The effect of learning Chinese Sign Language on spatial conceptualisation of time in hearing Mandarin speakers

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Abstract

Temporal-spatial metaphors can vary across languages, and such cross-linguistic influences may affect people's spatial conceptualisation of time. Mandarin (including co-speech gestures) has different spatial metaphors for time than Chinese Sign Language (CSL). This paper investigated whether native Mandarin speakers' mental space-time mappings would change after learning CSL for 14 weeks. Sixty native Mandarin speakers without prior knowledge of sign language took a pretest and posttest of space-time mappings before and after taking a CSL course. The results showed that participants changed their temporal-spatial mappings after learning CSL. Specifically, they had more sagittal space-time mappings and fewer lateral ones. They also had more "future-in-front/ past-in-back" mappings consistent with CSL space-time mappings. Furthermore, these changes were more significant in high-proficiency learners than low-proficiency ones. Our results demonstrate an effect of bodily experience on time conceptions and show that sign language can impact spatial-temporal reasoning.

Keywords: Chinese Sign Language (CSL); Mandarin; time conceptualisation; bimodal bilingual; language and thought

Introduction

When representing or thinking about time, people often rely on spatial representations, such as an hourglass, timeline, and position of the sun, etc., that is to say, there are implicit space-time mappings in human minds, with which people unconsciously associate temporal concepts with spatial construction. These mappings are widely reflected in languages around the world and their co-speech gestures (e.g., Boroditsky, 2000; Li, 2017; Moore, 2014), though varying their means (Athanasopoulos et al., 2015; Bender & Beller, 2014; Núñez & Cooperrider, 2013). For example, English speakers often say "The future lies *ahead*" and "The past is *behind*". By contrast in Aymara, speakers tend to talk and conceptualis e the past as *ahead* and the future as *behind*, which is also observed in their gestures about time (Núñez & Sweetser, 2006). In Mandarin, speakers can map the past *upward* and the future *downward*, gesturing vertically or using expressions such as "上周/shàng-zhōu" (up week, last week) and "下周/xià-zhōu" (down week, next week), although they may sometimes gesture laterally when talking about time vertically (Gu et al., 2017).

Despite the fact that mental space-time mappings and gestures may not always be congruent with the linguistic space-time metaphors (Casasanto & Jasmine, 2012), space-time metaphors in language can have an online influence on speakers' spatial conceptualisation of time (e.g., Bylund & Athanasopoulos, 2017; Gu, Zheng, & Swerts, 2019a). For example, Lai and Boroditsky (2013) found that the use of different spatial metaphors for time can affect speakers' choices of timeline axes. Specifically, Mandarin speakers were more likely to construct "front-back" timeline representations when interpreting words with "front" and "back" metaphors and were more inclined to construct "up-down" representations when interpreting temporal words with "up" and "down". Similarly, when temporal concepts were constructed with the spatial metaphor suggesting "past-in-front, future-at-back", participants were more likely to adopt the "past-in-front" mapping. In contrast, temporal concepts constructed with neutral phrases (i.e., words without spatial information) were less likely to trigger such mappings (see also Gu, Zheng, & Swerts, 2019a).

Additionally, there are cross-linguistic influences of spatial metaphors for time on mental space-time mappings (Boroditsky et al., 2013; Fischer et al., 2024). Bilingual speakers may employ different temporal-spatial metaphors depending on the language they are using (e.g., Gu et al., 2017; Li et al., 2019). For example, Lai and Boroditsky (2013) found that experiences of learning languages of different spatial metaphors for time can influence learners' choices of timeline axes. In a task where participants were explicitly asked to point about time, 93.5% of the Mandarin-English bilinguals pointed at the lateral axis when interpreting neutral temporal expressions in English, whereas only 43.6% of participants used the lateral axis when speaking in Mandarin. In spontaneous gestures, due to the lack of vertical-axis-based temporal expressions in English, Mandarin-English bilinguals produced significantly fewer vertical gestures when speaking in English than in Mandarin, and preferred vertical gestures to lateral gestures when perceiving Mandarin time references with vertical spatial metaphors than the corresponding English translations (Gu et al., 2017).

Furthermore, learning a language that has different space-time metaphors may change a learner's habitual temporal orientation on a given axis. For example, Lai and Boroditsky

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(2013) noted that bilinguals speaking Mandarin were equally likely to place "the past" either in front or behind, whereas the "past-in-front" mapping was almost nonexistent among native speakers of English (but see an alternative explanation with cultural temporal focus in Gu, Zheng, & Swerts, 2019a). In addition, partially due to the vertical space-time metaphors, Mandarin speakers were more likely to have vertical space-time mappings than English speakers (e.g., Fuhrman et al., 2011). Such effects of linguistic space-time metaphors have also been observed in non-linguistic tasks (Hendricks & Boroditsky, 2017).

Studies on the impact of a second language on spatial-temporal metaphors have accounted for users' L2 proficiency (Boroditsky, 2001; Fuhrman et al., 2011), but the effect of language proficiency on the spatial conceptualisation of time is unclear. Some studies found an influence of L2 proficiency on space-time mappings (e.g., Fischer et al., 2024; Fuhrman et al., 2011; Gu, Zheng, & Swerts, 2017), whereas others did not show any effect. For example, Yang et al. (2022) found that Mandarin-English bilinguals exhibited responses of temporal thinking similar to those of Mandarin monolinguals, regardless of their English proficiency. Gu et al. (2017) also did not find any differences in vertical gesture production and perception between participants of different L2 proficiency levels. It could be due to the reason that most studies had no formal assessment of bilinguals' L2 proficiency, or the effect may only occur in places where there are cross-linguistic differences in space-time metaphors.

Furthermore, almost all studies investigating the impact of L2 space-time metaphors on people's mental space-time mappings are based on spoken languages, whereas there is hardly any research on sign languages. The only related study was based on Mandarin-Chinese Sign Language (CSL) bimodal bilinguals. Gu, Zheng and Swerts (2019b) found that bimodal bilinguals exhibited significantly different temporal gestures than hearing non-signers, such as having more sagittal gestures and fewer lateral gestures. That is because Mandarin speakers produce mostly lateral gestures, and least sagittal gestures, while CSL signers mostly use the sagittal timeline, and barely use the lateral one. Additionally, due to the differences in sagittal space-time metaphors between CSL and Mandarin (CSL only has "future-in-front/ past-at-back mappings", but Mandarin has both "future-in-front/ past-at-back" and "past-in-front/ future-at-back mappings"), bimodal bilinguals also produced fewer past-in-front gestures than Mandarin-speaking non-signers.

However, Gu, Zheng and Swerts's (2019b) study had several limitations: first, the sample size is very small with only 10 participants, which may restrict its power to detect the clear effect of sign language proficiency on space-time mappings. Second, the study focuses on spontaneous temporal gestures, which share the manual modality with signs, thus making it difficult to fully rule out the co-activation of signs in gesture production. Third, the study did not consider the subtle differences in the degree of ambiguity in Mandarin sagittal space-time words. Specifically, the space-time word "hòu/ 后 " (back, after) in Mandarin predominantly expresses "future at back" mappings while the word "qián/前" (front) presents a larger degree of ambiguity as it can represent both future-in-front and past-in-front mappings (Xu, 2008; Jiang & Gu, 2024). Therefore, it is unknown whether the effect of space-time metaphors is stronger in space-time words with "hòu" as it is less ambiguous and completely different than CSL mappings.

The Current Study

Mandarin spoken language (including gestures) and CSL have different preferences for timelines and sagittal space-time mappings (Gu, Zheng, & Swerts, 2017), which provides an excellent opportunity to examine the effects of learning sign space-time metaphors on temporal thinking, considering the role of CSL proficiency. The current study aimed to find out whether native speakers of Mandarin would change their mental space-time mappings after attending a short course in CSL. Specifically, we studied three aspects as follows:

Firstly, we examined whether Mandarin speakers' preferences for timelines would change after learning CSL. Given neutral words often appear in spoken Mandarin such as "yesterday" without referring to space, and their co-speech gestures mainly involve the lateral axis, while CSL signers mainly take the sagittal axis (neutral Mandarin words are mainly sagittal in CSL), we predicted that CSL L2 learners would tend to have more sagittal but fewer lateral mental space-time mappings even when thinking in Mandarin. As for the vertical axis, both CSL and Mandarin have vertical space-time metaphors, and the only difference is that, unlike Mandarin, CSL mainly involves future-downward mappings but hardly any past-upward mappings. Thus, Mandarin speakers may have some reduction of the vertical timeline after learning CSL.

Secondly, focusing on the sagittal axis, we studied whether Mandarin speakers would shift their temporal orientation, from past-in-front to future-in-front mappings. According to the cross-linguistic differences in sagittal space-time mappings between Mandarin and CSL and based on the empirical evidence of previous research on sagittal gestures of hearing signers (Gu, Zheng, & Swerts, 2019b), we expected that Mandarin speakers would have more future-in-front mappings after learning CSL.

Furthermore, we investigated whether the learners' CSL proficiency would influence their space-time mappings. For example, if Mandarin speakers have more future-in-front mappings after learning CSL, will those learners with higher CSL proficiency have more such mental space-time mappings? Mandarin sagittal space-time words "qián" and "hòu" indicate asymmetric space-time mappings, where "qián" can have both the same future-in-front mappings as in CSL and the opposite past-in-front mappings, while "hòu" (back, after) only has an opposite sagittal temporal orientation than CSL. Thus we expected the effect of CSL proficiency will be mostly pronounced in space-time words "hòu" (shifting from future-at-back to future-to-front mappings).

To answer these questions, we conducted a longitudinal study to compare the way university hearing students conceptualise time before and after they learned CSL. To examine the effects of linguistic metaphors for time, we constructed different types of linguistic coding of space-time mappings ("front-back," "up-down," and "neutral"). We also tested learners' CSL proficiency after attending the CSL course to better understand its impact on their mental space-time mappings.

Methodology

Participants

Participants were 85 students enrolled in an introductory sign language course during the autumn term of the academic year 2023-2024 at Shanghai International Studies University. The course was taught by a native Shanghai Sign Language user and lasted for 14 weeks (2.5 hours per week).

Within the 85 students, 76 right-handed Mandarin native speakers growing up in mainland China were included in the study, while students growing up in other places (6), being left-handed (2) or being a non-native Mandarin speaker (1) were excluded. Since 16 out of the 76 did not finish the questionnaire after the last course, only 60 participants (55 females; and 5 males) were included in the final study. They came from various majors and cohorts (freshman to junior year), ranging in age from 18 to 21 years (Mean = 18.8, SD = 0.76). According to their self-reports, none had prior experience learning sign languages.

Materials and Procedure

We used a questionnaire powered by a Chinese survey platform WJX to test participants' mental spatial-temporal mappings. The same questionnaire was administered twice in the sign language class, once before the course started and once after it ended. The pretest and posttest were conducted 14 weeks apart.

At the beginning of the questionnaire, participants filled in their student ID, age, places they have lived since childhood, dominant hand, gender, and first language. Additionally, we selected 33 temporal expressions, 19 representing future concepts and 14 representing past concepts. Since the lateral gestures are mostly produced in Mandarin, especially for words without obvious space-time metaphors, and the same concepts in CSL are usually expressed using the sagittal axis, we take them as Mandarin temporal expressions with neutral wording to see if there would be a change in the preferences of lateral and sagittal axes after learning. As a result, among the former 19 words, 9 incorporate the sagittal axis to express time, 4 use the vertical axis, and 6 have no reference to a specific axis (but co-speech gestures are mainly lateral). Among the latter 14 words, 4 use the sagittal axis, 4 use the vertical axis, and 6 do not refer to a specific axis (but co-speech gestures are mainly lateral).

Finally, on the sagittal axis, 3 words have the spatial-temporal mapping of "future-in-front" (前途[front path, prospects], 前景[front scene, outlook], 前瞻[front look, foresight]), while 6 words have the mapping of "future-at-back" (后辈[back generations, descendants], 后代[back generations, future generations], 后顾之忧[back worry, concerns for the future], 后期[back period, later stages], 以后[to the back, in the future], 后天[back day, the day after tomorrow]). Similarly, within the 10 words with no obvious space-time metaphors, 4 represent future concept (将要[about to], 明天[tomorrow], 明年[next year], 将来[future]), while 6 of them represent past concept (当年[those years], 去年[last year], 以往[in the past], 昨天[yesterday], 曾经[used to], 往昔[former days]). For each word, the same question format was used in the questionnaire: 你觉得[该词]在你哪里？(Where do you think [The Word] is to you?)

For each question, participants were required to make a choice from six directions. To avoid the influence of Chinese characters, the options were presented in the form of images (Figure 1), whose order has been randomized. Plus, to make sure all participants made the right choice on the lateral axis, we designed all the pictures to face forward, so, in connection with the question, participants would all take the viewer's perspective and make the choices based on the model's body. Apart from the 33 temporal words, we inserted 27 Mandarin words unrelated to time concepts as fillers. At the end of the questionnaire, we asked participants to write what they thought the survey investigated. None of the participants was aware of the purpose of the study. The average completion time for the pretest was 8.3 minutes and 6.3 minutes for the posttest. This study was unpaid, and all participants voluntarily took part in the survey.

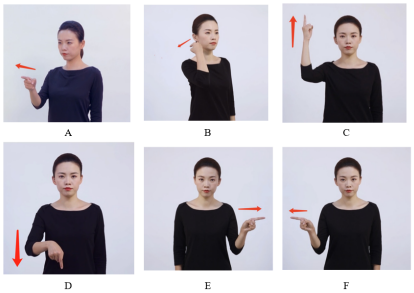

Figure 1: Six choices of directions in the questionnaire. Pictures from *A Dictionary of Common Expressions in Chinese National Sign Language* (China Association of Persons with Hearing Disabilities, 2019).

Participants' choices of "front, back, up, down, left, right" were coded in different directions. According to the research goal, we used the final exam scores as a measure of their sign language proficiency. The exam involved watching sign language and writing the corresponding Chinese translation, the scope of which covered the sign language vocabulary and sentences taught in class, including topics such as "food," "colours," "animals," "fruits," "dates," etc. The exam was designed and graded by the sign language teacher, who was not involved in this study. At last, all participants got an average score of 80.7, ranging from 53 to 98 (sd = 11.4).

Data Analyses

To predict the use of each timeline (i.e., sagittal/ vertical/ lateral), we coded a binary response for each temporal word according to the target timeline, which was used as a dependent variable. The main independent variables were *test_type* (pretest; posttest) and *lexically_implied_axis* (sagittal/ vertical/ lateral (neutral) word in Mandarin)" with *tense* (whether a word indicates a past or future concept)" as a control variable. Interactions between *lexically_implied_axis* and *test_type* were added when they were significant. We used three binomial generalized linear mixed models (GLMMs) for statistical analysis in R, assigning a random intercept to each participant.

To compare differences in sagittal temporal orientation, we built a binary mixed-effect logistic regression model took, using *test_type*, *lexically_sagittal_mappings* (whether the sagittal temporal expression suggests future-in-front/past-at-back mappings or future-at-back/past-in-front mappings) and *lexically_sagittal_direction* (whether a sagittal word is 'back' or 'front' indicating different degree of ambiguity) as predictors for *responded_sagittal_mappings* (whether it was a future-in-front response or future-at-back response). We also added by participant and by-word item as a random intercept, with a random slope of *test_type* to the participant.

Furthermore, focusing on words suggesting past-in-front mappings (qián/front, past and hòu/back, future) in the posttest, we examined whether CSL *proficiency* predicted their probability of sagittal future-in-front/past-at-back mappings. As the effect of proficiency may be nonlinear, we first applied a second-degree polynomial (quadratic term) to model proficiency, capturing potential nonlinear relationships. The observed potential threshold was further used as a categorical predictor in a binomial GLMER model.

Results

Were there any changes in timeline axes?

Overall, in the pretest, participants' choices for the sagittal, vertical and lateral axes accounted for 57.7%, 18.3%, and 24%, respectively. In the posttest, the proportion increased by 8.3% for the sagittal axis but decreased by 2.3%, and 6% namely for the vertical and lateral axes (see Figure 2).

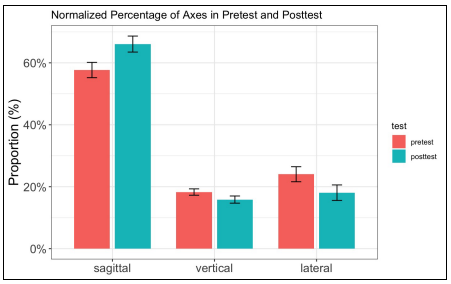

Figure 2: Distribution of three axes in pretest and posttest.

Sagittal axis

The overall proportion of choices for the sagittal axis was significantly higher in the posttest compared to the pretest (β = 0.340, p = 0.006, 95% CI = [0.42. 0.96], see Figure 3). The wording of temporal expressions also had effects. Specifically, in the pretest, sagittal temporal expressions elicited significantly more responses on sagittal axes than vertical temporal expressions (β = 0.35, p = 0.006, 95% CI = [1.58, 2.15]) and neutral time expressions (β = 1.86, p < 0.001, 95% CI = [0.99, 0.60]. In the posttest, sagittal words still had more sagittal choices than vertical words (β = 2.046, p < 0.001, 95% CI = [1.773, 2.320]), but did not differ from the neutral words (β = 0.002, p = 0.99). These results were also confirmed by a nonsignificant interaction between vertical words and the posttest (β = -0.18, p = 0.37), but a marginally significant interaction between neutral words and posttest (β = 0.35, p = 0.06). Additionally, participants' preference for the sagittal axis did not differ between words representing the past and future concepts (β = 0.13, p = 0.11, 95% CI = [0.028. 0.19]).

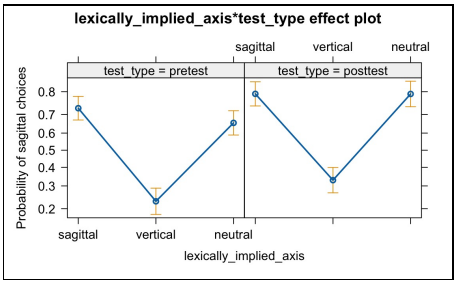

Figure 3: Interaction effect of *lexically_implied_axis* and *test_type* on the probability of sagittal choices.

Vertical axis

The proportion of choices for the vertical axis in the posttest was not significantly different than the pretest (β = -0.15, p = 0.107, see Figure 4). Compared to vertical words, both sagittal (β = -1.72, p < 0.001, 95% CI = [-1.94, -1.52]) and neutral words (β = -2.33, p < 0.001, 95% CI = [-2.60, -2.07]) led participants to fewer choices of the vertical axis. There were no interactions between any lexically implied axis and posttest (all p's > 0.52), nor any effect of *tense* (whether a past or future concept) (p = 0.383).

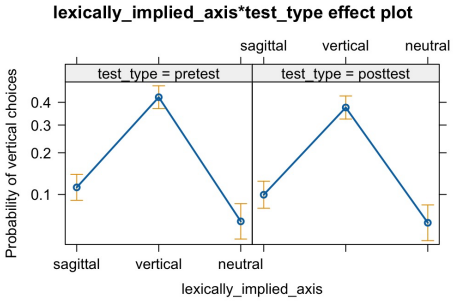

Figure 4: Interaction effect of *lexically_implied_axis* and *test_type* on the probability of vertical choices.

Lateral axis

As predicted, the proportion of the lateral axis in the posttest decreased significantly compared to the pretest (β = -0.84, p < 0.001, 95% CI = [-1.14, -0.53]). As shown in Figure 5, there were also effects of wording (reference: neutral word). Neutral wording had significantly more choices of the lateral axis than the sagittal wording both in the pretest (β = 0.83, p < 0.001, 95% CI = [0.54, 1.12]) and posttest (β = 0.38, p = 0.021, 95% CI = [0.55, 0.70]). However, the differences were significantly smaller in the posttest, which was also confirmed by a significant interaction between sagittal words and posttest (β = 0.45, p = 0.036, 95% CI = [0.027, 0.88]). Additionally, neutral wording was not different than the vertical wording in the choices of lateral axis in the pretest (β = 0.08, p = 0.57, 95% CI = [-0.21, 0.38]), but was significantly less than vertical wording in the posttest (β = -0.63, p = 0.00013, 95% CI = [-0.98, -0.11]). This was also confirmed by a significant interaction between vertical words and posttest (β = 0.54, p = 0.014, 95% CI = [0.11, 0.98]). Furthermore, when the word had past concepts, the number of lateral axes was significantly lower than "future" concepts (β = -0.25, p = 0.008, 95% CI = [-0.43, -0.07]), indicating that the choice of the lateral axis was influenced by the temporal relations of the words.

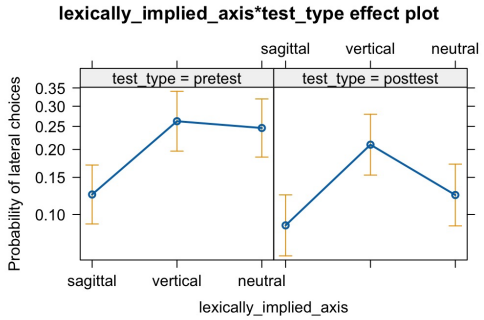

Figure 5: Interaction effect of *lexically_implied_axis* and *test_type* on the probability of lateral choices.

Were there any changes in sagittal mappings?

Focusing on the responses on the sagittal axis, we examined the effect of learning CSL (*test_type*) on sagittal temporal orientation accounting for *lexically_sagittal_mappings* (whether the sagittal temporal expression suggests future-in-front/past-at-back mappings or future-at-back/past-in-front mappings) and *lexically_sagittal_direction* (whether a sagittal word is 'back' or 'front' indicating different degree of ambiguity). The results showed that the proportion of future-in-front/past-at-back mappings made by participants in the posttest was significantly higher than in the pretest (β = 0.993, p = 0.001, 95% CI = [0.398, 1.588]), indicating a shift of spatial-temporal mappings after learning CSL (Figure 6). Additionally, words indicating "future-in-front/past-at-back" mappings (such as "前途[front path, prospects]") more often led participants to use the "future-in-front/past-at-back" mappings (β = 4.2973, p = 0.0017, 95% CI = [1.62, 6.975]). However, a word containing "back" only appeared to marginally lead participants to have fewer future-in-front/past-at-back mapping than "front" (*lexically_sagittal_direction*) (β = -1.72, p = 0.10).

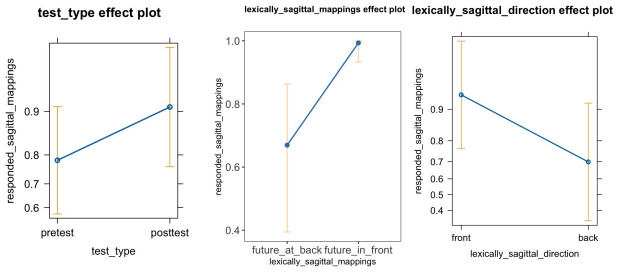

Figure 6: Predicted effects of learning CSL (*test_type*), suggested sagittal mappings (*lexically_sagittal_mappings*), and sagittal ambiguity (*lexically_sagittal_direction*) on the probability of choosing future-in-front/past-at-back mappings (*responded_sagittal_mappings*).

Did CSL proficiency predict sagittal mappings?

In the posttest, Mandarin speakers tended to adopt spatial-temporal metaphors in CSL. We further explored the impact of learning CSL on their use of the two spatial-temporal mappings on the sagittal axis. In the questionnaire, there were 3 sagittal words representing "the future is ahead" and 5 sagittal words representing "the future is behind". Concerning the 5 "future-at-back" words, participants used significantly more "future-in-front" mappings in the posttest (β = 0.91, p < 0.001, 95% CI = [0.5, 1.31]), while in the case of the 3 "future-in-front" words, the results did not show significant differences in mapping between the pretest and posttest (p = 0.733).

Furthermore, focusing on the posttest data of the 5 words representing "future-at-back", we examined the impact of CSL proficiency on mapping choices. The result of a second-degree polynomial (quadratic term) to model CSL proficiency showed that the effect of proficiency may be nonlinear. As suggested by the effect plot (Figure 7), there was an upward trend from scores above approximately 79, so we categorized the scores into binary with a cutoff point of 80 (mean = 80.66).

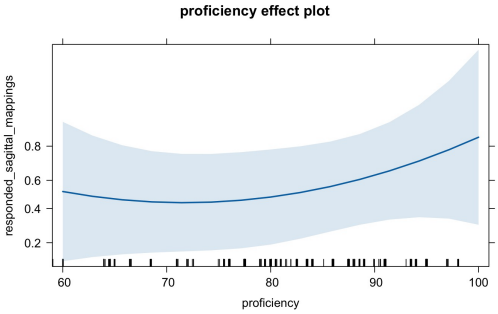

Figure 7: Potential nonlinear effect of CSL proficiency on sagittal future-in-front mappings.

We then divided participants into higher and lower proficiency groups with a threshold of 80. A binary mixed-effect logistic regression showed that the higher proficiency participants used significantly more future-in-front mappings than the lower proficiency group in the posttest ($\beta = 1.451$, $p = 0.027$, 95% CI = [0.16, 2.74], Figure 8). The effect of CSL proficiency was largely robust if we used a threshold of rounded up mean proficiency of 81 ($\beta = 1.26$, $p = 0.0497$).

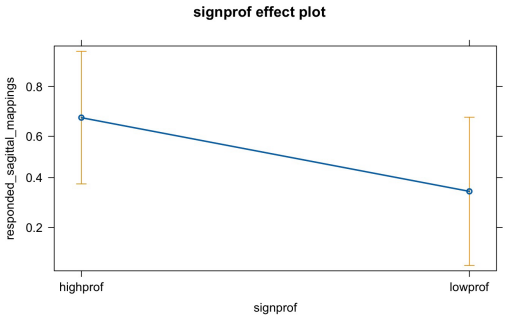

Figure 8: Effect of CSL proficiency on sagittal future-in-front mappings (direction of sagittal timeline).

Discussions

In this study, we asked native Mandarin speakers to make spatial judgments based on their knowledge of temporal concepts in Mandarin to observe the changes in their spatial understanding of time before and after learning CSL, as well as whether these changes were influenced by sign language proficiency. We had the following findings:

First, there were significant changes in the distribution of timeline axes. Overall, the number of choices for the sagittal axis significantly increased in the posttest, while those for the lateral axis significantly decreased, and there was no significant change for the vertical axis. As mentioned earlier, CSL primarily uses the sagittal axis to indicate time, with no significant difference from Mandarin in its use of the vertical axis and it lacks the use of the lateral axis. These changes show that participants' preferences for timelines when understanding temporal concepts shifted, gradually aligning with CSL even when they are processing Mandarin.

Unexpectedly, both in the pretest and posttest, the sagittal axis was the most frequently used, followed by the lateral axis, with the vertical axis being the least used. This result differs from the proportions of co-speech gestures produced by Mandarin speakers in past studies (Gu et al., 2017; Gu, Zheng, & Swerts, 2019b; Li, 2017). On the one hand, it could be due to the task differences as the current study examines the mental spatial representation of temporal concepts rather than merely gestures. There may be inherent differences between the perceptual understanding of spatio-temporal metaphors and the production of spontaneous co-speech gestures. On the other hand, 13 of the 33 words in our study inherently encoded sagittal-axis-related spatial orientations, which could have led to a higher proportion of sagittal axis usage (as also shown from the effects of sagittal or vertical wording on choices of corresponding axes). This aligns with previous findings that words inherently carrying spatial orientation along a particular axis increase participants' usage of that axis when understanding temporal concepts (e.g., Lai & Boroditsky, 2013; Gu et al., 2017; Gu, Zheng, & Swerts 2019a).

Second, we found that the influence of the lexically implied axis on the choices of sagittal and lateral axes differed between the pretest and posttest. This may also reflect the influence of CSL knowledge, as time in CSL is always associated with spatial orientation, and the orientations for the same temporal concept differ between Mandarin and CSL. In the pretest, participants considered only the Mandarin axes, but this fixed thought was reconstructed in the posttest.

Additionally, focusing on the sagittal timeline, the experience of CSL also changed learners' direction of sagittal space-time mappings. Looking specifically at the data for words with "future-in-front" and "future-at-back", the results showed no difference in the influence of "future-in-front" words on mapping modes between the pretest and posttest. However, "future-at-back" words significantly triggered more "future-in-front" mappings in the posttest. This demonstrates that learning CSL reinforced the "future-in-front" mapping, particularly causing the words originally suggesting "future-at-back" in Mandarin, to shift toward the mapping used in CSL.

Furthermore, our study also showed that changes in sagittal mappings were related to participants' CSL proficiency. However, this influence was not linear. According to the result, high-proficiency learners (above the average score) were significantly more likely to use the "future-in-front" mapping than low-proficiency learners (below the average score). This result also corroborates the view that different levels of L2 proficiency have varying impacts on bilinguals' spatio-temporal metaphors (Gu, Zheng, & Gu, 2019b; Fischer et al., 2024). Nevertheless, spatio-temporal metaphors are influenced by many factors (e.g., Callizo-Romero et al., 2020; Li & Cao, 2018; Yang et al., 2022). The non-linear results here may also indicate that the choice of mappings is likely not solely affected by L2 proficiency.

Our study also contributes to time research. Previous research showed that temporal focus (de la Fuente et al., 2014) or age (Bylund et al., 2020) are the key influences on people's conceptualisation of time, we found that bodily experience of CSL shapes sagittal space-time mappings. Given that habitual use of certain sign patterns may affect signers' spatial thinking (Emmorey, Klima, & Hickok, 1998), we conclude that experience of sign language may impact signers' spatial-motoric thinking (cf. Karadöller et al., 2023) and spatial-temporal reasoning, and such an impact is enhanced by a higher CSL proficiency. This study provides a first insight into the cross-modal influence of space-time metaphors on mental representations of time within a culture, with additional implications for the theories on space-time mappings and the relationship between language and thought.

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References

Athanasopoulos, P., Bylund, E., Montero-Melis, G., Damjanovic, L., Schartner, A., Kibbe, A., ... & Thierry, G. (2015). Two languages, two minds: Flexible cognitive processing driven by language of operation. *Psychological Science*, *26*(4), 518-526.

Bender, A., & Beller, S. (2014). Mapping spatial frames of reference onto time: A review of theoretical accounts and empirical findings. *Cognition*, *132*(3), 342-382.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, *75*(1), 1–28.

Boroditsky, L. (2001). Does language shape thought?: Mandarin and English speakers' conceptions of time. *Cognitive Psychology*, *43*(1), 1–22. https://doi.org/10.1006/cogp.2001.0748

Bylund, E., & Athanasopoulos, P. (2017). The Whorfian time warp: Representing duration through the language hourglass. *Journal of Experimental Psychology: General*, *146*(7), 911–916. https://doi.org/10.1037/xge0000314

Callizo-Romero, C., Tutnjević, S., Pandza, M., Ouellet, M., Kranjec, A., Ilić, S., ... & Santiago, J. (2020). Temporal focus and time spatialization across cultures. *Psychonomic Bulletin & Review*, *27*, 1247-1258.

Casasanto, D., & Jasmin, K. (2012). The hands of time: Temporal gestures in English speakers. *Cognitive Linguistics*, *23*(4), 643-674.

China Association of Persons with Hearing Disabilities. (2019). *Guojia tongyong shouyu cidian* [A dictionary of common expressions in Chinese National Sign Language]. Huaxia Publishing House.

De la Fuente, J., Santiago, J., Román, A., Dumitrache, C., & Casasanto, D. (2014). When you think about it, your past is in front of you: How culture shapes spatial conceptions of time. *Psychological Science*, *25*(9), 1682-1690.

Emmorey, K., Klima, E., & Hickok, G (1998). Mental rotation within linguistic and non-linguistic domains in users of American Sign Language. *Cognition, 68*, 221-46. doi: 10.1016/s0010-0277(98)00054-7.

Fuhrman, O., McCormick, K., Chen, E., Jiang, H., Shu, D., Mao, S., & Boroditsky, L. (2011). How linguistic and cultural forces shape conceptions of time: English and Mandarin time in 3D. *Cognitive Science, 35*(7), 1305–1328. https://doi.org/10.1111/j.1551-6709.2011.01193.x

Gu, Y., Mol, L., Hoetjes, M., & Swerts, M. (2017). Conceptual and lexical effects on gestures: The case of vertical spatial metaphors for time in Chinese. *Language, Cognition and Neuroscience*, *32*(8), 1048–1063. https://doi.org/10.1080/23273798.2017.1283425

Gu, Y., Zheng, Y., & Swerts, M. (2017). Does Mandarin spatial metaphor for time influence Chinese deaf signers' spatio-temporal reasoning? *Proceedings of the Annual Meeting of the Cognitive Science Society*, 39. Retrieved from https://escholarship.org/uc/item/1qq1f3rp

Gu, Y., Zheng, Y., & Swerts, M. (2019a). Having a different pointing of view about the future: The effect of signs on co-speech gestures about time in Mandarin–CSL bimodal bilinguals. *Bilingualism: Language and Cognition*, *22*(04), 836–847. https://doi.org/10.1017/S1366728918000652

Gu, Y., Zheng, Y., & Swerts, M. (2019b). Which is in front of Chinese people, past or future? The effect of language and culture on temporal gestures and spatial conceptions of time. *Cognitive Science*, *43*(12), e12804. https://doi.org/10.1111/cogs.12804

Hendricks, R. K., & Boroditsky, L. (2017). New space–time metaphors foster new nonlinguistic representations. *Topics in Cognitive Science*, *9*(3), 800-818.

Jiang, J., & Gu, Y. (2024). Asymmetry in language, asymmetry in mind: The effect of sagittal time-space metaphors on children's understanding of time. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *46*(0). https://escholarship.org/uc/item/0b9909n8

Karadöller, D. Z., Sümer, B., Ünal, E., & Özyürek, A. (2023). Late sign language exposure does not modulate the relation between spatial language and spatial memory in deaf children and adults. *Memory & cognition*, *51*(3), 582–600. https://doi.org/10.3758/s13421-022-01281-7

Lai, V. T., & Boroditsky, L. (2013). The immediate and chronic influence of spatio-temporal metaphors on the mental representations of time in English, Mandarin, and Mandarin-English speakers. *Frontiers in Psychology*, *4*, 142.

Li, H. (2017). Time on hands: Deliberate and spontaneous temporal gestures by speakers of Mandarin. *Gesture*, *16*(3), 396-415.

Li, H., Cao, Y. (2018). The influence of temporal focus on implicit space-time mappings on the front-back axis: Evidence from Han and Qiang Chinese (时间焦点对前后方向上内隐时空映射的影响——来自汉族和羌族的证据). *Acta Psychologica Sinica*, *50*(10), 1083–1093

Li, H., Cao, Y. (2019). The conceptualization of time in Chinese and English native speakers -- Evidence from behavioral and eye-tracking experiments (汉、英母语者时间认知方式研究——来自行为和眼动的证据). *Foreign Language Teaching and Research*, *51*(5), 712–722, 800.

Li, Y., Casaponsa, A., Wu, Y. J., & Thierry, G. (2019). Back to the future? How Chinese-English bilinguals switch between front and back orientation for time. *NeuroImage*, *203*, 116180. https://doi.org/10.1016/j.neuroimage.2019.116

Malyshevskaya, A., Fischer, M. H., Shtyrov, Y., & Myachykov, A. (2024). Lateral mapping of time-related words in first and second language. *Scientific Reports*, *14*(1), 9675. https://doi.org/10.1038/s41598-024-60062-1

Moore, K. (2014). *The spatial language of time: Metaphor, metonymy, and frames of reference.* John Benjamins Publishing Company. https://doi.org/10.1075/hcp.42

Núñez, R., & Cooperrider, K. (2013). The tangle of space and time in human cognition. *Trends in Cognitive Sciences*, *17*(5), 220–229. https://doi.org/10.1016/j.tics.2013.03.008

Núñez, R. E., & Sweetser, E. (2006). With the future behind them: Convergent evidence from Aymara language and gesture in the crosslinguistic comparison of spatial construals of time. *Cognitive Science*, *30*(3), 401–450. https://doi.org/10.1207/s15516709cog0000_62

Xu, D. (Ed.). (2008). *Space in languages of China*. Springer.

Yang, W., Gu, Y., Fang, Y., & Sun, Y. (2022). Mental representations of time in English monolinguals, Mandarin monolinguals, and Mandarin–English bilinguals. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.791197