Decoupling Hand and Mind in Abstract Temporal Reasoning: Variation in temporal gesture and temporal reasoning

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Abstract

Time is often conceptualized spatially. Some argue that this spatialization is essential for understanding time and should manifest reliably in temporal gesture. Here we ask whether people vary in their production of temporal gesture and what this variation might signal about abstract reasoning and communication. Participants (N = 94) watched time-travel narratives, reasoned aloud about the narrative's temporal structure, and later completed a computer assessment of their recollection and comprehension of the narrative's complex temporal structure. We found that participants varied considerably in how often they produced temporal gesture. This variation in temporal gesture was strongly associated with the production of non-temporal representational gesture, suggesting a 'gestural style' that governs the production of gesture in general. There was no association, however, between temporal gesture and temporal reasoning accuracy. We speculate about the role that temporal gesture might play in larger assemblages of temporal understanding and communication.

Keywords: space, time, gesture, temporal reasoning

Introduction

Whether it be moving next Wednesdays' meeting forward two days (McGlone & Harding, 1998) or remembering the plotline of the film *Memento* (2000), reasoning about time is *tough.* In attempting to reason about temporal sequences, even in simple cases, we often find ourselves moving our hands while talking. In a desperate attempt to get a grip on the abstract nature of *time*, we find ourselves gesturing. US American adults, for instance, gesture ahead or to the right when referring to the future and behind or to the left when referring to the past (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012). Yet reasoning about rescheduling meetings (McGlone & Harding, 1998) or the temporal order of months (Boroditsky, 2000) are instances of relatively simple reasoning about time. What happens when we push things to the limits of our capacity for temporal reasoning? What happens when we have to reason about incredibly convoluted, entangled, and complex conceptions of time — what happens when we reason about *time travel*? And what do our hands reveal when doing so?

Spontaneous co-speech temporal gestures are thought to reflect the foundational role of *space* in our temporal understanding. Various accounts have argued that space offers one, if not *the*, foundation for higher cognition (Lakoff & Johnson, 1980; Mandler, 2004; Tversky, 2019). The most extreme versions of these accounts argue that all abstract reasoning relies on a spatial strategy for making sense of the world. Some evidence for this account comes from patterns of metaphoric language. Lakoff & Johnson (1980), for instance, argue that expressions like "looking ahead to the future" and "putting the past behind us" are not mere linguistic trinkets but reflections of a deeper conceptual mapping between our concepts for space and time. At the core of temporal understanding, these accounts argue, is a spatial conception of time.

This line of reasoning suggests that people *necessarily* spatialize time. If so, then this spatial conceptualization should be expressed reliably in co-speech gesture. One influential model of gesture production, *Gesture as Simulated Action,* proposes that gesture production reflects the mental activation of visuospatial and motor imagery that 'spills out' as spontaneous hand movements (Hostetter & Alibali, 2008). It follows that reasoners' rich spatial models of time should reliably manifest as co-speech gestures that reflect the spatial features of their temporal understanding. For other complex conceptual domains, such as mathematics, co-speech gesture is known to accompany complex reasoning (Marghetis & Núñez, 2013), even if the gestures themselves might not play an active role in the reasoning process (Walkington et al., 2019). Other studies go further to suggest that spontaneous co-speech gestures not only reflect internal cognitive processing but might contribute actively to the reasoning process itself (Goldin-Meadow, 1999, 2005; Cook et al., 2008), perhaps by reshaping the spatial information that is expressed in gesture (Kita, Alibali, & Chu, 2017). Whether gestures are a mere index of reasoning or an active participant in the reasoning process, this family of accounts suggest that people should reliably express their spatial conceptions of time in spontaneous co-speech gesture.

Indeed, when people reason about time, they gesture spontaneously in ways that reflect a spatial understanding of temporal duration and order (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012). When people talk about temporal relationships, they gesture — and they do so in canonical ways: they *point* to and *place* temporal events, *bridge* together events across time, *mark duration* of temporal events, and *animate* time itself and give it its own agentive form (Cooperrider & Núñez, 2009).

In D. Barner, N.R. Bramley, A. Ruggeri and C.M. Walker (Eds.), *Proceedings of the 47th Annual Conference of the Cognitive Science Society*

While we know that people express their temporal reasoning in temporal gesture, we know little about individual differences in temporal gesture and what such variation might reveal. There is known variation in gesture more generally (McNeil, 1992; Kendon, 2004). There is also known cross-cultural variation in how space is used to encode aspects of time (Núñez & Sweetser, 2006; Núñez et al, 2012; Li, 2017; for review, see Núñez & Cooperrider, 2013). Against this backdrop of variation, there is often an implicit assumption of universality: Sure, people might gesture *differently* about time, but everybody should gesture in *some* way about time.

Some evidence against this assumption of universality comes from Yucatec Mayans, who appear to lack any reliable spatial encoding of time in their gesture (Le Guen & Balam, 2012). If an entire community can lack a predilection to gesture spatially about time, this raises the possibility that there may be heretofore unexplored variation in temporal gesture *within* communities where temporal gestures have been attested. Specifically, here we ask whether there are individual differences in the predilection to produce temporal gestures among US Americans, a community that has been shown repeatedly to gesture spontaneously about time (Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012). If, as many accounts have assumed, temporal understanding in many cultures is fundamentally spatial (Núñez & Cooperrider, 2013), and visuospatial reasoning should reliable manifest as co-speech gesture (Hostetter & Alibali, 2008), then people should gesture reliably when reasoning about time.

Indeed, there are reasons to expect variation in the production of temporal gestures to act as a reliable signal of other aspects of communication and cognition.

First, variation in the amount of temporal gesture could predict individual differences in *temporal understanding*. Support for such a connection comes from evidence of a close link between gesture production and spatial reasoning (Alibali, 2005). Some studies, for instance, report that people gesture more when recalling information that was encoded in a spatial format (Hostetter & Hopkins, 2002). Individuals with spatial representations of time that are more detailed, rich, or elaborated might thus gesture more often; in this scenario, the amount of temporal gestures could predict more effective or deep temporal understanding. On the other hand, increased gesture production is also thought to sometimes reflect cognitive difficulties (e.g., Kita & Davies, 2009); if the same applies to temporal gesture, then the production of temporal gesture might be anticorrelated with reasoning success. Variation in the production of temporal gesture could thus act as a signal of either improved or impaired temporal reasoning.

Second, variation in the amount of temporal gesture could signal *uncertainty* about the content of speech and gesture. While speaker uncertainty is often conveyed through hedges, hesitations, disfluencies, or explicit statements, the larger multimodal utterance may also include information about the speaker's uncertainty (e.g., Cheng et al, 2024). Variation in the production of temporal gesture could thus act as a signal of the speaker's uncertainty about the temporal structure of whatever they're describing.

Third, variation in the amount of temporal gesture could reflect the speaker's *gestural style* — an individual's characteristic pattern of co-speech gesture — thus signaling a more general predilection to gesture seldom or frequently. The predilection to gesture about time might thus reflect content-neutral individual differences in gesture production, such as a generic threshold to producing hand gestures (e.g., the threshold in the Gesture as Simulated Action framework, Hostetter & Alibali, 2008). If so, then variation in the production of temporal gesture might reflect a speaker's 'gestural style.'

In the current study, we set out to document individual variation in whether and how much people gesture about time. We then asked what this variation might tell us about other aspects of communication and cognition. As a testbed for reasoning about complex temporal information, we used *time travel narratives.* Participants watched brief videos of narratives involving time travel, and then recounted and reasoned about the story's plots while in conversation. We looked at whether and how much they gestured about time and non–temporal content during these conversations, along with how much they expressed uncertainty about their understanding. Participants then completed a computerized assessment of their recall of basic facts from the narratives and their ability to reason about the narratives' complex temporal structure, which served as a measure of their narrative memory and temporal reasoning. To foreshadow our results, we find considerable individual variation in how much people gesture about time. This variation, moreover, was unrelated to their uncertainty or temporal reasoning. The production of temporal gestures, however, was tightly linked to the amount of other gestures they produced, which suggests that people have a content-neutral 'gestural style.'

Methods

We employed a co-speech gesture observational paradigm, narrative retelling (McNeill, 1995), and additionally asked participants to answer a series of temporal reasoning questions. Materials and procedures used here are the same as Nosrati et al. (2024). Participants watched short videos of narratives involving time travel. They were then video recorded while responding to a series of temporal reasoning questions involving sequencing events from one of the narratives from two different perspectives (counter-balanced). Next they completed a post-interview questionnaire that tested their recollection of key facts from the narratives ("recall") and their comprehension of the complex temporal structure of the narratives ("temporal sequencing").

We measured variation in temporal and non-temporal gesture production from key questions of the initial interview (details below; interrater reliability, Pearson's r = .91). As a measure of temporal understanding, we used recall and temporal sequencing for accuracy on the

post-interview questionnaire. We recognize, however, that temporal understanding is multifaceted and involves more than memory for complicated temporal narratives.

Participants

Participants (N = 94; ages 18-30 years, median age = 20 years; 62 women, 27 men, 2 non-binary, and 3 preferred not to say), college students at an American university, participated in return for partial course credit. The study was conducted in English. Participants' native language and country of origin varied but were primarily native English speakers (n = 54), followed by Spanish (n = 30). Informed consent was obtained prior to the start of the study.

Materials

Stimuli consisted of short videos lasting around 5 minutes with plots that involved time travel. Here, we only analyze the results related to one of the two narratives: a segment from the Simpsons episode 'Treehouse of Horror V (Fig. 1, top).' In this story, the main protagonist, Homer Simpson, accidentally turns a toaster into a time machine. The toaster takes Homer back to prehistoric times when dinosaurs still roamed the earth. He then repeatedly travels back and forth between this prehistoric past and the present day. Ignoring his father's advice about the "butterfly effect" — the possibility for a tiny change to have massive repercussions — Homer continually makes small changes in the prehistoric past that result in comically drastic changes in the present. Participants also watched (in a randomized order) two other videos, another time-travel narrative involving a grandfather paradox called 'Tethers' (2021) and segments of an episode of Seinfeld 'The Opposite' (1994). Responses to these stimuli are analyzed elsewhere. For the purpose of understanding the relationship between temporal gesture and temporal reasoning, we focus on participants' responses to questions about the temporal structure of the Simpsons clip, which involves an especially complex temporal structure.

Procedures

Participants first watched the stimuli videos in a randomized order, on a computer laptop, followed by brief questions about whether they had seen any of the videos previously.

Participants were then video recorded as they answered questions posed by the researcher. The first questions prompted participants to retell the plot of each video. Participants were provided with as much time as necessary for their narrative retellings.

These narrative retellings were followed by a suite of temporal reasoning questions. In particular, participants were asked to describe the order of the main plot points of the Simpsons video from two perspectives: (1) from the perspective of the time travelling protagonist, Homer Simpson; (2) from the perspective of a being who can adopt a "god's eye view" on the events, that is a perspective "removed" from time. This task requires participants to adopt two alternative temporal perspectives, one in which they revisit the events as experienced by Homer within the narrative, and another from an outside perspective that is divorced from Homer's own idiosyncratic journey back and forth through time. The order of these perspective-taking temporal sequencing questions was counterbalanced. This prompt was intended to test to what degree participants would shift between construals of time that differed in viewpoint. Here we focus on participants' co-speech gesture while responding to these questions.

Participants then completed a computer-based assessment of narrative recall and temporal sequencing. The narrative recall questions asked participants to remember factual events from the story. The temporal reasoning questions on the post interview test involved sequencing the events from the story from two differing perspectives similarly to how they were asked to do so while being video recorded. We measured participants' temporal reasoning as their accuracy on the temporal reasoning questions for *The Simpsons* story.

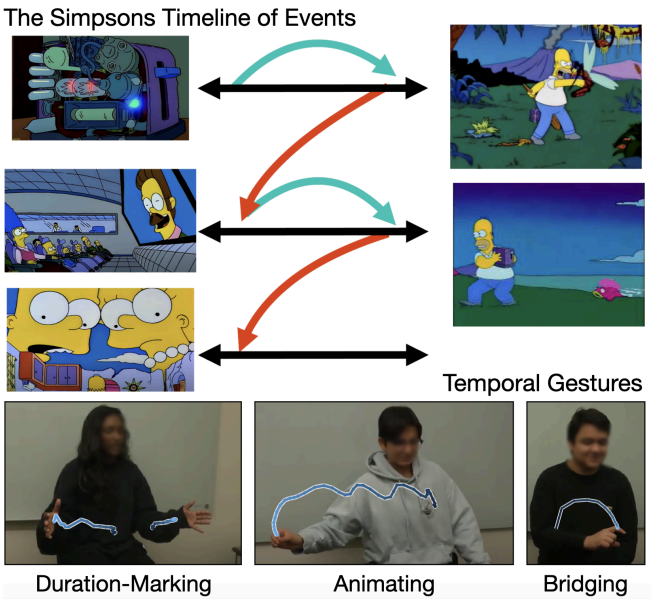

Fig. 1: (Top) Schematic diagram of the timeline of *The Simpsons* narrative. (Bottom) Examples of temporal gesture: *Duration-marking*, *Animating,* and *Bridging.*

Video coding

To quantify variation in gesture production, we counted the number of temporal and non-temporal representational gestures produced by participants while they answered questions about the sequence of events in the *The Simpsons* Representational gestures depicted or resembled in shape, position, or trajectory the concrete or abstract referents of accompanying speech (McNeil, 1992). Temporal gestures depicted the temporal content of co-gesture speech; the taxonomy of temporal gestures identified by Cooperrider & Núñez (2009) were considered paradigmatic, and the temporal content of speech was used to help identify which gestures qualified. Each response was coded twice; inter-rater reliability was high across both measures of gesture (Pearson's r = .91).

We also coded participants' uncertainty while describing the sequence of events in *The Simpsons*. Coders rated uncertainty on a scale of 1 to 3, for four different expressions of uncertainty: 1) Hesitations/pauses, 2) Hedging, 3) Disfluencies, and 4) Explicit expressions of uncertainty.

Modeling approach

To investigate whether variation in the amount of temporal gesture was a signal of temporal understanding, we used a multilevel logistic regression, in which item-by-item temporal reasoning accuracy was predicted by the amount of temporal gestures, non-temporal representational gestures, and recall accuracy (all z-scored). Recall was included in the model as a predictor to contextualize the results for gesture production. The model incorporated random slopes by subjects and items to account for variation between subjects.

To investigate the association between gesture production, reasoning, recall, and uncertainty, we computed pairwise correlations among six variables: explicit uncertainty, implicit uncertainty (hesitations, hedging, and disfluency), temporal gesture, non-temporal representational gesture, temporal sequencing accuracy, and narrative recall accuracy. Correlations were computed across all participants and are reported as Pearson's *r* values.

Results

In what follows, we quantify variation in the production of co-speech temporal gesture, as well as the relationship between temporal gesture and temporal reasoning accuracy. We also report on our findings on the association between temporal gesture and participant's uncertainty. Finally, we report the association between temporal gesture and non-temporal representational gesture.

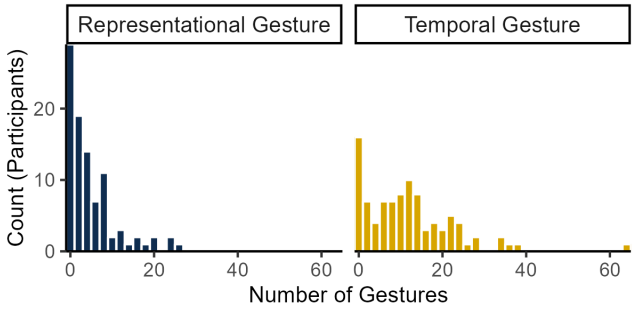

Fig. 2: Histogram of representational (left, blue) and temporal gesture (right, gold) production across participants.

Variation in temporal gesture

Participants varied in how much they gestured about time while recalling and reasoning about the time travel narratives. Spontaneous temporal gestures were common but not universal. Most participants produced at least one temporal gesture (85% of participants, n = 80). Some participants, however, recounted the complex time travel narrative from multiple perspectives without producing any temporal gestures at all (15% of participants, n = 14). The amount of temporal gesture production varied considerably, with some producing no temporal gesture and others producing dozens (max = 64, min = 0, M=12, SD=10.7).

Relationship between temporal gesture and temporal reasoning accuracy

We next investigated whether variation in the production of temporal gesture was a signal of the speaker's understanding of the complex temporal structure of the narratives. There was no relation between temporal gesture and any facet of comprehension of the time travel narrative. We found no correlation between temporal gesture production and temporal reasoning accuracy (Pearson's r = .07). Similarly we found no correlation between non-temporal representational gesture and temporal reasoning accuracy (Pearson's r = .07). A multilevel Bayesian model confirmed that variation in temporal gesture was unrelated to successful temporal reasoning (β = 0.21, 95% CI [-0.07, 0.49]). The 95% credible interval of temporal gesture is tight around 0, indicating that temporal gesture is not predictive of temporal reasoning accuracy. Additionally, the model shows that non-temporal representational gesture may be slightly predictive of temporal reasoning accuracy (β = -0.29, 95% CI [-0.54, -0.04]).

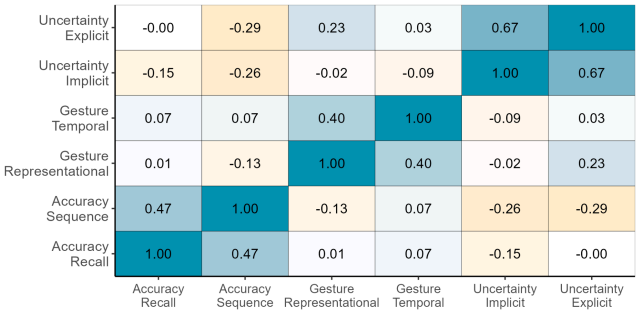

Fig. 3: Correlation matrix displaying associations between measures of uncertainty, gesture type, and accuracy on the post interview recall and temporal sequencing questions. Values displayed represent Pearson's *r*.

Uncertainty

Next, we investigated whether variation in the production of temporal gesture was a reliable signal of the speaker's uncertainty. We found no correlation between temporal gesture and either implicit measures of uncertainty (Pearson's r = -.09, $p > 0.05$) or explicit measures of uncertainty (Pearson's $r = 0.03$, $p > 0.05$). Thus, while some features of multimodal communication may predict uncertainty (Cheng et al, 2024), the amount of temporal gesture does not appear to be one such feature.

Does temporal gesture tell us about the production of other gestures?

Finally, we investigated how variation in temporal gesture related to the production of other, non-temporal gestures. There was considerable variation in the production of non-temporal representational gestures (Fig. 2, left). Most participants produced at least one non-temporal representation gesture (81% of participants, n = 76), although a sizable minority produced none at all (19% of participants, n = 18). The amount of non-temporal gesture production also varied, there was a considerable range in the amount of gesture, with some producing as many as 27 gestures (range = [0, 27]). Individual variation in the amount of non-temporal representational gesture, however, was smaller than the variation in the amount of temporal gesture (non-temporal gestures: SD = 5.9; temporal gestures: SD = 10.7).

This variation in non-temporal representational gestures was related systematically to the production of temporal gestures We found that variation in the production of temporal gestures was highly correlated with variation in the production of non-temporal gestures (Pearson's r = .40, p <.001).

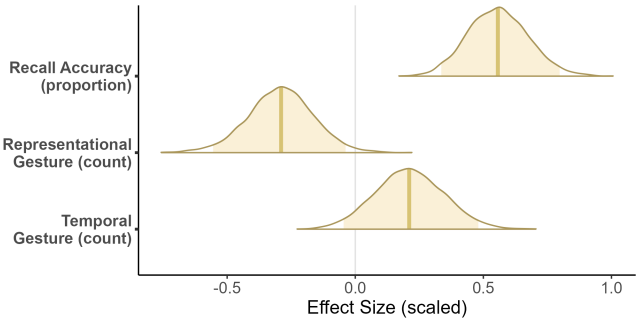

Fig. 4: Credence plot of posterior distributions for coefficients in the multilevel Bayesian model of temporal sequencing accuracy. Predictors on the y-axis include total number of temporal gestures, total number of representational gestures, and recall accuracy. The shaded region is the 95% credible interval.

Discussion

We investigated variation in temporal gesture production, its relationship to non-temporal representational gesture production, and its relationship to comprehension of complex temporal narratives. We found that temporal gesture occurs spontaneously but that the production of temporal gestures varies considerably between individuals. This variation in temporal gesture, in addition to a strong association between temporal gesture and non-temporal representational gesture, was a signal of variation in individuals' 'gestural style' more broadly. Those that gestured temporally also did so representationally writ large. The production of temporal gestures, however, was dissociated entirely from participants' subsequent recall and comprehension. These facts in tandem suggest that variation in the production of temporal gesture can act as a signal of individuals' broader tendency to use gesture as part of their communicative style, rather than as a signal of variation in their underlying certainty or comprehension.

What does variation in temporal gesture tell us about temporal reasoning?

We found no association between temporal gesture and temporal reasoning ability. This is surprising if gesture production is an index of reasoning difficulty or richness of visuospatial imagery. If spatializing is indeed necessary and foundational to abstract thought (or thought more generally), then spatialization is not necessarily manifested in gesture.

It is still possible that gesture supports temporal understanding, but maybe only in those who haven't developed stable spatial models of time travel. Gesture may have a differential impact on reasoning and comprehension across developmental time or even for understanding novel abstract concepts in adulthood. We may use the spatial and analog sensori-motor affordances provided by gesture in order to scaffold our understanding and form stable models of abstract concepts like time travel. Although previous research has found that gesture production can support abstract reasoning in the domain of mathematics (Cook et al., 2008), this effect may be more pronounced in children who have yet to develop stable spatial models for abstract conceptual domains.

These findings are consistent with the possibility that gesture production is epiphenomenal — lacking causal efficacy — in the task of abstract reasoning in mathematics (Walkington et al., 2019). Moreover, this is consistent with the *gesture as simulated action* account of gesture production (Hostetter & Alibali, 2008). Either in that some are not engaging in simulating sensori-motor actions metaphorically related to temporal reasoning, or that they simply are not breaching some threshold of neural activation in sensori-motor neurons related to those simulated actions.

Further, another possibility for this disassociation is that people may vary in their strategies for abstract reasoning. Gesture may help some but not others — it is only one resource amongst many. If the degree of individual differences is too high, future studies will require much more power. If the impact of gesture on abstract reasoning is highly contingent on individual differences — the use of different cognitive strategies in abstract reasoning — then this study simply lacks enough power to account for these differences.

Here we focused exclusively on variation in the *amount* of temporal gesture. It's possible that variation in other aspects of temporal gesture might be more reliable signals of temporal reasoning and understanding. For instance, temporal gestures can use space in a variety of ways — for instance, using spatial length to indicate temporal duration, or spatial location to indicate temporal order. It's possible that variation in the use of these different strategies — strategies for representing time spatially — might tell us

more about individual differences in temporal reasoning. For instance, creating highly idiosyncratic complex assemblages of temporal gesture specific to the structure of the narrative, or even simply having a high degree of *placing* time in the same spatial locations coherently with the storyline may reliably signal successful temporal reasoning. Indeed, individuals deploy a variety of different strategies when describing time travel narratives (Nosrati, Niehorster-Cook, & Marghetis, 2024); this variation in gesture type or form might tell us more than variation in gesture production. Thus, while here we have reported evidence that the relation between temporal gesture counts and temporal understanding is either small or non-existent, it remains possible that other features of a reasoner's temporal gestures might serve as a reliable index of their temporal understanding. In ongoing work we are exploring this possibility.

What does variation in temporal gesture tell us about uncertainty?

Variation in the production of temporal gesture doesn't seem to be a signal of a speaker's uncertainty about the temporal structure of events. Possibly because we may gesture about temporal events regardless of whether we're certain or uncertain about the nature of complex temporal narratives. However, other aspects of multimodal communication or other gestural forms may be a more reliable signal of uncertainty in abstract temporal reasoning. Speakers might still use gesture to scaffold their thinking in uncertain moments, but this may vary significantly between individuals. If gesture is a signal of uncertainty, it may do so through hesitations, self-repairs, or shifts in gestural space rather than through variations in whether or not temporal gestures occur at all.

What does variation in temporal gesture tell us about communicative style?

Although temporal gesture doesn't seem to point to anything about their underlying competence in complex temporal narrative comprehension, this variation in temporal gesture production and the tight coupling between temporal gesture and non-temporal representational gesture suggests that participants had a 'gestural style' that governed their gesturing in general. Some individuals may rely on spatial affordances to communicate complex abstract concepts more so than for the purpose of aiding in their own understanding — for the purpose of aiding in the understanding of *others*.

Gestural styles may be a product of highly idiosyncratic, flexible, and adaptive processes. Idiosyncratic in that individuals may develop a unique relationship to gesturing as a product of their particular linguistic and socio-cultural histories forming stable tendencies in how they gesture about abstract concepts. Flexible and adaptive in that the character and amount of gesturing is context dependent — specific to the particular task, spatial affordances, and communicative needs of the moment. Gesture seen through this lens, is part of a system of semiotic resources that can be soft-assembled to achieve various cognitive and communicative functions.

Limitations and future directions

This is a correlational analysis of a laboratory based observational study, and hence we cannot draw strong conclusions about the causal relationship between temporal gesture and temporal reasoning. That said, the lack of an association between temporal gesture and temporal understanding undermines claims of a simple causal link between the two.

In order to account for individual differences in the relationship between temporal gesture and temporal reasoning, future work may benefit from pre-experiment assessments of spatial reasoning strategies and much larger samples. Lastly, our sample included Spanish-English bilinguals, some of whom were native Spanish speakers. Given that the study was conducted in English, this may have influenced their rate of gesture production, although there are mixed findings on the relationship between bilingualism and gesture frequency (Gullberg, 2012).

Our findings that temporal gestures occur spontaneously, reflect each speaker's gestural style, but are unrelated to recall and comprehension seem inconsistent with accounts of abstract temporal reasoning that *require* spatialization. These results are surprising if a spatial conception of time is necessary and temporal gestures are an automatic manifestation of that spatial conception. We speculate that our comprehension of time can blend various semiotic and cognitive resources, with considerable individual differences. While some individuals may produce temporal gestures when they are struggling to understand, others may produce temporal gestures to convey their deep understanding. While there is considerable work on cross-cultural variation in temporal gesture, there is relatively little on within-cultural variation. Ongoing work is investigating whether individuals vary not just in the presence or frequency but also the type or content of temporal gesture.

Conclusion

We find that people vary in how much they gesture when making sense of complex conceptions of time. Some deploy space through communicative bodily expression — they gesture — and some do not. Among those that do gesture, they gesture more not just about time but in general, reflecting a broader communicative style. These findings are consistent with accounts that foreground variation in individuals' habitual use of gesture. This variation underscores how spatializing is just one possible strategy in abstract reasoning. But it remains a powerful strategy, communicating the spatial structure of complex time in a way that words cannot.

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