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Spatial Construals of Time… Travel

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Abstract

From H.G. Wells' *The Time Machine* to the recent Hollywood blockbuster *Arrival*, the notion of time-travel is a firmly established narrative trope. Yet tales of travel back and forth through time are essentially absent before the mid-1800s. This invites the question: How *do* people make sense of time-travel, and how does it build on the more basic building-blocks of our conception of time itself? Here, we investigate lay conceptions of time-travel using a gesture elicitation paradigm. Participants watched brief videos of time-travel stories and then recounted the plots. Combining qualitative analysis and machine learning extraction of co-speech gesture trajectories, we describe how participants' construals of time-travel cobble together more basic spatial construals time (e.g., length-duration; past-left vs. future-right), combined to create layered, ad-hoc, flexible representations of time. We discuss implications for how spatial metaphor can offer a foundation for more complex, elaborated forms of reasoning and understanding.

Keywords: Gesture, Metaphor, Space, Time, Time Travel

Introduction

In 1895, H.G. Wells' published *The Time Machine* and introduced a story that radically reimagined our relationship with time. How did readers make sense of this new conception of time? One hint comes from the story's opening scene. The protagonist explains in extended, almost pedantic detail that time can be considered a fourth dimension… on par with the standard spatial dimensions… and that, if we can move to and fro through space, then we should be able to move through time. The amount of text dedicated to this exposition suggests Wells thought it would be difficult for his 19th century readers to grasp.

Time and *travel* — what sort of conceptual feat does it take to join these two words together? Wells himself through the idea was novel for his time:

> In the universe in which my brain was living in 1879, there was no nonsense about time being space or anything of that sort. There were three dimensions, up and down, fore and aft, and right and left, and I never heard of a fourth dimension until 1884 or thereabout. (quoted in Gleick, 2016)

So although it may seem natural to the modern reader that the concepts of time and space are linked, the idea of time as a space-like dimension is a rather modern addition to our conceptualization of time. Indeed, one could easily conceive of time in non-spatial ways. Aristotle, for instance, described time as dynamic transformation without invoking space, writing in *Physics* that "there is no time apart from change" (Coope, 2005).

Philosophers have settled on two competing accounts of time (Emery, 2020). *Presentism* claims that the past and future do not exist. Rather, all that exists is an ever-changing present. One consequence of this view is that genuine time travel appears impossible. One simply cannot travel to "other" times if they don't exist. According to *eternalism,* sometimes referred to as the *block universe* framework, there is no ontological distinction between past, present, and future. In the block universe, there is no flow of time or a privileged present, but rather everything exists concurrently as an unchanging static object. In this and related theories, time is treated as a fourth space-like dimension. This view makes time-travel at least conceivable — a kind of motion along a space-like dimension. These alternative views of time have a range of supporters and detractors. Buonomano (2017), for instance, speculates that most physicists are eternalists, while presentism best conforms to most people's intuitions about the flow of time.

So how *do* we make sense of time-travel, an idea that challenges conventional understandings of time? One recurring strategy for understanding more basic notions of time — a strategy that has been documented across widely varying cultures — is to conceive of past, present, and future in terms of space, as metaphorical locations along a path (Lakoff & Johnson, 1980; Boroditsky, 2000; Casasanto & Boroditsky, 2008; Cooperrider & Núñez, 2013; Winter, Marghetis, & Matlock, 2015). Evidence for this spatial conception of time comes from polysemy. In English, for instance, we talk about "putting the past behind us" and "looking ahead to the future," while duration can be described using the language of spatial extent (e.g., 'a long meeting') (Lakoff & Johnson, 1980). Similar patterns of space-time polysemy have been documented in a wide range of languages and cultures (Cooperrider & Núñez, 2013).

But are these just figures of speech? *Gesture* provides critical evidence that actually think about time in terms of space. Gestures are spontaneous movements of the body (typically hands) that accompany speech. When people talk

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about basic aspects of time—when explaining the meaning of *yesterday*, for instance—they gesture in ways that use space systematically to represent temporal duration and location (Núñez & Sweetser, 2006; Cooperrider & Núñez, 2009; Casasanto & Jasmin, 2012; Walker & Cooperrider, 2016). Speakers of English, for instance, gesture leftward (and sometimes backwards) when referring to the past and rightward (sometimes forward) when referring to the future.

Cooperrider & Núñez (2009) developed a taxonomy of temporal gesture that identified five distinct types that use space in different ways. *Placing* gestures locate a temporal event in the speaker's peripersonal space. *Pointing* gestures use motion to project a line to a temporal event. *Duration-marking* gestures demarcate a spatial length that conveys the time between two events or the duration of one event. *Bridging* gestures express a transition between two temporal events. Finally, *animating* gestures enact the idea of time as an agent with motion of its own. These gesture types are distinguished by their morphodynamic properties (handshape, movement, location) and relationship to speech.

How do we go from this spatial foundation — a metaphorical understanding of duration and temporal order in terms of spatial extent and location — to make sense of something as tangled and unintuitive as *time-travel?* One possibility, explicit in the work of Lakoff and Johnson (1980), is that basic metaphors lay the foundation for ever more complex conceptions. On this account, the temporal gestures identified by Cooperrider & Núñez (2009), and the conceptions of time that they reflect, should appear not only when people are recounting their summer vacations or explaining the meaning of 'yesterday' but also when grappling with notions as complex as time-travel and temporal paradoxes. But are the same basic building blocks really used to construct ever more complex understandings of time? If so, how are basic gesture 'types' combined to convey notions like *time-loop* or *grandfather paradox?* When pushed to the limits of temporal understanding, do people begin to use gesture and space in entirely new ways?

As a first attempt at answering these questions, here we report a qualitative analysis of co-speech gestures produced while people reckoned with complex time-travel narratives. Participants watched videos of time-travel stories and then recounted their plots. We combined qualitative analysis and machine learning extraction of gesture trajectories to investigate participants' spatial construals of time-travel. How do people spontaneously deploy their bodies and space in making sense of not just *time* but *time-travel*?

Methods

Participants

Participants (N = 40; ages 18-30 years, M = 20.5 years; 12 men, 27 women, 1 unreported), 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. Informed consent was obtained prior to the start of the study.

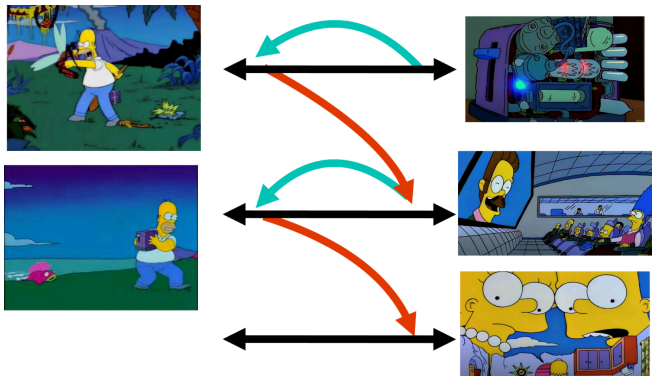


Figure 1: Timeline of the time travel plot in The Simpson's story. Horizontal black lines represent the sequence of events on an objective timeline, ranging from the ancient past (still images on left) to the present (still images on right). Arched aquamarine arrows indicate moments when the protagonist traveled back in time. Arched red arrows indicate moments when the protagonist traveled forward through time.

Design

We employed a classic co-speech gesture observational paradigm, *narrative retelling* (McNeill, 1995). Participants watched brief videos and were then asked to retell the plot as if they were talking to a friend. Participants were not made aware of the fact that we were interested in gesture (e.g., the consent forms described the study's focus as "abstract reasoning" and did not mention gesture). Researchers were trained to never gesture during the study.

This paradigm allows us to examine co-speech gesture production in the naturalistic context of conversation. Retelling the plot of a fictional story is a common experience. Patterns of speech and gesture produced in this context, therefore, are likely to generalize to more ecological settings of everyday conversation and reasoning.

Materials

Stimuli consisted of short videos involving time travel.

The first video was a segment from the *Simpsons* episode 'Treehouse of Horror V.' 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 (Fig. 1). 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.

The second video was the short film *Tethers* (2021). In this story, the main protagonist, Anna, travels back in time in order to stop her mother from marrying her father. While she is aware that doing so would prevent her own birth— a version of the "grandfather paradox" — Anna hopes to

sacrifice herself to prevent her mother from suffering a life of abuse at the hands of her father. The themes of time-travel, including the potential for paradox, are not addressed explicitly but exist in the story's subtext.

Participants also watched a third video that did not include any elements of science fiction (clips from the sitcom *Seinfeld,* Season 5, Episode 22, 'The Opposite'); here we do not analyze data elicited by this video.

Procedure

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. For each video, participants were asked to retell the plot in two ways: first, a brief summary in just a few sentences, and second, an in-depth play-by-play with as much detail as possible. 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 main protagonist, Homer Simpson; (2) from the perspective of an eternal being who can adopt a "god's eye view" on the events. 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. This prompt was intended to test to what degree participants would shift between construals of time that differed in viewpoint.

Participants then completed a computer-based test of narrative recall and temporal reasoning. The results of this battery of questions will be analyzed elsewhere. The study ended with standard demographic questions.

Analysis

One coder viewed participants' narrative retellings and identified every instance of co-speech temporal gesture (specifically, hand gestures that expressed temporal content in coordination with temporal speech). These instances were segmented for subsequent in-depth qualitative analysis.

To quantify the use of space in temporal gestures, we deployed a pre-trained machine learning model for 'pose estimation', or inference of body location and orientation from images. We used MediaPipe Pose (Google, 2022), a pre-trained convolutional neural network which estimates the location of 33 'keypoints' or locations on the human body in 3-dimensional space from video. The MediaPipe Pose model has been validated against human annotations[1] and found to reliably estimate the location of keypoints. This machine learning pipeline allows us to estimate the spatial trajectories of gesture strokes (Fig. 2). Here we use model-estimated trajectories to visualize our qualitative analysis of temporal gestures.

Results

Most participants (n = 35 out of 40) produced at least one temporal gesture, resulting in a corpus of N = 151 temporal gestures. This proportion of co-speech temporal gesture production is in line with past research that used a similar gesture elicitation task but a simpler temporal scenario (Cooperrider & Núñez, 2009). Here, we report qualitative analyses of these gestures to support four broad claims: conceptions of time-travel build on more basic spatial construals of time; basic types of temporal gesture can be blended together to create complex, 'laminated' construals of time; these temporal gestures may reflect constraints from both cultural conventions for gesture and the spatial content of accompanying speech; and conceptions of time travel reveal a striking conceptual flexibility.

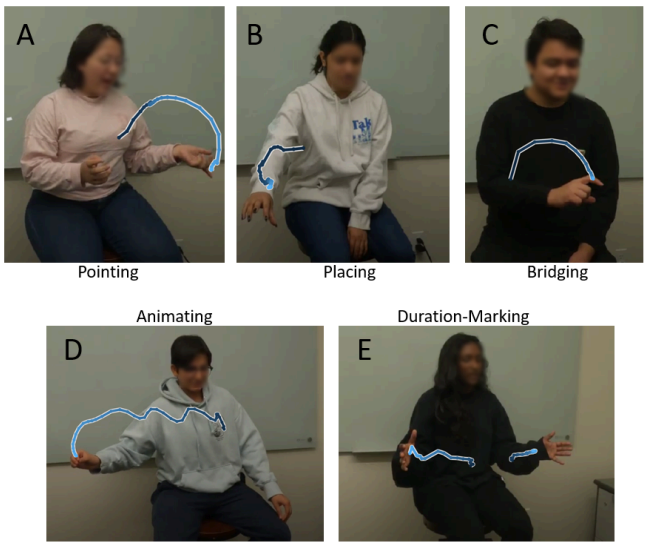


Figure 2: Examples of the Cooperrider & Núñez (2009) taxonomy of temporal gestures, with trajectories extracted by MediaPipe Pose. The beginning of the stroke is dark blue, and the end of the stroke is light blue. (A) Pointing: "She gets sent back in time presumably to this big party." (B) Placing: "It was the bug, then the future" (C) Bridging: "He fixed the toaster, went back, he killed the mosquito." (D) Animating: "It's kinda one of those years past kinda situations." (E) Duration-marking: "Ok this guy's gonna come in like five minutes, and there's like this whole kind of like timeframe."

[1]https://research.google/blog/on-device-real-time-body-pose-tracking-with-mediapipe-blazepose/

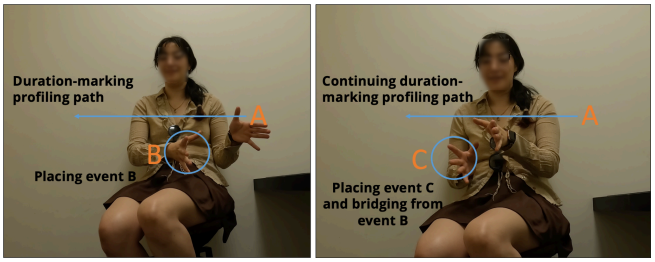


Figure 3: Complex lamination of spatial construals of time. The participant reorders events from The Simpsons' story from a god's-eye perspective. The orange letters indicate the three different gesture phrases. The motion of the left hand, A, continues during the entire utterance. Gesture phrases B and C are co-timed with the first and second underlined text: "Everything like dinosaur times and then all of a sudden homer appears and then kills this mosquito, disappears and then appears again kills the fish."

Complex construals of time travel are built out of canonical spatial building blocks

In retelling complex time-travel narratives, participants produced temporal gestures that exemplified every type from Cooperrider & Núñez's (2009) taxonomy of temporal gestures: placing, pointing, duration-marking, bridging and animating (Fig. 2). Below we describe examples of these types of temporal gesture and their accompanying speech. The underlined portion of the speech indicates where the gesture phrase occurred.

Some examples from the Cooperrider & Núñez taxonomy are rather straightforward. For instance, the speaker in Fig. 2B produces a ***placing*** gesture that places a temporal event in the speaker's peripersonal space. The speaker is placing plot points in the space around her while sequencing events from The Simpsons' story: "It was the bug, then the future." Here, temporal location is the same whether experienced from the protagonist's perspective (i.e., Homer Simpson) or an objective outside perspective.

Other temporal gestures, however, take on new complexities when deployed to recount time travel narratives. Recall that ***pointing*** gestures indicate a spatial location that stands for a temporal event. During a narrative retelling, for instance, a pointing gesture might indicate when an event is going to occur relative to the protagonist's present. In time travel narratives, however, a point to the *left* can represent an event that the protagonist might experience in the future… except the event itself is located in the past (Fig. 2A). The speaker in Fig. 2A, for instance, is pointing to her left with a canonical pointing handshape (i.e., extended index finger) while she describes the protagonist from the Tethers story traveling to the past to save her mother: "She gets sent back in time presumably to this big party." Note that in this example, the event is in the protagonist's future but, from the outside perspective of an omniscient being, a block universe, or even just a non-time-traveler, the event is in the past.

Bridging gestures are especially evocative when talking about time travel. The speaker in Fig. 2C connects two temporal events in space using a looping gesture. The participant gestures by drawing an arch with their index finger between two locations while sequencing events from The Simpsons' story: "He fixed the toaster, went back, he killed the mosquito." Note that this bridging gesture is not just comparing the temporal location of two events, but simultaneously conveying the *movement of an individual through time*. This would never happen when talking about the temporal structure of a typical narrative; events might be connected temporally by a bridging gesture but the motion would never convey a movement *backward* through time.

Animating gestures typically convey the passage of time, but in the context of time travel they can simultaneously represent the movement of a time traveler. The gesture in Fig. 2D illustrates this complexity. The participant creates a wave of small arches while describing a succession of events across a long timespan: "It's kinda one of those years past kinda situations." While a typical animating gesture might evoke a 'moving time' construal of time (e.g., as expressed in speech with the phrase, "My life is passing me by"), here the animating gesture simultaneously evokes both the passage of events but also the potential movement of a time traveler along that evoked path.

Finally, the speaker in Fig. 2E produces a **duration-marking** gesture that carves out a specific chunk of space to profile the duration of an event. The participant has both hands in a palm-vertical orientation spreading them apart in synchrony with saying "whole" and then keeps her hands spread apart and ends the gesture phrase with a beat on "timeframe": "Ok this guy's gonna come in like five minutes, and there's like this whole kind of like timeframe." On its own, this duration-marking gesture is similar to ones we might encounter in more traditional temporal narratives. When combined with other spatial strategies, however, speakers are able to construct complex, laminated spatial structures to convey the knotted structure of time travel.

For example, in some instances participants would combine basic 'types' of temporal gestures in a single gesture phrase, using them as building blocks to form more complex laminations of meaning. Figure 3 illustrates one such instance. Here, a participant is sequencing the order of events from The Simpsons' story as construed from a god's-eye perspective. As she is ordering these events she holds one hand up in a palm-vertical orientation slowly moving it from her left to her right profiling a sliding window of time (both **duration-marking** and **animating**), all the while gesturing with her other hand to insert various events from the story line (**placing**). The two hands together use space to **bridge** between the events. Thus, in a single bimanual sequence, the hands combine four different 'types' from the Cooperider & Núñez taxonomy — deploying them not as discrete types but rather as flexible spatial *strategies* that can be layered and blended to construct the complex structures that are required to represent time travel plots.



Figure 4: Gestural direction reflects both temporal content but also the spatial content of speech. Here, a pointing gesture that represents motion from past to future is directed *backwards* as the speaker says, "Him transporting back to the future."

"Back to the Future:" Time travel highlights the tension between spatial construals and language

Recall that American English users canonically place future events in front of them and past events behind. In a number of instances, however, participants gestured in ways that conveyed the literal spatial content of *speech* rather than the canonical spatial construal of time, as when gesturing about how Homer went 'back to the future' (Fig. 4). While our observational design does not allow us to draw strong inferences about why participants gestured backward when talking about a return to the present, we suspect there are two contributing factors. One is the constraint imposed by the spatial construction itself; 'back' might invite a backward gesture, even when it means metaphorically a movement forward in time. In addition, the particular frame of reference that a speaker adopts may shape the way they situate themselves relative to the passage of time: When speakers adopt the viewpoint of a time-traveling protagonist they may gesture differently from when they adopt the viewpoint of an objective 'outsider.' Indeed, as we discuss next, shifts in viewpoint were part of the fantastic conceptual flexibility in time travel retellings.

Flexible viewpoints on the order of time [travel]

When prompted, some speakers were able to adopt different perspectives on the same sequence of events: the "god's-eye" perspective of an objective outside observer, or the 'insider's' perspective of the time traveling protagonist. We observed that when some participants ordered the events from the god's-eye perspective they moved one hand laterally across their body to construct an ephemeral timeline (Fig. 3). These kinds of 'external timeline' gestures could either represent the movement of focus (from the god's eye perspective) across a sequence of events, ordered from past to future, or might profile the movement of time itself. Thus, unlike the bridging or animating gestures that speakers produced when recounting the protagonists' experience, here they used a spatial trajectory to objectify time: tracing out a timeline, typically left-to-right, in which they could place events from the story. Contrast this unified, unidirectional timeline with the way some speakers conveyed Homer's perspective: hand oscillating along the lateral axis, arching from left to right and back again (Fig. 5). When participants shift their temporal viewpoint from objective-outsider to subjective-insider, the same sequence of events can be given an entirely new spatial construal, revealing the dynamic and ad-hoc nature of spatial construals of time.

Discussion

Time travel narratives are ubiquitous in fiction today, but seem to have appeared from nowhere in recent cultural history (Gleick, 2016). Here, we combined machine-learning-supported motion capture with qualitative microanalysis to investigate the elaborate yet flexible ways that people use *space* to make sense of complex time travel narratives. First, we documented that spatial construals of time-travel make use of the basic spatial strategies that have been documented with more simple, non-fantastical temporal content. These basic building blocks, however, were combined in complex laminations of spatial construals as people blended basic spatial metaphors in creative and ad-hoc ways. Moreover, the deployment of space to make sense of time reflected both the standard cultural conventions — placing past events on the left and future to the right — but also the constraints of linguistics constructions that are specific to time-travel ('back to the future') and the flexible viewpoints on time that time-travel narratives invite. All told, the spontaneous temporal gestures elicited by these time travel retellings highlight the immense flexibility of our temporal reasoning, but also its heavy dependence on space.

Implications for spatial construals of time

Our analyses of the temporal gestures elicited in this study reveal that the previously identified temporal gestures (Cooperrider & Núñez, 2009) are used in far more flexible and creative ways than a rigid taxonomy of distinct `types' might suggest. The intricate lamination of multiple styles of temporal gesture and their conceptual malleability invites a more nuanced framing — one that views these temporal gestures, not as distinct categories, but as flexible and combinatorial spatial *strategies* for making sense of time. On this view, spatial strategies of pointing, placing, bridging, duration-marking, and animating are flexible tools for constructing unified single construals of complex temporal narratives, blended together into a gestural gestalt.



Figure 5: Flexibility of event sequencing construals. Participant is sequencing events in The Simpsons' story from Homer's perspective. Their right hand oscillates from left to right placing the main plot points in contrasting spatial locations in the order that Homer experienced them. The right hand moves in an arch profiling the character's movement through time.

Real trajectories through pose detection

What do the precise spatial trajectories generated by the MediaPipe Pose machine learning model reveal about spatial construals of time and perception of gestural forms? One thing to note is the difference between the objective trajectories of the hands and our schematized perception of their motion. What appears to be a clean vector traced by the hand when pointing reveals itself to be an arch, and what appears to be a clean arch when placing reveals itself to be a tangled mess (Fig. 2). These gesture forms might be seen through the lens of schematic spatial structures that differ from their actual physical form (Hassemer & Winter, 2018).

Indeed, what appear to the viewer as two very different gestural forms can actually have very similar spatial trajectories. For example, compare the gestures captured in Fig. 2A (pointing) and 2C (bridging). When we view the video of the gesture in Fig. 2A, the pointing gesture genuinely appears to us like it is projecting a straight vector to the left (the 'past'), while the bridging gesture in Fig. 2C genuinely appears to us like it is connecting two points in time and space. However, the actual spatial trajectories, as captured by the ML-supported motion tracking, look nearly indistinguishable. It is only when these gestures appear in context that they *appear* so very different. This speaks to how much work is being done by the rest of the composite signal: the context, the speech, the microdynamics of pauses, and the morphology of the handshape.

Spatial and cultural affordances

Pushing temporal reasoning to its limits revealed more complex and creative uses of space to make sense of time. In performing temporal gestures, participants evoked complex temporal relationships as spatial locations, regions, movements, and links — and thus made those invisible temporal relationships available for visual processing. In a sense, these gestures create ephemeral cultural artifacts.

When describing events from an outsider 'god's-eye' perspective, temporal gestures objectified time in various ways that contrasted with the 'insider' viewpoint of the time-traveling protagonist. These 'god's-eye' gestures evoked unidirectional timelines and sliding windows of focus. These gestural construals suggested a conceptualization of space-time as a block universe — one where past, present, and future exist simultaneously, separated only by the dimension of time. Adopting this perspective allowed speakers to adopt the perspective of an omniscient being who can move their gaze along the various events that exist within this static block universe. Distinct perspectives on time travel may tap into different philosophies of time, and appreciating time travel narratives may cultivate a flexible appreciation for different visions of the nature of time.

It may be that the rich, flexible spatial conceptualizations of time evoked here are a product of a particular culture in our current times. Perhaps we wouldn't have seen such gestural construals if we had conducted this study in the time of H.G. Wells, using his first readers as participants. Just as our cultural relationship with time has changed with the advent of time-travel stories, our individual understanding of the nature of time may have changed, too. Without access to an actual time-machine, we can only speculate about the cultural history of these spatial construals of time. But, as argued by Muthukrishna, Heinrich, and Slingerland (2021), *psychology [and cognitive science] is a historical science*. It may be that the widespread rise of an "objective" notion of time in the 19th century — prompted in part by the spread of train travel (Gell, 2021) — may have made possible the advent of time travel narratives. The scientific study of conceptions of time travel is thus an opportunity to understand the historical and cultura contingency of temporal cognition.

Conclusion

Time has been called the 'fruit fly' of cognitive science (Casasanto, 2009) — a simple model system for understanding basic mechanisms of metaphorical and analogical thought. Building on this analogy, perhaps the study of time travel can be a Human Genome Project: a scientific endeavor that pushes us to consider how basic processes of metaphor and analogy can build up to create rich, structured, yet flexible conceptions.

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References

Buonomano, D. (2017). Your brain is a time machine: The neuroscience and physics of time (First edition). W. W. Norton & Company.

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

Casasanto, D. (2009). When is a linguistic metaphor a conceptual metaphor. *New directions in cognitive linguistics*, 24, 127-145.

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. Cognition, 106(2), 579-593.

Casasanto, D., & Jasmin, K. (2012). The Hands of Time: Temporal gestures in English speakers. Cognitive Linguistics, 23(4), 643–674. https://doi.org/10.1515/cog-2012-0020

Coope, U. (2005). Time for Aristotle: physics IV. 10-14. Oxford Aristotle Studies.

Cooperrider, K., & Núñez, R. (2009). Across time, across the body: Transversal temporal gestures. Gesture, 9(2), 181–206. https://doi.org/10.1075/gest.9.2.02coo

Emery, N., Markosian, N., & Sullivan, M. (2020). Time. Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/time/#PresEterGrowBlocTheo

Gell, A. (2021). The anthropology of time: Cultural constructions of temporal maps and images. Routledge.

Gleick, J. (2016). Time travel: A history (First edition). Pantheon Books.

Google. (2022). Pose landmark detection guide | mediapipe |google for developers. Google. https://developers.google.com/mediapipe/solutions/vision/pose_landmarker/

Hassemer, J., & Winter, B. (2018). Decoding gestural iconicity. Cognitive science, 42(8), 3034-3049.

Kendon, A. (2004). Gesture: Visible action as utterance. Cambridge University Press.

Lakoff, G., & Johnson, M. (1981). Metaphors we live by. University of Chicago Press.

McNeill, D. (1995). Hand and mind: What gestures reveal about thought. The University of Chicago Press.

Muthukrishna, M., Henrich, J., & Slingerland, E. (2021). Psychology as a historical science. Annual Review of Psychology, 72, 717-749.

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.

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

Walker, E., & Cooperrider, K. (2016). The continuity of metaphor: Evidence from temporal gestures. Cognitive Science, 40(2), 481-495.

Winter, B., Marghetis, T., & Matlock, T. (2015). Of magnitudes and metaphors: Explaining cognitive interactions between space, time, and number. Cortex, 64, 209-224.