's books, which have fewer words per line than books for adults. Additional research will be needed to directly test whether children with more print exposure are more likely to make linear mappings between time and space — whether horizontal, vertical, or both.

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