Cognitive models of time: Across the lifespan, the world, and the mind

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Introduction

How is it possible to mentally represent abstract concepts? One abstract domain, which has been explored by scholars across disciplines, is time. A concept of time allows us to understand our world and our memories, and to make decisions. However, "*the* concept of time" is a vast oversimplification. Time encompasses durations, sequences, locations relative to the ego, Newtonian beliefs, causal reasoning, linguistic structure, episodic memory, the "mental timeline," and more. These facets of time span the gamut from perception to cognition, and scientists across fields explore relevant questions. However, they often do not use the same methods, vocabulary, or populations. The complexity of temporal cognition means that, if scientists are ever going to get a handle on the psychological nature of time, interdisciplinary dialog is necessary.

Some components of temporal processing and ways of mentally representing time are present from birth, but many others appear to be environmentally driven. Evidence for this can be found in extensive cross-cultural and cross-linguistic differences, and developmental change that extends for years. Cross-cultural and developmental studies provide unique opportunities to tease apart aspects of time that are universal and evolutionarily-ancient from those that aren't, and to identify the factors most important for the formation of mature mental representations of time. Prior studies, and new ones that will be discussed here, indicate that relationships between time and space are critical, though exactly how the relationships are instantiated remains debated. Languages and cultural tools provide means of representing temporal relationships that are not available to other animals, but vary across humans.

We bring together researchers from three countries, who have overlapping interests, but examine different facets of time, different populations, and different levels of representation. **Pitt, Bender,** and **Starr** explore relationships between time and space, but **Pitt** discusses time-space mappings in different sensory modalities, while **Bender** and **Starr** discuss the linguistic and cultural factors later shaping them. **Tillman**, **Starr**, and **Pathman** discuss developmental change in temporal cognition. **Pitt** explores time at the level of perception, **Pathman** at the level of memory, and **Tillman** at the level of theories of time itself. **Tillman** will also serve as moderator.

Space-time asymmetry in vision and audition (Tom Gijssels, **Benjamin Pitt,** Roberto Bottini, Ceren Battal, Olivier Collignon, Daniel Casasanto)

How are space and time related in the human mind? Many experiments using visual stimuli show a space-time asymmetry: People use space to think about time more than vice versa. Why? Here we tested whether the extent to which people use one domain to think about another depends on how reliably people can typically perceive or think about each domain. We tested this proposal by comparing the relationship between space and time across two sensory modalities in which the reliability of each domain typically reverses: Whereas space tends to be more reliable in vision than in audition, time is more reliable in audition than in vision. In separate visual and auditory tasks, participants reproduced the spatial and temporal extents of stimuli that traveled for varying distances and durations. In two experiments, we found that space and time interfered with each other in different ways across modalities, as predicted by differences in the relative reliability of the domains: In vision task-irrelevant spatial information influenced temporal reproductions more than vice versa, but in audition task-irrelevant temporal information influenced spatial reproductions as much as, or even more than, vice versa. These results show that the relationship between space and time in nonlinguistic thought differs across sensory modalities, and validate a principle that governs cross-domain interactions: When two domains are correlated in experience, people will use the domain that is typically easier to perceive, imagine, or remember to structure their thoughts about the other domain.

Representing time in terms of space: Directions of mental timelines in five different languages (**Andrea Bender** & Annelie Rothe-Wulf)

People often use spatial vocabulary to describe temporal relations, and this has motivated attempts to map spatial frames of reference (FoRs) onto time. How people assign FRONT to temporal entities and to time itself is crucial for diagnosing which temporal FoR a person actually adopts, yet strongly depends on cultural conventions. To assess the

cultural conventions involved in FRONT assignment, we conducted a survey with speakers of English, Norwegian, German, Chinese, and Japanese, which differ on several potentially relevant dimensions, including traditional writing direction and preferences for spatial and temporal referencing. Data on temporal movements of events, on the temporal order of events, and on explicit FRONT assignments to events, time units, and 'time itself' suggest that speakers of these languages use different principles for describing fixed relations (static time) versus moving events (dynamic time).

The future is in front, to the right, or below: Development of spatial representations of time in three dimensions (**Ariel Starr** & Mahesh Srinivasan)

The experience of mapping time onto space is likely universal, but these mappings can take many forms. Previous work has demonstrated that cultural differences in writing direction, metaphorical language, gesture, and temporal focus all influence the way time is mapped onto space. Even within a culture, it is common to use different spatial reference frames to represent different temporal concepts. Here, we explored the development of two types of spatiotemporal representations: sagittal representations of time (the front-back axis as one moves through time and space) and the mental timeline (a linear reference frame that is typically oriented horizontally or vertically) in Indian schoolchildren aged 6 to 15 years. We show that these two different types of spatiotemporal mappings are constructed in parallel throughout childhood and become increasingly aligned with cultural norms. In addition, we identify multiple factors that influence the orientation of these mappings. Individual differences in children's attitudes towards the future influenced sagittal spatiotemporal mappings, and experience with horizontal and vertical calendars influenced the orientation of children's mental timelines. Taken together, our results demonstrate that children are sensitive to both internal and external factors when building their mental models of time.

Examining the development of memory for temporal order in a naturalistic setting (**Thanujeni Pathman**, Lina Deker, Tida Kian, Puneet Parmar & Giulia Fabiano)

Episodic memory (EM) is memory for past events from a particular time and place. Temporal memory (memory for 'when') is a critical feature of episodic memory, yet relatively little is known about the developmental trajectory of temporal memory in childhood. The aim of this study was to examine temporal memory development in early to middle childhood using naturalistic and engaging events experienced over an extended period. Participants were 4- to 5-year-olds, 6- to 7-year-olds, and 8- to 10-year-olds (N=129) who took part in a 5-day camp at a local zoo. Children visited various animals every day, according to a predetermined schedule. On day 5, children participated in various tests, including a primacy/recency task. Using each individual child's schedule, pairs of events were selected from the week and children were asked questions about the temporal order of the events ("which animal did you visit first, the polar bear or the giraffe?"). The elapsed time (lag) between events pairs were manipulated to examine the effect of temporal distance in children's accuracy. In addition to this temporal order task, children were asked to provide autobiographical memory narratives; narratives were coded for various features, including references to time and space. We found age-related improvements in the accuracy of temporal order judgments. Further, the oldest group showed a temporal distance effect (higher accuracy for event pairs with a long lag compared to a short lag; effect seen in adults), but younger groups did not. These data, along with the data from the autobiographical memory narratives, and implications of this work to our understanding of EM development will be discussed.

Children's theories of the past and future (**Katharine Tillman**, Cole Dougherty, James Daly, & Caren M. Walker)

Adults often think of time as an abstract domain: linear, unidirectional, and divisible into past, present, and future. I discuss two studies exploring 3- to 6-yr-old US children's developing beliefs about the nature of the past and future. In the first study, we tested when children know that present actions can change the future, but not the past. We told children 3-step causal stories, and asked about the effects of an intervention at step 2. We found that children's reasoning about effects on the future event improved gradually from age 4 to 6, but even 3-yr-olds judged that the past event would not change. Although Newtonian time is unidirectional, adults nevertheless make retrospective inferences about what occurred in the past, based on observations of the present. Using the same paradigm, we found that while even 4-yr-olds treated such scenarios differently from interventions on past events, consistent retrospective reasoning only emerged around age 6. In the second study, participants made explicit judgements about the (im)possibility of various temporal phenomena. Interestingly, the majority of 4-yr-olds judged that it is possible to travel back in time, and to see into the future. In contrast, only about a third of 6-yr-olds (and few adults) said either phenomenon was real. Thus, while intuitions about the causal unchangeability of past events emerge early in development, conventional theories about the nature of time itself emerge gradually in early and middle childhood.