Understanding Time in Children's Mind: Development of Mental Timelines on Three-dimensional Axes

Jiayu Jiang (jjiang59@syr.edu)
Department of Preschool Education, East China Normal University, China
Department of Education, Syracuse University, USA

Yan Gu (yan.gu@essex.ac.uk)
Department of Psychology, University of Essex, UK
Department of Experimental Psychology, University College London, UK

Abstract

Mandarin speakers have different space-time mappings than English speakers, but how Mandarin-speaking children spatialize time is unknown. We explored the development of 3D time-space representations in Chinese children aged 3 to 5. 145 Mandarin-speaking children, divided into three conditions (Exp1: horizontal, vertical, and Exp2: sagittal axes), undertook an MTL task for ten picture stories. We analysed their choices in 3-step temporal events, intending to test their sequential and directional preference of time (e.g., order vs. disorder; left-to-right vs. right-to-left). The results showed that Chinese children acquired sequential temporal representations on the horizontal and vertical axes at age 4, similar to English-speaking children. However, their directional preferences appeared earlier than English children (Exp1). Furthermore, the sagittal axis had different patterns: sequentiality emerged only at age 5, but directional preference still has not emerged in the whole 3-5 age group. These findings emphasize that language and culture impact children's conceptualization of time.

Keywords: Time and cognition; Chinese children; Timeline development

Introduction

Long, long ago, humans already started to use space to represent time (Bender & Beller, 2014; Boroditsky, 2000; Casasanto & Boroditsky, 2008; Núñez & Cooperrider, 2013). For example, in ancient times, before the advent of words, *tying knots in ropes* was a meaningful way to represent events at different times (Day, 1967; de la Puente, 2019). Time was represented through the placement and spacing of knots along the rope. It suggests that space is one of the essential ways for people to understand and record time. Likewise, in modern industrial society, products such as calendars and books have allowed people to grow accustomed to time being sequential (especially linear) rather than chaotic (Starr & Srinivasan, 2021). People usually map time onto space and conceptualize it as a line termed the "mental timeline" (MTL), which was found in many cultures and languages (e.g., Bottini et al., 2015; Casasanto & Boroditsky, 2008; Droit-Volet & Coull, 2015; Gu & Zhang, 2012). Even in an indigenous culture that has not yet been affected by industrialization, it was found that people tend to organize temporal events in a particular order (Pitt et al., 2021). Like adults, children also have such a trend beginning around age 5 (Coull, Johnson, & Droit-Volet, 2018; Tillman et al., 2018; Tillman, Fukuda, & Barner, 2022; Tversky, Kugelmass, & Winter, 1991). Tillman et al. (2022) revealed that 3-6-year-old English-speaking children are learning to organize the MTL linearly and in an orderly manner. 5-year-old children begin to arrange time-related events in a sequential rather than a random representation and in a specific direction, such as placing earlier events on the left. These studies indicate that linking time and space sequentially seems to be a cross-cultural, natural impulse. Hence, this study hypothesizes that Mandarin-speaking children, like children from other cultures, prefer MTL in a sequential rather than disordered form.

At the same time, culture and language significantly impact the mental timeline and may change its direction (Boroditsky, 2001). For example, Hebrew speakers and English speakers have left-to-right and right-to-left MTL directions, respectively, which were thought to result from opposite reading or writing directions (Bergen & Chan Lau, 2012; Fuhrman & Boroditsky, 2010). Notably, even in Modern Chinese and English, which are written in the same direction, the MTLs of Mandarin-speaking and English-speaking adults exhibit differences on the vertical timeline. Unlike the horizontal axis, Mandarin speakers use the vertical axis more often than English speakers (Fuhrman et al., 2011). Additionally, due to the traditional writing direction and linguistic vertical space-time metaphors (e.g., 上周, literally, *up week*, meaning 'last week'), Chinese adults prefer to associate the "bottom" with the future and the "top" with the past (Bergen & Chan Lau, 2012; Gu et al., 2017), whereas English adults are less of such a preference (Fuhrman et al., 2011). Given that language and culture specific space-time mappings have an impact on children's spatialization of time (Tversky, Kugelmass, & Winter, 1991), we expect that Mandarin-speaking children, starting from certain age, may develop a vertical MTL with a direction from top to bottom similar to that of Chinese adults.

Conceptual Metaphor Theory (CMT) (Lakoff & Johnson, 1980) offers an explanation for this inclination to link time and space, which suggests that abstract concepts like time are understood through metaphorical mappings onto tangible experiences and rely on embodied physical experience. For instance, the metaphor "looking forward to the future" aligns

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with future events ahead in space, indicative of our physical experience of moving forward. Examining specific linguistic examples from Mandarin can provide further insights. Mandarin uses spatial-temporal metaphors such as "上周" (shàng zhōu, "up week" for "last week") and "下周" (xià zhōu, "down week" for "next week") (Gu et al., 2017), embedding time in vertical spatial terms, which is reversed to the metaphorical orientation in English. These metaphors reflect a deep cognitive link of time among Chinese speaker with space direction, influenced by cultural and linguistic contexts. Such insights highlight how Mandarin speakers, unlike those in languages that lack vertical time direction experience, develop mental timelines that incorporate these unique past-top and future-bottom time-space mappings, thus offering a broader understanding of CMT and its application in different cultural contexts. It also shows the possibility that Chinese children might develop a top-to-bottom direction of the MTL earlier than children in languages without such metaphorical enhancement due to the prevalence of vertical metaphors in Mandarin.

Chinese speakers also have different front-back mental timelines than English speakers. In Mandarin, the word 'front' may refer to both the future and the past—an ambiguity uncommon in English (Gu, Zheng, & Swerts, 2019). For example, some of the words containing "front" (前) correspond to the past (e.g., "before," 以前) and some to the future (e.g., "prospect," 前景). Such language-based mapping differs from mapping based on embodied experience (Boroditsky, 2000; Clark, 1973; Gentner, Imai, & Boroditsky, 2002; Lakoff & Johnson, 2003; K. E. Moore, 2006): the term "ahead" often represents the direction someone is facing and also implies a place not yet reached, thereby frequently being associated with the future. Conversely, "behind" signifies what is 'back' or 'after,' typically representing a place someone has already passed, and is often linked with the past. All these ambiguities contribute to the complexity of time-space mapping in the Chinese context, making it difficult for children to understand (Gu, 2022). The ambiguity of sagittal time-space metaphors in Mandarin invites a hypothesis: the development pattern of direction of sagittal MTL may be different than horizontal and vertical axes among Mandarin children.

Another factor affecting the direction of sagittal mapping is the temporal focus, which is also different between the Chinese and English cultures. The Temporal Focus Hypothesis (TFH) posits that the conceptualization of the past or future as being in front is contingent on one's temporal focus (Callizo-Romero et al., 2020; de la Fuente et al., 2014). For instance, Spaniards, who tend to focus more on the past, often perceive the future as lying ahead (de la Fuente et al., 2014). Numerous studies have consistently demonstrated that China's temporal focus diverges from that of North America. North Americans typically exhibit a more future-oriented mindset (Callizo-Romero et al., 2020; Graham, 1981; Lyu, Du, & Rios, 2019; Spears et al., 2023; Spears, Lin, & Mowen, 2000), whereas Chinese individuals generally display a stronger direction towards the past (Brislin & Kim, 2003; Ji et al., 2009; Kluckhohn & Strodtbeck, 1961; Spears, Lin, & Mowen, 2000). Research by Guo et al. (2012) found that European Canadians prioritize the future, in contrast to Chinese and Chinese Canadians, who place greater emphasis on the past. Similarly, a study conducted by Levinson and Peng in 2007 revealed that Chinese people attribute greater value to items from the past compared to Americans. Recent studies on Chinese temporal focus showed that Chinese people are slightly more future-focused (Gu et al., 2019) but there are great individual variations (Li & Cao, 2017).

Although these studies consistently show the specificity of China's temporal mapping on the sagittal axis, it remains unclear how this temporal mapping develops in Mandarin-speaking children. This highlights the importance of exploring Mandarin-speaking children's sagittal axis in time-space mapping, as they might exhibit unique patterns in organizing time along the sagittal axis due to distinct cultural practices and language differently than in cultures with less emphasis on sagittal time representation.

Considering the possible impacts of Chinese culture and language on time-space mapping, in the current study we conducted two experiments to investigate when and how Mandarin-speaking children develop the sequentiality of MTL and its direction in three-dimensional axes. Experiment 1 replicated and extended Tillman's (2022) research to Chinese children's mental timeline (MTL), aiming to reveal differences in MTL between Chinese and English children on horizontal and vertical axes. Experiment 2 adapted the paradigm to explore the conceptualization of MTL on the sagittal axis in Chinese children.

Experiment 1

In Experiment 1, we did a conceptual replication of Tillman's (2022) study to explore the development of time-space representations in 4- to 6-year-old Mandarin-speaking children, thereby verifying whether the trajectory of Chinese children's time conceptualization was similar to that of previously reported English children. Specifically, we investigated the emergence of sequential temporal representation and preferred timeline direction in children.

Methods

Participants A total of 108 Mandarin-speaking children, aged between 3 and 7 years, were initially recruited for this study from three preschools in Shanghai, China. Seven participants were excluded because they withdrew partway through the task ($n = 3$) and were outside the target age range ($n = 4$). The final sample consisted of 101 children (mean = 4.82, 48 girls). 51 participants were assigned to the horizontal axis condition (mean = 4.81, 24 girls). 50 participants (mean = 4.83, 24 girls) were assigned to the vertical axis condition. Participants were rewarded with stickers for completing the tasks. All children and their parents spoke Mandarin as their primary language. Informed consent was obtained from the guardians of all participants.

Stimuli We utilized 7 of the 8 stories originally employed in Tillman's (2022) experiment. One story named "Caterpillar" was excluded because this story was more challenging for Chinese children to comprehend. To replace the excluded story and enrich the material, we added three new stories that were easier to understand given our participants. The stories were translated into Mandarin, ensuring their structure and time expressions matched the English versions, as ensured by two translators fluent both in Mandarin and English. Each story included three sequential temporal events, represented by three pictures. For example, the chick story and its temporal events included pictures of “egg,” “egg creaked,” and “baby chick.” Three pictures were arranged on a story card in different orders or directions to test the sequential and directional preference of MTL (see details in Figure 1 and 2).

Our experiment was conducted electronically using an 11-inch iPad, which was positioned perpendicular to the table at a 90-degree angle to avoid the potential mixing of the vertical and sagittal axes, as occurred in Tillman's (2022) experiment (placing it flat on the table).

	Event	First…	Then…	Finally…
1	Egg	There was an egg	The egg cracked	A baby chick came out!
2	Apple	There was an apple	Someone took a bite	They ate it all!
3	Drawing	Someone strarted drawing a stem	They assed blue petals	It was a flower!
4	Ice Cream	There was an ice-cream	It started melting	They was all gone!
5	Baby	A baby was born	He started growing	He was a big kid!
6	Rose	A rose started growing	It opened	It got big and pink
7	Watermenl on	There was a watermelon	We cut it all up	Everyone ate it!
8	dog	There was a dirty puppy	It went to take a bath	After washing, it became dry and clean
9	hair	There was a child with long hair	He went to cut his hair	After the cut, his hair became shorter
10	blocks	Started to build blocks	Built it higher and higher	A tall castle was built!

Figure 1: Ten picture stories with instructions used in the experiments.

Procedure The procedure and materials were similar to Tillman's (2022) research, with some adaptations to better suit Mandarin-speaking children. Participants undertook a forced-choice MTL task for ten picture stories. First, the task introduction was “We are going to play a picture game together. Each time, I will tell you a story, and you will choose one of the two cards that matches the sequence of the story.” Then, the children heard the story divided into three sentences corresponding to three pictures that appeared in sequence, which also represented three time periods from the past to the future. For example: “First, there was an egg. Then the egg cracked. And a baby chick came out!”. Children were asked to do two trials after each story: both needed to choose the most appropriate card from two cards for examining the sequential preference (ordered vs. disordered) and directional preference (e.g., left-to-right vs. right-to-left), respectively (see Figure 2). The instruction for these two types of trials was the same: the experimenter asked, “Which card shows that story? Which one is better? Is it this one [point to card] or this one [point to card]?” There were a total of twenty trials for ten stories.

In the horizontal axis condition, participants chose between left-to-right (LR) and right-to-left (RL) cards, whereas in the vertical axis condition, they chose between top-to-bottom (TB) and bottom-to-top (BT) cards (Figure 2a-2b). The order of stories 1 to 10 was counterbalanced; two cards randomly appeared on the left or right side of the screen; and trials for sequential and directional preferences were randomized. Participants were randomly assigned to either the horizontal or vertical axis conditions. This was followed by other tasks that were not related to the current study. In the end, all children received a sticker as a reward, regardless of whether they withdrew partway through these tasks.

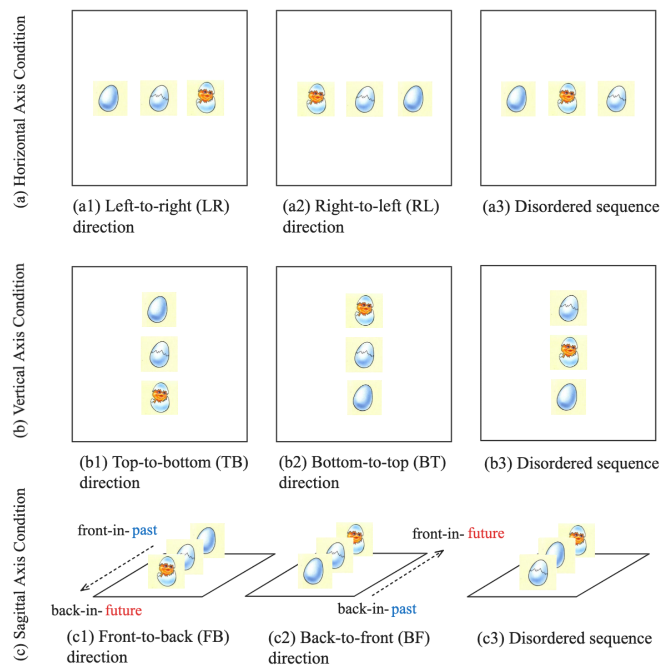

Figure 2: Story cards for linear and directional preference trails in three conditions of two experiments. The materials (a) and (b) were utilized in Experiment 1, and (c) in Experiment 2, using the story ‘egg’ as an example.

Coding and analysis We coded each child’s sequential preference choice and directional preference choice both as binary responses. To explore whether the horizontal and vertical axes affected participants' preferences, we used the glmer model in R to analyze the data, with the dependent variable being children’s binary responses in ten sequential or directional preference tests (i.e., ten stories). The model included age (a continuous variable) and axe type (horizontal or vertical) as fixed effects, with story type and participants as random effects. Secondly, for both horizontal and vertical axes, we used the chi-square test to compare the rate of selection with the chance level (50%) to find out when children began to have such sequential or directional preferences. A selection of the sequentially arranged card over a disordered one indicated a sequential preference. Similarly, choosing the LR over an RL arrangement indicated a preference for the LR direction (see details in Figures 2a, 2b).

Results

Axes preference Figure 3 (upper panel) presents the proportion of sequential and directional preference on the horizontal and vertical axes. As can be seen, the proportions of each age group were quite similar on both axes. Regression analyses showed that the effect of axis type was neither significant on sequential preference ($\beta = 0.17$, $p = .504$) nor on directional preference ($\beta = 0.02$, $p = .958$). Therefore, data from the two axes were merged and analyzed together in the same way as in Experiment 1 by Tillman et al., (2022).

Sequential Preference The results showed that age significantly predicted children's sequential preferences ($\beta = 0.89$, $p < .001$) and improved the fit of the model over the reduced model without it ($\chi^2(1) = 17.94$, $p < .001$). On the horizontal axis, 69% selected sequential over disordered (31%); on the vertical axis, 72% selected sequential over disordered. Compared to the chance level (50%) children significantly preferred sequential over disordered MTL, both at 4 years old (horizontal: 62%; vertical: 65%, p's $< .001$) and 5 years old (horizontal: 80%; vertical: 82%, p's $< .001$). However, it was not significant at 3 years (horizontal: 55%, $p = .519$; vertical: 57%, $p = .282$).

Directional Preference The results showed that age significantly predicted children's directional preferences ($\beta = 0.67$, $p <$ . .003), and including age in the model had a better model fit than excluding it ($\chi^2(1) = 8.88$, $p = .003$). As for the emergence of children's directional preferences, children significantly preferred LR and TB MTLs at age 4 (LR: 61%, $p = .001$; TB: 62%, $p = .002$) and age 5 (LR: 73%; TB: 73%, p's $< .001$), rather than at age 3 (LR: 52%, $p = .897$; TB: 46%, $p = .55$).

Discussion

Both sequential preference and directional preference in children appeared at age 4 rather than age 3. At this stage, children begin to prefer sequential temporal events over chaotic ones. This suggested that age 3–4 is a critical stage when Mandarin-speaking children begin to represent time sequentially.

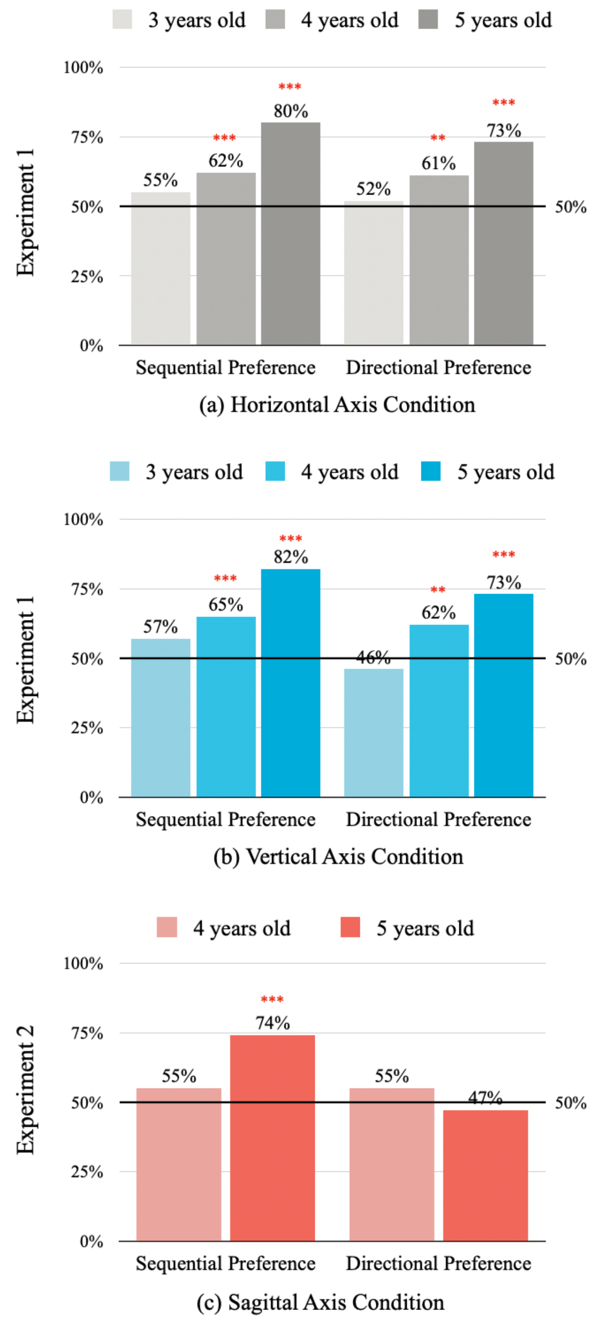

Figure 3: Percentage of children's choices on the preference tasks in Experiment 1 and Experiment 2. Percentages for the sequential preference task represent the proportion of participants who chose sequential rather than the disordered pictures. Percentages for direction preference task (a) on the horizontal axis condition represent the proportion of LRs selected; (b) on the vertical axis condition represent the proportion of TBs selected; and (c) on the sagittal axis represent the proportion of FBs selected.

At the same time, they produced MTL with directions — LR and TB — which is consistent with the MTL direction of Chinese adults (e.g., Boroditsky, 2001). Even though children in this period have very few writing experiences, which is considered to be an important factor in the formation of MTL direction. The results suggest that other cultural exposures in daily life have been able to support it, such as the left-to-right page-turning order, graph-arranging experience, and top-to-bottom calendars.

In addition, with age, there is a decline in the differences in preference between LR and TB directions. For example, at 3 years, the preference gap is 6% (LR 52%, TB 46%); at 4 years the gap is less than 2% (TB 62%, LR 61%); and at 5 years, the gap tends to be 0 (LR 73%, TB 73%). This trend implies that the proportion of choices favoring LR over TB becomes more stable as people grow older. This could suggest a developmental shift in perceptual or cognitive processing, leading to a more uniform approach to spatial direction in decision-making tasks.

Experiment 2

Experiment 1, as well as Tillman's (2022) research, only focused on the horizontal and vertical axes but not in three-dimensional space. Considering the specificity of Chinese sagittal space-time metaphors and culture, we further explored the MTL of 4-6-year-old Mandarin-speaking children on the sagittal axis. Specifically, we investigated 1) the emergence of sequential temporal representation in children on the sagittal axis. 2) the temporal directional preferences and their emergence on the sagittal axis by measuring whether children prefer front-to-back (FB) or back-to-front (BF) space-time mappings.

Methods

Participants Only 4- and 5-year-old subjects were recruited in Experiment 2 because of difficulties with the sagittal axis condition in the pilot in 3-year-old participants. A total of 45 Mandarin-speaking children, aged between 4 and 6 years, were initially recruited for this study from three preschools in Shanghai, China. One participant was excluded because they withdrew partway through the task. The final sample consisted of 44 children (mean = 4.96, 20 girls), including 21 4-5 years (mean = 4.42, 11 girls) and 23 5-6 years (mean = 5.46, 9 girls). The rewards and consents were consistent with Experiment 1.

Procedure The procedure and stimuli for Experiment 2 were identical to Experiment 1, except that the pictures were arranged on the sagittal axis (see Figure 2c).

Coding and analysis If children chose the FB (Figure 2, c1; counted as 1) over the BF (Figure 2, c2; counted as 0) arrangement, it indicated they have a preference for the FB direction. In other words, these children tend to represent the front in the past. The glmer model and chi-square test were used to investigate the sagittal axis to determine whether age affects children's sequential preferences and when children's sequential preferences appear.

Results

Sequential Preference As shown in Figure 3c, the proportion increased for older children in the sequential preferences. Results of regressions showed that age indeed significantly predicted children's sequential preferences (β = 0.76, p < .001) and the model including age had a better fit than excluding it ($\chi^2(1)$ = 10.35, p = .001). Sequential was chosen in 65%, while disorder was chosen in 35%. Compared to the chance level, 5-year-old children significantly preferred sequential over disordered MTL (74%, p < .001) but there was such a strong preference at age 4 (55%, p = .147).

Directional Preference Results showed that age did not significantly predict children's directional preferences (β = -0.08, p = .84). As for the emergence of children's sagittal directional preferences, FB was not significantly higher than 50%, irrespective of age 4 (55%, p = .19) or age 5 (47%, p = .468). It indicated children did not prefer to map the front in the past.

Discussion

Results suggested that only sequential preferences appeared at age 5. Five-year-old children have not yet developed these sagittal time-space mappings, neither for the past or future. This suggests that they have already understood how the sequence of events was arranged. However, they do not yet conceptualize time in a certain direction on the sagittal axis, even though the future-in-front mapping is supported by the cross-culture embodiment experience (Gentner et al., 2001; Glenberg & Kaschak, 2002). It could be that the ambiguous Mandarin sagittal space-time metaphors pose a challenge to children, hindering them from forming a preferred sagittal space-time mapping. Thus, in contrast to the vertical timeline, Chinese children may develop preferred sagittal space-time mappings at an older age.

General Discussion

In our two experiments, we studied the mental timelines of Mandarin-speaking children aged 3-6 along three axes: horizontal (left-right), vertical (top-bottom), and sagittal (front-back). In experiment 1, we revealed that by the age of 4, children had acquired the sequentiality of mental timelines on the horizontal and vertical axes, showing preferences for left-right (LR) and top-bottom (TB) directions. In experiment 2, it was not until age 5 that children developed sequentiality on the sagittal axis; however, we did not find evidence that children had preferred the sagittal time direction at this age.

Mandarin-speaking children exhibited the development of sequential preferences on both horizontal and vertical axes by age four, paralleling findings in four-year-old English speakers (Tillman, Fukuda, & Barner, 2022). Tillman's study identified a tendency among children of this age to favor linear (left-to-right or top-to-bottom) arrangements of MTLs over L-shaped ones, indicating a preference for sequential rather than non-linear (e.g., L-shaped) organization of stimuli. Our study controlled for shape differences and revealed that even within linear arrangements, four-year-olds began to show a preference for sequential over disordered temporal sequences. This suggests an emerging cognitive concept in children of time as order rather than chaos, which has also been observed in research on indigenous cultures (Pitt et al., 2021). These together indicate that such a sequential development might be a common feature shared in different cultures.

By age 4, Chinese children already show a marked preference for left-to-right (LR) and top-to-bottom (TB), reaching 69% and 72%, respectively. In contrast, English-speaking children do not exhibit this preference until age 5, with only 62% showing it (Tillman, Fukuda, & Barner, 2022). This highlights a milestone difference in the development of horizontal and vertical MTL directions across cultural backgrounds. One key to this difference may lie in Mandarin's time-related metaphors. In Mandarin, certain spatial metaphors representing the past and future include the characters 上 'top' (e.g., '上午' morning) and 下 'bottom' (e.g., '下午' afternoon), respectively, which is a rarity in English (Boroditsky, 2001; Fuhrman & Boroditsky, 2010; Gu et al., 2017). Such a distinctive linguistic structure in Mandarin could foster an earlier understanding of the vertical time-space mappings for children to form an earlier MTL direction preference, which emphasizes the impact of linguistic structure on children's time-space cognitive development and reveals cognitive differences from a cross-cultural perspective. In addition, given that reading order and calendars also provides experiences where 'up' for the past and 'down' for the future (Bergen & Chan Lau, 2012; Pitt & Casasanto, 2020; Starr & Srinivasan, 2021) and given that culture specific writing directions can impact children's space-time mappings (Tversky, Kugelmass, & Winter, 1991), Chinese children must have emerged in an environment where graphs and characters are often vertically presented, which may facilitate their vertical timeline as well.

However, this still does not explain the differences in horizontal timelines between the Chinese and English children. One possibility is that these children are from Shanghai, where children have relatively higher literacy than average. Language and intelligence contribute to the ability to think about the past and future (Moore, Brooks, & Rabin, 2014). Similarly, emergent literacy skills, especially writing scores, are related to the development of mental timelines (Autry et al., 2020; Tillman, Fukuda, & Barner, 2022). Therefore, it could be that our sample has generally higher literacy than the American children in the greater San Diego, CA, area.

Compared to the horizontal and vertical axes, preferences for sequentiality and directionality on the sagittal axis emerge later in children. Preferences on the horizontal and vertical axes appear at age 4, while those on the sagittal axis do not emerge until age 5. This suggests that constructing time-space concepts on the sagittal axis poses a challenge for Chinese children. This delay might be attributed to how time metaphors influence temporal representation, such as mental space-time mappings. In Mandarin, sagittal metaphors can indicate both the future and the past, adding confusion for children and resulting in the later development of directionality on this axis (Gu et al., 2019).

Our study is the first to reveal the development of a three-dimensional mental timeline in Chinese children. We discovered that Chinese children begin to prefer MTL's sequentiality and direction by age 4, which marks a developmental milestone earlier than that observed in American children, who achieve this by age 5 on the horizontal and vertical axes (Tillman, Fukuda, & Barner, 2022). This finding suggests the potential influence of cultural and linguistic frameworks on the early stages of temporal understanding in children. Furthermore, later than the horizontal and vertical axes, 5-year-old children only start to develop sagittal MTL's sequentiality rather than the direction preference. These delays may be due to the ambiguity of time expressions related to sagittal axes in Mandarin. It highlights the complexity of the sagittal axis and indicates that the difficulty of metaphors can hinder time cognition development, offering a unique perspective on how culture and language influence thinking. In short, our study provides insight into how temporal cognition develops in young children, particularly in non-Western contexts. As the first study to examine 3D time-space mapping in Mandarin-speaking children, it expands our understanding of how language and culture interplay with the cognition of time.

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