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Thinking Tools: Gestures Change Thought About Time

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Abstract

Our earliest tools are our bodies. Our hands raise and turn and toss and carry and push and pull, our legs walk and climb and kick allowing us to move and act in the world and to create the multitude of artifacts that improve our lives. The list of actions made by our hands and feet and other parts of our bodies is long. What is more remarkable is we turn those actions in the world into actions on thought through gestures, language, and graphics, thereby creating cognitive tools that expand the mind. The focus here is gesture; gestures transform actions on perceptible objects to actions on imagined thoughts, carrying meaning with them rapidly, precisely, and directly. We review evidence showing that gestures enhance our own thinking and change the thought of others. We illustrate the power of gestures in studies showing that gestures uniquely change conceptions of time, from sequential to simultaneous, from sequential to cyclical, and from a perspective embedded in a timeline to an external perspective looking on a timeline, and by so doing obviate the ambiguities of an embedded perspective. We draw parallels between representations in gesture and in graphics; both use marks or actions arrayed in space to communicate more immediately than symbolic language.

Keywords: Gesture; Time; Thought; Visualspatial communication; Language; Representation; Embodied cognition; External mind

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1. Introduction

The moniker, *Homo sapiens*, for our species has inspired many variations, calling attention to what distinguishes *sapiens* from other species. A popular one is *Homo faber*, the toolmaker or designer (e.g., Arendt, 1958); followed by *Homo fabricans* and *Homo fabricator*. The fascinating nuances of these uses go back and deep, even forward and broad, far too much for now. Here we keep the essence of that one: our species makes an enormous variety of tools, primarily with our hands, and those tools make artifacts that enhance our well-being. It is not that other species do not make tools and artifacts, it is just that our tools proliferate, and that we build new tools from old tools, new artifacts from old ones. What further distinguishes our species is that we create tools that increase the well-being of our minds as well as the well-being of our bodies, that is, cognitive tools. Primary among those tools are gestures, language, and graphics (e.g., Clark & Chalmers, 1998; Donald, 1991; Harari, 2014; Henrich, 2015; Norman, 2014; Tversky, 2019).

The focus here is gesture, in particular, representational gestures, gestures that, like language, carry meaning. We show that arrays of gestures that represent events in time can, by themselves, change understanding of events in time. Gestures can impart meaning directly, whereas language imparts meaning arbitrarily, symbolically. Many representational gestures transform actions on perceptible objects into actions on invisible thought. Those gestures pop out when we talk about, but do not perform, actions on objects and they pop out when we talk about actions on thought. Not only gestures but the very words we use to express actions on thought are those that we use for actions on objects. We raise them, toss them out, pull them together, turn them inside out. Indeed, it is not easy to talk about actions on thought without using the language of action on objects.

Gestures take many forms and serve many functions, for self and for other (e.g., Goldin-Meadow, 2003; Kendon, 2004; McNeil, 1992; Tversky, 2019). For especially representational gestures, form follows function. Gestures that represent actions are often miniature stylized actions like bringing the hands together to show closeness, spatial or metaphoric. Gestures can also stand for static ideas, people, places, and things. In those cases, gestures are often points of fingers or placements of hands, sometimes directed at things or places that represent things, sometimes sketched in the air. A series of gestures placed in an imaginary space, a virtual blackboard or tabletop or page, can be used to convey the spatial locations of a number of places in an environment, much like a map (e.g., Emmorey, Tversky & Taylor, 2000) or the workings of a mechanical system, much like a diagram (e.g., Kang & Tversky, 2016) or an array of ideas, as in "on the one hand, on the other" or "first, second, third…" Thus, gestures can convey noun-like and verb-like ideas, like language, though more immediately than language; actions represent actions and places represent things or ideas. Gestures can also array a set of places or ideas in a real or conceptual space, a feat not easily accomplished by words.

Gestures do more than express thought; they affect thought, the thought of those who make them and the thought of those observe them. Numerous studies have shown that gestures can express ideas that are not in the words, but are fundamental to communication (e.g. Goldin-Meadow, 2003; Hoestetter, 2011). Deictic expressions like "over there" or "this way" need appropriate gestures for clarification (e.g., Clark, 2003). College students learning the workings of a car engine from a videoed explanation grasp the actions of the engine far more clearly and deeply when the explanation is accompanied by gestures animating the actions of the parts rather than by gestures illustrating the shapes of the parts. This despite identical verbal scripts that are sufficient for understanding the actions (Kang & Tversky, 2016). Note that this study, as well as others, was with adults; it is not just children (Hoestetter, 2011) who are deeply influenced by gestures. When adults sit on their hands, they have difficulty finding words (Krauss, 1998). The gestures we make for ourselves in the absence of speech can also have powerful effects on comprehension and learning. They support mental rotation (Chu & Kita, 2008; Wexler, Kosslyn & Berthoz, 1998; Wohlschlager & Wohlschlager, 1998) and counting (Carlson, Avraamides, Cary & Strasberg, 2007; Segal, Tversky & Black, 2014). In several experiments, college students were alone in a room studying descriptions of complex environments or mechanical systems for a later test. Around 60–70% of students spontaneously gestured for at least one description as they studied. Their gestures created spatial models of the environments or systems they were learning. Remarkably, they performed better on tests of knowledge for the descriptions they gestured. When asked to sit on their hands while they studied, they performed worse. Some even said, "I can't think without my hands" (Bradley-Zrada, 2018; Jamalian, Giardino & Tversky, 2013; Yang, 2019). Gestures are actions in space so it is natural that they influence thought about actions in space. Here we show that gestures can also influence thought about time.

The influential philosopher, Immanuel Kant, challenged his empiricist predecessors, notably Locke, arguing that certain fundamental concepts originate in the mind rather than from experience (1781). Primary among those fundamental concepts are space, time, and causality. The empiricist-rationalist debates are alive today in psychology as well as philosophy. It is not our purpose here to settle them, but rather to explore how people think about events in time and how thinking about time is reflected and affected by gestures, that is, actions in space.

Time and space are inextricably interwoven in thought, in language, in gesture, in visualizations. All the events of our lives, the quotidian and the consequential, take place in time. Time moves inexorably forward, the proverbial arrow of time. Note "moves." Note "forward," Note, also, "arrow." That inexorable forward motion does not stop us from reimagining time, undoing one string of events and imagining another, one with a better ending. Consulting the past allows us to anticipate the future and to plan it. Time is often conceived of as one-dimensional and unidirectional, on a line. People from different cultures from preschoolers to adults typically map time to space along an imagined or actual one-dimensional line, usually but not always horizontal and usually in reading order (e.g., Bender & Beller, 2014; Boroditsky, 2000; Casasanto & Boroditsky, 2008; Clark, 1973; Cooperrider & Nunez, 2009; Fillmore, 1971; McGlone & Harding, 1998; Núñez & Cooperrider, 2013; Talmy, 2000; Tversky, Kugelmass & Winter, 1991; Xiao, 2012).

One way of talking about events in time is relative to ego, to a deictic center, the here and now, invoking one of two spatial metaphors, each of which involves an ego embedded in a timeline and movement in space along that line: either ego moves along a time line, as "we are approaching the holidays" and "we have moved past the deadline" or ego is stationary, and events move up to and past ego, as in “the holidays are approaching” or “the deadline is behind us” (e.g., Boroditsky, 2000; Clark, 1973; Gentner, 2001; McGlone & Harding, 1998). Being embedded in a time line, a point on it, is analogous to being embedded in a space, walking a route (e, g, Taylor & Tversky, 1992). “You” are on a line dotted by events in time just as “you” are on a route dotted by landmarks in space. Adopting the moving ego perspective, ego moves through landmarks in time, as in “we are approaching New Year’s” just as ego moves through landmarks in space, as in “we are approaching the Empire State Building.” Adopting the moving time perspective, ego is stationary in space and events are moving as in “New Year’s is coming up” just as ego is stationary in space with landmarks moving as in “The Empire State Building is coming up.” Note that that statement is not odd even though the Empire State Building cannot move.

These two ways of thinking about time can lead to ambiguities in talking about time, giving rise to the famous ambiguous question: Wednesday’s meeting has been moved forward 2 days; when is it? If ego is moving forward in time, the meeting should now be on Friday. However, if ego is stationary and time is moving toward ego, the meeting should now be on Monday. Responders split just about evenly, baffled by the responses of others. Yet how they respond can be primed by moving in space; actually moving primes ego moving and watching movement primes time moving (Boroditsky, 2000). Note that moving in space or watching movement in space, unlike gestures in space, do not represent time; they simply prime either moving or staying in place. Significantly, space is primary: the spatial perspective primes the temporal but not vice versa (Boroditsky, 2000). For time, as well as many other aspects of thought, spatial thinking is fundamental (Tversky, 2019).

Despite the fascination—and confusion—with these perspectives on space and time, avoiding the fascinating but confusing ambiguities is a cinch: think of space and time from the outside instead of from the inside. For maps of space and calendars or timelines or schedules, viewed before the eyes or in the mind, the perspective is from outside, looking onto a map or a calendar or timeline rather than being embedded in it. You can move a dinner date from Monday to Friday just as you can change the dinner place from one restaurant to another. There is motion, but it is the event or the location that changes, not you, not time, nor space. Taking an outside view of space and time is possible even for preschool children. When children (and adults) from different cultures are asked to arrange temporal events, such as the meals of the day, on a page, they array them along a line, usually horizontal and in the direction of reading order (Tversky, et al., 1991). They almost never produce circles even for familiar cyclical events, like routines of the day or seasons of a year. When speakers of languages written left-to-right talk about events in time, they gesture along a horizontal line that goes left to right (Cooperrider & Nunez, 2009; Ouellet, Santiago, Israeli & Gabay, 2010; Torralbo, Santiago & Lupianez, 2006). Both unique events, such as a first visit to Disneyland or the 2009 presidential inauguration, and repeating classes of events, such as eating in a restaurant or going to a movie, are sequences in time that can be conceptualized as a series of points on a line, each point representing a separate segment that is part of the entire event (e.g., Zacks & Tversky, 2001). The temporal relations are between the events themselves, before or after, earlier or later, rather than between an event and ego just as the spatial relations in a map are between the places, as in a survey perspective, rather than between places and ego, as in a route perspective (e.g., Taylor & Tversky, 1992).

Although time is typically regarded as one-dimensional and linear, we can think about time in other ways; for example, keeping track of simultaneous or overlapping events. Thinking about simultaneous or overlapping events requires integrating more than one timeline, a difficult task for minds biased toward one-track linear thinking. Yet thinking about simultaneous and overlapping events in time can be simplified by arraying events in time on a page; that is, by a diagram (Bauer & Johnson-Laird, 1993; Glenberg & Langston, 1992). Gestures can create virtual diagrams; perhaps gestures can also promote understanding simultaneity.

Yet another way of thinking about time is cyclical. Many of the important and unimportant events and processes that fill our lives can be regarded and understood as cycles of events that repeat. Winter turns to spring then to summer and fall and then (*back*) to winter again. Day after day, people wake in the morning, have breakfast, go to work, come home, go to sleep, and wake again in the morning. The same clothes go through the laundry each week, washed, dried, folded, put away, only to be worn and washed again. Water evaporates, forms clouds, condenses, and rains, flowing into ponds and lakes from which water evaporates again. The cells of the body undergo mitosis, where the genetic material of the cell replicates itself and then splits, followed by division of the cell into two new identical cells, each of which eventually replicates and divides in a similar way. A seed grows into a plant, which forms a flower, which creates seeds from which new plants, then flowers and seeds can grow. The elusive business cycle. What goes around comes around. Those events and processes in which the sequence of steps keep repeating are often referred to as cycles. Cultures all over the world have attributed great meaning to cycles, of the day, of the year, of the sun and the moon, of life, and more. Cycles proliferate in the myths, legends, stories, sayings, and science of cultures traditional and modern (e.g., Atran & Medin, 2008; Boorstin, 1983). Cycles are often depicted as circles; indeed, the words have the same origin. In contrast to lines, circles have no beginnings, middles, and ends, no initial conditions and outcomes, just endless repetition. The ancient chicken-and-egg conundrum.

Thinking about general processes with steps that recur requires abstraction from thinking about individual events to thinking about classes of events. That includes cycles, but it also includes the many repeating events that are viewed as sequences of events in time that have a beginning, middle, and end, such as going to a restaurant or visiting a physician. Such sequences are often referred to as scripts when they involve human behavior (e.g., Bower, Black & Turner, 1979; Casati & Varzi, 1996; Shank & Abelson, 1977; Zacks & Tversky, 2001). The beginnings are typically some initial state such as buying a ticket for a movie, entering a restaurant, or packing a suitcase, preceded by an intention or goal. The ends are usually outcomes, something was accomplished or produced: the movie is over, the meal was consumed and paid for, the suitcase is packed and ready for travel. Even preschoolers know the scripts for repetitive events they have experienced (e.g., Baldwin & Baird, 1999; Nelson & Gruendel, 1986). Both the general class and each specific event are readily viewed as linear, with a beginning, middle, and end and can be represented as lines.

Yet, thinking about repeated events as circular is more complicated than thinking about them as linear in many ways. The individual and the general diverge. An individual occurrence, any particular day or division of a cell or rainstorm is a sequence in time with a beginning, middle, and end. Viewing cyclical processes as circular entails seeing a set of sequences as identical in core features despite inevitable differences other features. Each day, each seed to flower is different. Crucially, each time is different. Yet repeating days and repeating divisions of cells can be viewed as cycles because core features repeat. Viewing repeating events as general abstractions, as cycles, means abstracting their core features and recognizing that they repeat even if each individual day or division cannot repeat. Regarding processes and events as circling back endlessly defies the relentless forward march of time. We can return to a previous place, but we cannot return to a previous time. Going back in time is the stuff of regret, of philosophy, of science fiction, all, for better or worse, hypothetical. Thinking of repeating events as circular, as returning to their beginning, requires countering time's arrow.

Conceiving of repeating events as cyclical requires yet another abstraction, thinking of them as continuous with no beginning and no end, just endless repetition, raising the proverbial chicken-or-egg conundrum. In spite of the presumed underlying continuity, many cyclical events are regarded as having a natural beginning, January for the year, morning for the day, a single cell for mitosis, a seed for plants, the pile of dirty clothes for the laundry, the calm before the storm. Adding yet another obstacle to cyclical thought, so much human reasoning is structured around beginnings, middles, and ends: story-telling, causal reasoning, deductive and inductive inference. For each, there is a beginning, an initial condition, even a problem, setting up expectations. Following that logically and in time, a sequence of interrelated events and ending in an outcome, a new state or condition that completes the initial condition or resolves a problem (e.g., Rumelhart, 1975; Tversky, Heiser & Morrison, 2013) In short, thinking about cycles, and especially thinking about them as endless, beginningless, repeating circles entails more complexity than thinking about events or processes as lines. It entails resisting the strong conception of time as linear and of processes as ending.

Thought is internal; we can know how people think only when they externalize their thought, often through language but also through gesture or by creating or selecting visualizations. Language is inherently sequential, words in general come one after the other in time, so that descriptions of events are necessarily linear. Because language is linear, it may bias linear thinking (Levelt, 1982). Gestures and visualizations also put thought in the world but can use space to overcome the built-in linear bias of production. A survey of ways that time is spatialized, either in gesture or on a page, shows variability, variability that is conditioned by the aspects of time represented, the medium of representation, and the audience, factors that affect just about all communications to self or other (e.g., Boorstin, 1983; Cooperrider, 2017; Kessell & Tversky, 2011; Lewis & Stickles, 2017; Tversky, Gao, Corter, Tanaka & Nickerson, 2016; Tversky & Lee, 1999; Tversky, in press), Timelines are certainly frequent for ordering events in history, and they are typically, but not always, horizontal in reading order, beginning at the top (Rosenberg & Grafton, 2013). In graphs, time is typically represented on the horizontal axis beginning on the left, and dependent measures such as economic or health data on the vertical; that way, changes over time are salient. Train schedules often represent time both vertically and horizontally in matrices, with the stops of each train ordered in vertical columns. Calendars are also matrices, most likely both to be legible on a page and to show the rhythms and regularities of the days of the week. Calendars and other matrices are organized in western reading order, beginning upper right and proceeding downwards in left-to-right rows. Mandarin Chinese echoes the top-down organization of reading and calendars in some expressions for relative time, namely, earlier is higher (Boroditsky, 2001). Circles were used even in ancient cultures to show the repeating rhythms of years and are common today in textbooks of science and engineering. In gesture, events in time are typically ordered horizontally, with the line arrayed parallel to the body or perpendicular from it, depending on the locations of the speakers and listeners as well as the culture (Cooperrider, 2017; Lewis & Stickles, 2017; Sweetser & Nunez, 2006),

If people use gestures; that is, actions in space, to express and understand conceptions of events in time, can viewing different gestures for the same description change understanding of time? We show that we can change three conceptions of temporal events by using different gestures accompanied by identical verbal descriptions. For each experiment, discrete events are represented by discrete gestures, points of the finger or chops or slices of an outstretched hand. These gestures are commonly used spontaneously to represent discrete ideas such as places in space or events in time (e.g., Clark, 2003; Cooperrider, 2017). We used sequences of gestures arrayed in space to reflect the conceptual array, linear, circular, or side-by-side. Thus, the gestures create a diagram in space; they are dots on a timeline or circle. First, we show that gestures can change thinking about repeating events such as seed to flower to new seed or the events of a day from linear to cyclical. Previous work has shown that people overwhelmingly tend to represent cyclical events as linear (three unpublished studies by Noel & Tversky, manuscript available). Next, we turn to pairs of events that can occur in either order. Previous research has shown that people tend to remember unordered events as linearly ordered (Glenberg & Langston, 1992). Here, we show here that gestures help people understand simultaneous events. Finally, we turn to perspective on a timeline. Previous research has called attention to the differing interpretations of temporal expressions like "Next Wednesday's meeting has been moved forward 2 days" depending on the embedded temporal perspective adopted (e.g., Boroditsky &and Ramscar, 2002; McGlone & Harding, 1998). We show that congruent gestures disambiguate that statement and promote an outside view of time. More generally, we ask, can the unique information in gesture alter listeners' mental models of highly abstract yet familiar concepts? In a series of studies on reasoning about time, we demonstrate that gestures alter people's conceptions of time by keeping speech constant but varying the gestures that accompany speech.

2. Circular versus linear thinking: Drawing diagrams

Many general events, such as the events of a day, the seasons of the year, the cell cycle, doing the laundry, and so on, are regarded as cyclical because the same general processes or procedures occur over and over again. Prior work has shown that people prefer to represent repeating events as linear rather than circular; that is, they are biased towards linear thinking. In several studies (Noel & Tversky, unpublished; for Chinese participants, Xiao, 2012; for Arab and Israeli children and adults ordering events of the day, Tversky, et al., 1991), participants were asked to diagram four-step processes typically regarded as cyclical, including those above. The majority drew linear diagrams even for events commonly seen as cyclical. Regarding even familiar repeating events as cycles may be difficult for several reasons. Time does not go backwards, often to our dismay. Classes of events may repeat, but individual instances do not, nor does time. Thinking of time as cyclical, then, requires abstraction from tokens to types, from a particular instance of an event; for example, a seed to a flower, to general classes of events, many seeds to many flowers. True cycles have no beginning and no end, they repeat endlessly. Yet, when events are retold in narratives or explanations, human or scientific, they are typically retold from a natural beginning to an end (Noel & Tversky, unpublished). Cell division begins with a single cell; flowers begin with a seed. Thinking of time cyclically requires ignoring the forward progression of time to thinking of time as traveling in a circle with no beginning, middle, or ending. Although people tend to represent cyclical events on a line, they readily understand cyclical events depicted circularly (Noel & Tversky, unpublished). Could circular hand gestures prime cyclical thinking?

2.1. Method

2.1.1. Participants

Sixty-three (40 female, 23 male; self-identified) volunteers, mostly graduate students from Columbia University, participated, assigned randomly to gesture conditions. In this experiment and in all others, we did not collect information about culture, race, age, country of origin, ethnicity, languages spoken, or the like. However, the graduate student population is highly diverse along all those lines and that diversity is represented in our samples.

2.1.2. Procedure and design

An experimenter approached each participant in an informal setting such as a campus cafeteria, and said: "I will tell you about some events. I would like you to think about these events and then construct a simple schematic diagram to convey them." One-third of participants were then told twice about one of the three cycles below:

Each example was identically worded (see Fig. 1) but accompanied by linear, circular, or no gestures. For the gesture conditions, each of the four steps of the procedure was timed with stating the step. For the *linear* gesture condition, each step was represented by a vertical hand slice; the path of the gestures began left from the participant's point of view (reversed for the experimenter) and progressed rightwards along an imaginary horizontal like. For the *circular* gesture condition, each step was represented by a finger point; the path of the gestures began at 12 o'clock and proceeded clockwise from the participant's point of view, from 12 to 3, to 6, to 9 o'clock. For the *no-gesture* group, the experimenter kept her hands in pockets. Thus, the sets of gestures constituted a linear or circular array, with 4 discrete steps corresponding to the four stages of the process, analogous to a linear or circular diagram of a process.

2.2. Results

2.2.1. Coding the diagrams

Participants' diagrams were coded blindly by the first author in consultation with the second author as either linear, or circular. In circular (or *repeating*) diagrams the last event was connected back to the first, but not in linear (or *ending*) diagrams. Two of the diagrams from the circular-gesture condition, and 2 from the no-gesture condition were coded as "other" (see Fig. 2).

Cycles
Seed to flower: • A seed germinates • A flower grows • The flower is pollinated • A new seed is formed
Events of a day: • Wake up • Go to work • Come home • Go to sleep
Clothing Cycle: • Take clothes out • Wear clothes • Wash clothes • Put clothes away

Fig. 1. Cyclical Stimuli.

	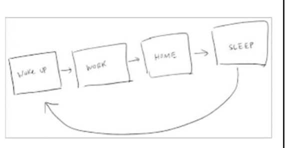	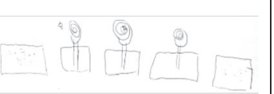	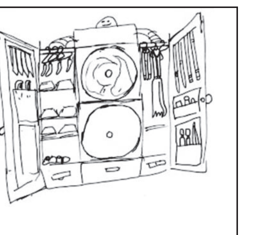
Circular Diagram	Circular Diagram	Linear Diagram	"Other"

Fig. 2. Examples of Diagrams.

Findings. The form of gesture participants saw influenced the diagrams they drew; in a log-linear analysis (excluding "other" diagrams), the two-way association between gesture condition and diagram type was significant, $\chi^2(2) = 17.668$, $p < .001$. Of those who saw circular gestures, 66.7% drew circular diagrams. Of those who saw linear gestures, 85.7% drew linear ones and only 14.3% drew circular diagrams. As expected, of those who saw no

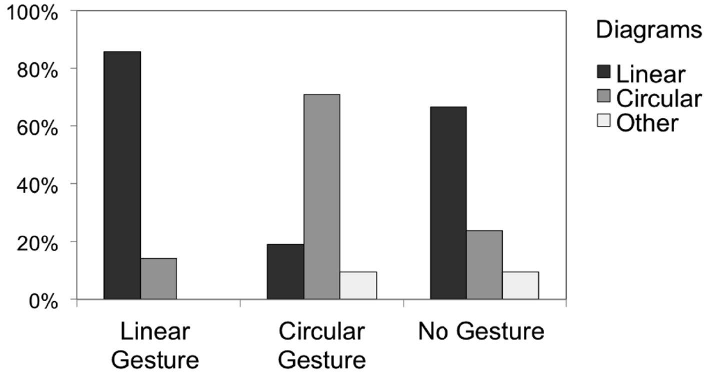

Fig. 3. Proportion of linear, circular, and "other" diagrams by gesture conditions.

gestures, 66.7% drew linear diagrams. Fig. 3 shows the percent of linear, circular, and "other" types of diagrams for the three gesture conditions.

Post hoc analyses showed significant effects of circular versus linear gesture, $\chi^2(1) = 16.851$, $p = .001$, and circular versus no-gesture, $\chi^2(1) = 10.556$, $p = .001$, on diagrams. No significant differences were found for linear versus no-gesture conditions, $\chi^2(1) = 0.902$, $p = .342$. The arrays of diagrams for linear gestures and no gesture are strikingly similar. The number of circular diagrams was significantly higher than the number of linear diagrams in the circular-gesture condition, $\chi^2(1) = 4.439$, $p = .035$. As expected, the number of linear diagrams was significantly greater than the number of circular diagrams in the linear-gesture, $\chi^2(1) = 11.872$, $p = .001$, and no-gesture conditions, $\chi^2(1) = 4.439$, $p = .035$.

2.3. Discussion

Gestures had powerful effects on people's diagrams of events in time. People listened to a description of one of three cyclical events accompanied by punctuated circular, linear, or no gestures, and were asked to put something down on paper to represent what they heard. Without gestures or with linear gestures, a large majority of participants drew linear diagrams, replicating earlier research. However, after viewing circular gestures, a majority drew circular diagrams. If the way people design diagrams reflects the way they think, and there is considerable evidence for this (e.g., Tversky, 2011; Tversky, et al., 2002), then we can conclude that gestures affect the way people think about temporal events. However, it could be argued that participants copied the circular gestures made by the experimenter. The next study obviates that objection by asking participants to make inferences.

3. Circular versus linear thinking: Next step

The next experiment replicates the first one with a different request from participants. Instead of being asked to diagram what they heard, after hearing the "last" step of the cycle, they were asked, "What comes next?" If seeing circular gestures induces cyclical thinking about time, then when participants are asked what comes after the "last" step they should tend to respond with the "first" step. This tendency should be reduced if linear gestures promote linear thought. The no-gesture condition was eliminated because it elicited linear responses in the first study as well as numerous previous studies.

3.1. Method

3.1.1. Participants

60 volunteers, mostly graduate students from Columbia University participated in this study, randomly assigned to gesture condition.

3.1.2. Procedure and design

The procedure and design were the same as the previous experiment except that the no-gesture condition was eliminated, only the seed cycle was used, and instead of being asked to produce a diagram, participants were asked: "What comes after the new seed forms?" We eliminated the no-gesture condition because we know from the first experiment and the previous work that the majority of people represent cycles linearly; that is, the no-gesture condition yields results quite close to the linear gesture condition. For this experiment, participants in both conditions see gestures.

3.2. Results

3.2.1. Coding

Participants' answers to the question "what comes next?" were coded as linear or circular as before. Circular answers included repeating the first or any other stage or saying words such as *repeating* and *cycle*. Any other answer, such as "that was the last stage," "nothing," or "a fruit" were coded as linear.

3.2.2. Findings

In the circular gesture condition, 90% responded with circular answers, but in the linear gesture condition, only 60% responded circularly (Fig. 4). In a log-linear analysis, the two-way association between gesture condition and answer type was significant, $\chi^2(1) = 7.595$, $p = .006$. Interestingly, 30% of those who answered circularly in the linear gesture condition seemed unsure about their answers as they answered with a question tone.

3.3. Discussion

The previous experiment had shown effects of gesture form on diagram form independent of language. Here, we found effects of gesture form independent of language on inferences. When asked "what comes next?" after hearing the last of four stages of a cycle, participants who saw circular gestures were far more likely to respond with the first or subsequent step of

Fig. 4. Proportion of linear and circular answers for each gesture condition.

the cycle than those who saw linear gestures. Will gesture affect other kinds of thinking about time?

4. Temporal perspective

The first two experiments showed that circular gestures promoted cyclical conceptions of time. The next experiment asks whether gestures can bias perspective on time.

When people are asked "Next Wednesday's meeting has been moved forward 2 days; when is the meeting now that it has been rescheduled?" their answers split. Around half say Friday, and half say Monday (Boroditsky, 2000; McGlone & Harding, 1998; though see Stickles & Lewis, 2018 for a slight moving ego preference in English). *Forward*, like many spatial terms, is ambiguous, and requires taking a perspective to disambiguate. Those answering Friday are presumed to take an ego-moving perspective and see themselves as embedded in a time moving forward along a timeline from Wednesday to Friday. Those who answer Monday are presumed to take a time-moving perspective; they see themselves as stationary embedded in a timeline and time moving forward toward them, from Wednesday to Monday (Boroditsky, 2000; McGlone & Harding, 1998; McTaggart, 1908). According to both perspectives, ego is on a time line, not external to it.

In a series of clever experiments, Boroditsky & Ramscar (2002) showed that although people have strong intuitions about which answer is correct, their answers are influenced by how recently they have experienced or viewed movement in time; that is, either they themselves have moved or they have watched movement. For example, people who have just landed at an airport are more likely to take an ego-moving perspective than those waiting to meet passengers. People sitting still but watching things move are more likely to take a time-moving perspective. Thus, actual movement in space biases perspective on time; if experienced, toward a moving ego conception but if viewed, toward a moving time conception. In these cases, movement in space does not represent a sequence on a timeline as gestures can; rather it primes moving or watching movement which in turn biases temporal perspective.

Here we ask a different question. Will seeing gestures that represent actions in space change temporal perspective? Note that in both cases, the gestures are viewed movements in space, but they represent different movements of events in time and thereby in thought. What is more, the gestures can prompt people to take an outside overview perspective of events in time rather than an insider perspective embedded in time. The outside view is like looking at a timeline or calendar, where ego's viewpoint is outside time observing an array of events in a space representing time. In the cases of timelines or calendars, events like meetings can be moved from one place to another with respect to an external or absolute representation of time rather than with respect to ego's place in time. The external viewpoint has parallels in spatial thinking, graphics, and language. It is the overview or survey or outside or allocentric or absolute perspective that maps provide as well as the perspective taken when landmarks are described as north/south/east/west of one another (Levinson, 1996; Taylor & Tversky, 1992a, b).

Space is usually construed as two- (or three-) dimensional but time is often construed as one-dimensional, linear, Timelines keep that linearity. Calendars, perhaps because of the restrictions of a page or slab of stone, break up time into weeks, and stack the weeks, earlier at the top, later at the bottom, much like the text you are reading. Gesturing events in time is often linear, though events can be arrayed in circles for cycles or in matrices for events occurring more or less simultaneously in different places. The array of gestures for events in time construed linearly can be along a left-to-right axis across the body especially for speakers of left-to-right languages or along an axis extending from the body forward. Choice of axis would depend on the relative locations of speakers and listeners as well as culture (e.g., Alibali, Heath & Myers, 2001; Cooperrider, 2017; Lewis & Stickles, 2017).

In this experiment, the ambiguous sentence was accompanied by different gestures, both intended to convey an external perspective. The experimenter stood next to the participant so that they had a shared perspective. When she said, "This Wednesday's meeting," for all participants, she made a gestural slice to represent Wednesday in front of her body. When she said, "moved forward 2 days," she made a second hand slice to represent the new time. For half the participants, the second slice was closer to her body as if placing the event closer in time; that is, Monday, and for the other half, the second slice was farther from her body, as if placing the event farther in time, that is, Friday. If seeing movement per se biases a time-moving perspective, then the direction of movement should not matter, and a majority of participants should adopt a time-moving perspective, answering Monday. However, if participants adopt an outside perspective, a perspective external to the time line, then they could interpret the gesture as moving the event, the meeting, from point on a timeline to another. According to Núñez & Sweetser (2006) and Núñez & Cooperrider (2013), speakers of English and other western languages often conceive of the future as in front of ego, with events more distant in time as more distant in space; that is, more distant from the body, Thus, if participants interpret a closer gesture as "Monday" and a farther gesture as "Friday," then it is likely that they see the hand as representing the meeting and the gesture as moving the meeting along a

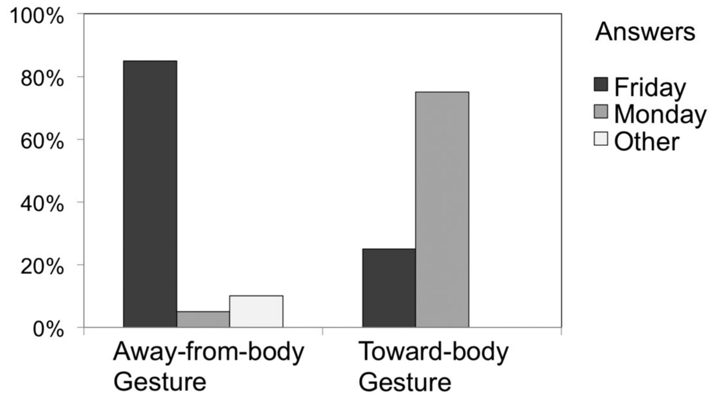

Fig. 5. Proportion of participants answering "Friday" and "Monday" in each gesture conditions.

timeline stretching from the near future to the far future. The underlying space-to-time mapping is proximity, close in space is close in time, father in space is farther in time. According to the external perspective view, then, the gesture toward the body should elicit Monday and the gesture away from the body should elicit Friday.

4.1. *Method*

4.1.1. *Participants*

40 volunteers (25 female, 15 male), mostly graduate students from Columbia University participated in this study, assigned randomly to gesture condition.

4.1.2. *Procedure and design*

As before, the experimenter approached each participant and when side-by-side said: "Next Wednesday's meeting has been moved forward 2 days. What day is the meeting, now that it has been rescheduled?"

Participants were divided into two conditions: (a) away-from-body sagittal gesture, and (b) toward-body sagittal gesture. In both conditions, the experimenter made a vertical slice of her hand in the space in front of her body, while saying "next Wednesday's meeting," and then moved her hands away from her body for the *away-from-body-gesture* condition, and towards her for the *toward-body-gesture* condition while saying "has been moved forward." Note that participants and experimenter had identical points of view.

4.2. *Results*

The majority of participants who saw the gesture away from the body answered that the meeting was moved to Friday whereas the majority who saw the gesture toward the body answered that the meeting was moved to Monday (Fig. 5). Those who saw the gesture that moved farther forward from the body presumably interpreted the gesture as moving farther in the forward direction of time, hence Friday. Likewise, those who viewed the gesture that moved closer to the front of the body presumably interpreted the gesture as closer in the direction of time, hence, Monday. One participant answered “not sure” and another, “Based on your gesture I would say Friday, but based on your words, Monday”; these were coded as “other” and not included in the statistical analysis. In a log-linear analysis, the two-way association between condition (forward versus backward sagittal gesture), and answer type (Friday vs. Monday) was significant, $\chi^2(1) = 21.510, p <. 001$.

4.3. Discussion

In many previous studies, when people were told that Wednesday’s meeting was moved forward 2 days and asked when the meeting is now, around half spontaneously answered *Friday*, taking an *ego-moving perspective*, and half answered *Monday*, taking a *time-moving perspective*, (e.g., Boroditsky, 2000; McGlone & Harding, 1998; McTaggart, 1908; Stickles & Lewis, 2018). Actually moving in space biased respondents toward the ego-moving perspective and watching movement from a stationary position biased the time-moving perspective (Boroditsky & Ramscar, 2002). Here, we found that observing representational actions, namely, gestures, also dramatically affected temporal perspective-taking. The experimenter first established a reference point for Wednesday in front of her body by making a slice gesture to represent Wednesday. When she gestured in a direction away from her body while saying “moved forward,” a majority of participants responded that the meeting was moved to Friday and when she moved her hand in a direction towards her body, a majority of participants responded that the meeting was moved to Monday.

Notably, the gestures were along the sagittal front-to-back axis of the body. For English speakers, the future is thought of as in the front of the body, with events farther in the future farther from the body (Núñez & Cooperrider, 2013; Núñez and Sweetser, 2009). Farther away from the body is farther away in time. Here, the experimenter made the Wednesday meeting a reference point by placing her hand in front of her body saying “Next Wednesday’s meeting.” When the experimenter’s hand moved farther away from the body, most participants answered “Friday” and when the hand moved closer to the body, most participants answered “Monday.” In both cases, the language was the same, the experimenter said “the meeting was moved forward.” The effects cannot be accounted for by assuming that participants adopt either a moving-ego or a moving-time perspective. Rather, in both cases, they seem to adopt an outside perspective on time, watching the event, represented by the hand, move either closer or farther in space; that is, closer or farther in time. The situation is essentially one of changing an event on a timeline or in a calendar from one day to another. In this case, the ego is outside, external to the timeline, looking onto it, analogous to taking an overview or survey or map-like perspective on an environment. This external perspective on time is of course quite prevalent in both describing the past and in planning the future. The invention of maps and timelines and calendars, all ancient and widespread, further attests to the usefulness of outside, external perspectives on space and time.

5. Parallel versus sequential thinking

So far our experiments have shown that gestures alter the way people think of sequences of events in time. Yet in life, people often have to keep track of events that are simultaneous or whose order might not matter, tasks that are not easy (e.g., Bauer & Johnson-Laird, 1993). In one study, students had difficulties comprehending that the two middle steps of a four-step procedure for writing a paper should be simultaneous, not sequential After reading the procedure, participants tended to think of the middle steps as ordered in time as they had been ordered in language. A diagram showing the middle steps side-by-side helped participants overcome linear thinking (Glenberg & Langston, 1992). Speech is linear, and necessarily linearizes even two- or three-dimensional space (e.g., Levelt, 1982). In contrast to language, diagrams are spatial and can show simultaneity in time (Bauer &and Johnson-Laird, 1993). Gestures, like diagrams, are a form of spatial communication and can explicitly represent events as unordered or simultaneous; might gestures help people think about parallel events in time?

5.1. Method

5.1.1. Participants

Sixty volunteers, mostly graduate students from Columbia University participated in this study, assigned randomly to gesture and question conditions.

5.1.2. Procedure and design

As before, an experimenter approached each participant and said: “I will tell you about a procedure, and then ask you a quick question about it.” Participant and experimenter were facing each other. Participants were then told the following procedure for writing a paper, adapted from Glenberg & Langston (1992): “There are four steps to be taken when writing a paper. The first step is to write a first draft. The next two steps should be taken at the same time: One of the steps is to consider the structure; the other step is to address the audience. The final step is to proofread the paper.”

Participants were divided into two gesture conditions, parallel gestures congruent with thought or sequential gestures, in essence, congruent with speech. The sequence of four gestures, one for each step, followed the top first-down path characteristic of gesture, reading, and calendar (e.g., Tversky, 2011). Each step or temporal event was represented as a horizontal palm-down hand slice timed with each step of the spoken procedure. Both conditions began with an event slice at the top while saying “the first step is to write a first draft.” The conditions differed in how the simultaneous steps were arrayed. For the *parallel* or *thought-congruent* condition, the path of the gestures showed the two unordered middle steps as parallel or side-by-side in space. The experimenter made two slices with two hands simultaneously side-by-side below her first hand gesture, while saying “the next two steps should be taken at the same time.” Next, she moved her right hand back and forth from her wrist, in place, with her left hand still in the air, while saying, “one of the steps is to consider the structure.” Then, she moved her left hand back and forth, in place, with her right hand still in place while

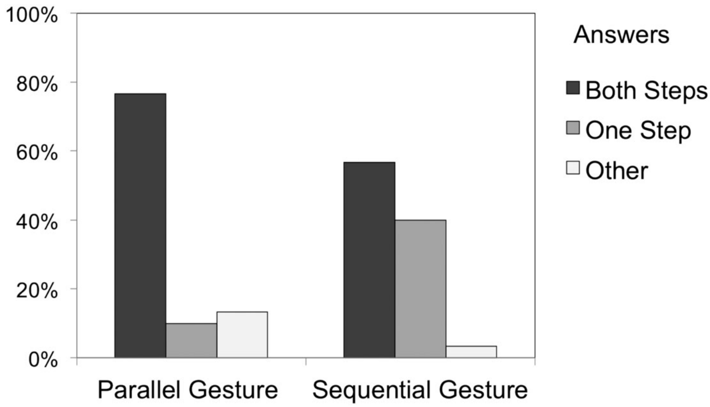

Fig. 6. Proportion of parallel, sequential, and "other" answers in parallel- and sequential-gesture conditions.

saying, "the other step is to address the audience." Next, she took away her left hand and made a slice with her right hand facing down, below the initial spot, while saying, "the final step is proofread the paper." For the *sequential* or *speech-congruent* condition, the gestures were similar to beat gestures, emphasizing and distinguishing the four steps, on a linear path. The experimenter made 4 slices with her right hand facing down, from top to bottom on a vertical line in front of her, timed with the four steps of the procedure. Thus, the parallel or thought-congruent gestures were coordinated with the content of the speech and the sequential or speech-congruent gestures were coordinated with the speech itself.

After hearing the description twice, participants were asked: "Here is the question now: According to the procedure I just gave you, what should one do immediately after writing the first draft/ before proof reading the paper?" Half of the participants in each condition were asked about steps *after* writing the first draft, and the other half were asked about steps *before* proof reading the paper.

5.2. Results

5.2.1. Coding

Participants' answers to before/after questions were coded as sequential, parallel, or other. Coding was done by the first author in consultation with the second author. Answers that mentioned only one of the two steps (*considering the structure* or *addressing the audience*) were coded as sequential. Answers that mentioned both steps were coded as parallel. Any other answer was coded as "other."

5.2.2. Data analysis

In the *parallel-gesture* condition, 76.7% responded with both steps while only 56.7% in the *sequential-gesture* condition gave both steps. Forty percent of participants in the sequential-gesture condition but only 10% of subjects in the *parallel-gesture* condition mentioned a single step (Fig. 6). Four participants in the parallel-gesture condition, and one in the sequential-gesture condition mentioned other steps and were excluded from the data analysis.

In a log-linear analysis, the two-way association between gesture type and answer was significant, $\chi^2(1) = 6.276$, $p = .012$. However, the two-way association between question type (before vs. after) with answer (parallel vs. sequential) was not significant, $\chi^2(1) = 1.988$, $p = .159$, nor was its three-way association with condition (parallel- vs. sequential-gesture) and answer type, $\chi^2(1) = 0.114$, $p = .736$.

In addition, significantly more participants in the parallel-gesture condition gave parallel answers than sequential answers, $\chi^2(1) = 17.447$, $p <. 001$. There was no significant difference between number of parallel and sequential answers in the sequential-gesture condition, $\chi^2(1) = 0.866$, $p = .35$.

5.3. Discussion

We have shown yet again that gesture influences how people think about time, independent of speech. Previous research (e.g., Bauer & Johnson-Laird, 1993; Glenberg & Langston, 1992) had shown that people find it difficult to conceptualize events that can happen in parallel or in either order. Here we showed that gestures that represent the optional order of events help people to overcome the bias of thinking of events as strictly ordered. Words come one after another, in serial order, but space has more communicative dimensions. When procedures are explained in language, events are necessarily referred to in serial order, and the serial order of referring events can be confused with the serial ordering of the events. Gestures can directly represent that events are strictly ordered or that the order is optional. In this case, the thought-congruent gestures first established a representation of temporal order using a spatial order, and then represented optional temporal order by using parallel gestures at the same spatial level conveying a temporal level. Participants who saw those gestures used the spatial representation of time established by gesture to correctly understand the information conveyed in the words. Participants who saw gestures coordinated with the necessarily linear spoken description frequently incorrectly understood that the steps were strictly ordered.

6. General discussion

Events in time are often thought of and described as places in space, and changes in time as movement in space. Gestures are representational actions in space: can they alter thought about time? We showed that thought about three aspects of time is uniquely altered by gestures in space. In each case, participants heard the same descriptions but saw different gestures. The gestures people saw changed thought about a sequence of events from linear to cyclical, from a perspective embedded in a timeline to an external perspective looking onto a timeline, from misinterpreting simultaneous events as linear to correctly understanding simultaneity.

Evidence that people think about time in terms of space and changes in time in terms of changes in space abounds. We describe time and events in time using spatial terms like “before” “up,” “from,” and “near;” we describe changes in time using verbs of motion like “move” “put,” “approach,” “rearrange,” and “shorten;” and we use spatial prepositions like "at," "on," and "in" to indicate 0-, 1-, and 2-dimensional perspectives on temporal events (e.g., Clark, 1973; Talmy, 2000; see also Bender and Beller, 2012, for a detailed review and slightly different analysis). We use space to represent time in many forms of visualspatial communication, timelines, calendars, schedules, graphs, diagrams, and gesture among them (e.g., Bauer & Johnson-Laird, 1993; Casasanto & Jasmin, 2012; Cooperider & Nunez, 2009; Emmorey & Casey, 2001; Tversky, et al., 1991; Tversky, 2011). Even preschool children reliably graph events in time using space, placing tokens representing events in temporal order on a line in space (Tversky, et al., 1991). Whether in gesture or on a page, these expressions are diagrammatic and schematic, showing time as a continuous line and events as discrete marks on it. For gesture and graphics, the line and marks are explicit and direct; for words, the mapping of events on a timeline is indirect, the line and marks must be constructed in words and imagined in the mind.

6.1. Linear conceptions of time

Time lines, mental or on a page, have a spatial orientation, a directionality. In readers of languages that go left to right, the timeline is typically mapped horizontally from early to late in reading order in both gesture and diagram (e.g., Casasanto & Jasmin, 2012; Fuhrman and Boroditsky, 2010; Tversky, et al., 1991). In gesture, time can be mapped across the body from left to right and can also be mapped sagittally with the future in front of the body and the past behind in some cultures (e.g., Experiment 3; Cooperider & Núñez, 2009; Nunez & Sweetser, 2006) or vice-versa in some languages (e.g., Cooperider & Núñez, 2009; Hill, 1982; Núñez & Sweetser, 2006). The sagittal axis is an especially important anchor for spatial thinking; notably, it separates the body's front from the body's back. Both the perceptual and the motor apparatuses of the body are oriented forwards, so movement forwards in space is more agile and coordinated than movement backwards in space (e.g., Clark, 1973; Franklin & Tversky, 1990). This strong asymmetry makes the front-back axis of the body the strongest axis for spatial reasoning, along with but perhaps stronger than the axis conferred by gravity, the only asymmetric axis in the world (Franklin & Tversky, 1990). The privileged status of frontwards over backwards in space seems to be easily transferred to time, corresponding nicely to both moving-ego and moving-time metaphors. Yet, both on the page and in canonical face-to-face communication, the horizontal left-right plane is more discriminable than the sagittal plane. However, left-right asymmetry is a much weaker than either the asymmetries of the sagittal and vertical axes, as its asymmetry derives from a variable cultural convention, namely, reading order (and for evaluative attributes from another variable axis, handedness, e.g., Casasanto, 2009) in the absence of salient universal properties of the body or the world.

6.2. Perspective on time

Thinking and talking about arrangements of events entail target and reference events and usually a perspective on time, just like thinking and talking about arrangements of things in space (e.g., Clark, 1973; Levinson, 1996; Talmy, 2000; Taylor & Tversky, 1992a). Just as there are several possible perspectives on space, there are several possible perspectives on time. People can think of themselves as embedded in a timeline, just as they can think of themselves embedded in space. For time as well as space, an embedded perspective has two possibilities. In the moving-ego metaphor, ego is thought of as moving along a timeline much as in an embedded spatial perspective, ego is thought of as moving along a path in space. In the moving-time metaphor, ego is thought of as stationary, with future events moving toward it, analogous to a stationary spatial perspective observing things moving toward it. For time, some statements are ambiguous with respect to these metaphors. One has become famous: “Wednesday’s meeting has been moved forward 2 days; what day is it now?” Spontaneously, around half say “Friday,” suggesting a moving ego-perspective, and half say “Monday,” indicating a moving-time perspective.

Continuing the analogy from space to time, yet another perspective that people can take on time is an external one, looking at the timeline (or calendar or schedule) from outside or above, much like taking an overview of an environment or looking at a map. In this case, events (at least future ones) can be moved from place to place in the timeline or calendar or schedule to represent changes in time, avoiding the ambiguity of the embedded perspective.

Whether viewed from above or viewed from within, changes in time are conceived of as actions in space. If so, then actions in space might affect conceptions of time. Indeed, Boroditsky & Ramscar (2002) showed that moving in space biases moving ego and watching movement in space biases moving time. In these situations, the movement does not represent anything else; it simply is, so the effect on linguistic perspective is priming. By contrast, gestures represent events and moving events, they are not movement in and of itself. Here we found that information represented in gestures but not in speech alters people’s perspectives on time from an embedded view to an overview. Contrary to Boroditsky and Ramscar, in the present experiment, witnessing movement in space did not bias the moving-ego perspective. Rather, gestures away from or toward the body were interpreted as movements of the event (Wednesday’s meeting) itself, and induced taking an overview perspective on events in time.

6.3. Circular conceptions of time

Timelines are conceived of as straight and moving or pointing forward, the only direction time can go in the world we know. Yet, thought about time is more complex than order on a timeline. For categories of events that repeat, like the events of the day or the seasons of the year or the cycle of life, time can be regarded as cyclical, and the timeline can be represented as circular. Circular representations of time are abstractions that show generalities, that the kinds of events repeat even if individual instances do not. However, previous research (Noel & Tversky, unpublished) and the present study revealed a strong bias toward linear representations of cyclical events. There are several reasons for a linear bias. Time does not go backwards on itself. Each spring is a new spring, and the two cells that result from the division of one do not become one again. Thinking about events as cyclical requires abstraction from many cases. It also requires recognition that the circular representation is not of time but rather of the order of the processes or stages. Perhaps for this reason, many cyclical concepts, such as business cycles and Fourier transforms, are plotted as successive hills and valleys on a linear time line. There is another powerful reason for thinking of events as linear. Most narratives, explanations, and instructions are regarded as having beginnings, middles, and ends; that is, initial conditions, then a set of episodes or procedures or processes, and, finally, an outcome. Although most people depict cyclical events linearly, they do comprehend circular representations. However, even when people represent cyclical processes as circles, those circles typically have conventional beginnings, such as morning or a single cell or a seed, placed at 12 o'clock. That is, they are not thought of as true circles, with no beginnings or ends.

In the research reported here, discrete hand gestures represented each stage of the process and the path of the gestures represented the order of the stages. Arraying the gestures for each stage in a circle induced participants to think about the events as cyclical. After seeing circular gestures, most people drew circular diagrams to represent the events. After seeing circular gestures, when asked, "what is next?" after the last stage, most replied with the first stage. By contrast, most participants who saw no gestures or saw linear gestures accompanying the same verbal description drew linear diagrams. Similarly, those who saw linear gestures and were asked "what is next?" typically answered with something other than the first stage of the set of events.

6.4. Parallel conceptions of time

Events are easily thought of as ordered, but there are also simultaneous events as well as events whose order is optional. In making a salad, it does not matter whether the tomatoes or cucumbers are cut first. The semi-final games of a tournament can occur at the same time. However, because speech is ordered, many people misinterpret descriptions of procedures as strictly linear, even when the words are explicit that the two middle processes take place simultaneously or can take place in either order. Simultaneous events can be thought of as parallel lines branching from a single timeline. Diagrams showing such branching help people understand that two events are simultaneous (Bauer & Johnson-Laird, 1993; Glenberg & Langston, 1992). In the present research, participants saw one of two sets of gestures, accompanying the same speech. The speech made clear that the two middle steps were simultaneous, but because speech is sequential, the two steps had to be referred to sequentially. In both cases, discrete hand gestures accompanied the mention of each step of the process. In the speech-congruent case, the gestures followed a straight path, emphasizing and distinguishing the four steps. In the thought-congruent case, the path of the gestures for the two simultaneous steps branched and the gestures were parallel, showing that the two middle steps were co-temporaneous. Those gestures enabled people to understand that the middle two steps were to be taken simultaneously. For the temporal concepts investigated here, the gestures both abstracted a conceptual model of time and showed it.

6.5. Gesture and thought: Direct mapping

Gestures are powerful tools for shaping thought. Here, we have shown that they alter people's conceptions of time. Other research has shown that information conveyed only in congruent gestures and not in language, has substantial effect on thought; for example, enabling adults to more precisely understand descriptions of complex spaces and systems

(Bradley, 2018; Heiser, Tversky & Silverman, 2004; Jamalian, Giardino & Tversky, 2013; Kang & Tversky, 2016; Yang, 2019), children to better understand a variety of math concepts (Jamalian, 2014; Novack, Congdon, Hemani-Lopez & Goldin-Meadow, 2014; Segal, Tversky & Black, 2014; Singer & Goldin-Meadow, 2005), and adults to solve a range of spatial problems more adeptly (Chu & Kita, 2008; Jamalian, Giardino & Tversky, 2013; Kessell & Tversky, 2006; Schwartz & Black, 1996; Wexler, Kosslyn & Berthoz, 1998; Wohlschlager & Wohlschlager,1998). Gestures can help create novel problem-solving strategies (Broaders, Cook, Mitchell, Goldin-Meadow, 2007) and to activate implicit ideas in nonspatial domains like morality (Beaudoin-Ryan & Goldin-Meadow, 2014). Spontaneously produced gestures can reveal more about what adults and children are thinking than their words (e.g., Alibali, Bassok, Solomon, Syc & Goldin-Meadow, 1999). Cases where the meaning conveyed by gesture and word diverge have been called "mismatches" and have been extensively documented by Goldin-Meadow and her colleagues (e.g., Church & Goldin-Meadow, 1986; Goldin-Meadow, 2013; Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow, Alibali & Church, 1993). For example, kids often show rudimentary understanding of conservation in their gestures—for example, pouring—that is revealed in their words only months later. One of our spouses frequently pointed left while saying, "go right;" the gesture was reliable, the words had to be ignored.

Here is why gestures have such powerful effects on thought: they can represent thought more directly than words and they can arrange thought in a spatial framework that is a conceptual framework. Effective gestures are congruent with thought; they resemble the thinking and the thought they are meant to convey. Discrete gestures can represent discrete concepts: objects, places, events, actions, ideas. Path-like gestures can represent relations between places, events, objects, and ideas. Many gestures are miniature actions in space that represent mental actions on thought, *raise* and *turn* and *combine*. Manipulating thought is like manipulating Legos. Spaces created by the hands can represent regions or sets. 0, 1, 2 or 3 D. Simple forms, but capable of so much complexity. Of course, context is crucial, just as for words. Is the relationship romantic or mathematic?

Gestures have an additional power, one they share with another form of visualspatial representation, graphics of all sorts, diagrams, charts, and sketches. Both can efficiently and directly map general ideas or sets of ideas onto marks arrayed in space (Tversky, 2011; Tversky, et al., 2009). We have seen that for time: gestures trace temporal paths in space, and mark locations of specific events along the paths. A string of interrelated gestures can create a model of space, time, action or ideas (e.g., Emmorey, Tversky & Taylor, 2000; Enfield, 2003; Jamalian, et al., 2013; Bradley-Zrada, 2019; Yang, 2019). An array of lines, dots, and regions can serve as a schematic diagram of numerous ideas and sets of ideas. Lines and dots can represent time and events or space and places or costs and items or premises and conclusions. A tree-diagram created by hands or on a page can represent any sort of hierarchy, kinds, parts, descendants (Enfield, 2003; Miller & Johnson-Laird, 1976; Tversky & Hemenway, 1984). Boxes, by the hands or on a page, delineate regions or sets. Paths of dots and regions are expressed in language, *connect the dots*, *think out of the box*. The hands can be used to establish contrasting spaces, on the one hand, on the other hand, after which gestures pointing to each side can rapidly convey which things or arguments go with which side. Place in space in and of itself is replete with meaning, revealed by the hands, on the page, and in words: *central* or *peripheral*, *up* or *down, in* or *out*. Gestures and graphics show thought and structure thought.

Can visualspatial forms of representation represent all thought? Certainly not, or not by themselves. Most communication in the wild, prototypically, conversation, is naturally multimodal, a harmonious combination of words, gestures, prosody, the world, and more. Even written language. Look again at the text you are reading: it is filled with spatial devices that in essence diagram and structure the text. The spaces between words help you differentiate the words. The spaces between sentences, the indentations for paragraphs, the empty space before a new chapter each cue you to new sets of ideas of varying leaps. For many aspects of thought, gestures, as well as gestures frozen as diagrams, can be more effective than words, and still more effective when combined with words.

The mind is small but the world is large. Eons ago, people expanded their minds by putting their thoughts into the world. Thoughts expressed in the world serve as cognitive tools, expanding memory, promoting information processing, and communicating to ourselves and to others. Putting thought in the world allows us and others to work with the thoughts. Putting the mind into the world takes many forms, language, gesture, and graphics among them. Language and gesture are ephemeral, they disappear, leaving no traces in the world, so we do not know when humanity began to use them. Graphics can and do remain in the world, some as long as 120,000 years (Prevost, Groman-Yaroslavski, Gerstein, Tejero & Zaidner, 2021). They stand as the earliest evidence of symbolic thought. Ancient remains of visible thought can be found all over the world, painted on walls of caves, incised in slabs of stone, carved on wood or bone, long predating the invention of writing. Communications from the distant past. Despite vast distances in time and place, the same themes recur in early graphic representations: *things*, notably people, animals, and tools; *space*, notably maps; *time*, notably events in time like hunts, and abstractions of time, calendars; *number*, typically tallies (Tversky, in press). These tools of thought expressed graphically, using arrays in space and marks in it, proliferate today, in print, online, and along the streets.

Gestures, like graphics, get their power from the immediacy, precision, and congruence of their meanings. Gestures are visible actions on ideas in the mind that are essences of visible actions on objects in the world. They resemble the ideas they convey. They arrange those ideas in a diagrammatic space. They are readily understood, in a context. Those actions on objects are the way we talk about thinking, about actions on ideas. We push ideas forward, we bring them together, or turn them upside. Externalizing those actions in the form of gestures that are palpable to those who make them and perceptible to those who see them convey their meanings more directly and change thought. Just as the actions of our hands are tools that alter the world, the actions of our hands are tools that alter minds, our own and those of others.

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