Prècis of *Constructing the Concept of Time: Roles of Language, Perception, and Culture*

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PhD 2017

1. Overview

How are humans able to think about abstract concepts that transcend what we can perceive with our senses? What role do perceptual primitives – evolutionarily-ancient representations that are available from birth – play in this process? Is abstract thought simply a matter of combining old "building blocks" in new ways, as many philosophical accounts posit? Are the "blocks" themselves far more complex than perception allows? How does language fit into this puzzle? Understanding the nature and origin of abstract concepts is a fundamental problem in cognitive science – one that goes to the core of what it means to be human, and to have a human mind.

In my dissertation, I tackle one of the most historically elusive of abstract concepts: time. Understanding mental representations of time has long been a topic of interest to researchers from many fields within cognitive science, including psychology, philosophy, linguistics, anthropology, and education. Modern physics teaches that linear time as we know it is not a property of the universe itself. So, where do intuitive theories of time come from? Some ways of thinking about time are built-in: human infants can discriminate brief durations, represent event sequences, and associate temporal and spatial magnitudes. However, by adulthood, Westerners construe of "time itself" as an abstract dimension, separate from particular temporal events. This dimension is described and measured using external symbol systems, including language and spatial artifacts such as clocks and calendars, which require years to learn. The gap between our slippery, subjective experience of temporal events and the formal systems we use to represent time is wide. My dissertation asks how this gap is traversed in the mind of a child, as she learns to express time visually and verbally. By understanding how time concepts emerge over development, we may gain greater insight into what they consist of in adults.

Using converging developmental evidence from three study sets, I argue that mature, adult-like concepts of time are not built from innate primitives, but from representational structures available in language and cultural artifacts. In the first two of three sets of studies, I show that the perception of time plays little to no role in the initial construction of children's temporal concepts. Instead, children's earliest meanings for time words like "minute" do not include knowledge of their approximate temporal durations (Chapter 1). From the start, concepts like "yesterday" are not tied to representations of experienced events (Chapter 2). Instead, in both these cases, children use linguistic cues to construct ordered semantic domains for time words, and do not map them to time perception until several years later. Finally, considering spatial representations of time, Chapter 3 demonstrates that the left-to-right "mental timeline" English-speaking adults use to organize temporal events is not derived from innate space-time associations. In fact, I find that most pre-school children do not spontaneously represent time linearly at all – and must learn this convention slowly through cultural exposure and education.

2. Background and Introduction

A goal of this dissertation is to help illuminate how adult-like temporal concepts develop in the minds of young children. This raises a challenging question: What is an adult-like concept of time? The nature of time has long been a subject of debate by philosophers and physicists, and more recently by cognitive scientists of all stripes. My work concerns the psychological foundations of several aspects of the multifaceted Newtonian view of time: namely, that time is an event- and observer-independent dimension which is measurable, absolute, linear, unidirectional, and divisible into past/present/future (for further discussion; see Bardon, 2013). These properties of time are held as "common sense" by most adult laymen in industrialized nations, and underlie many forms of cognition and behavior, including schedule-keeping, future planning, causal reasoning, and the construction of autobiographical narratives. However, especially in light of the scientific evidence that these Newtonian assumptions do not reflect "ground truth" about the physics of the universe, the question of their psychological origins becomes increasingly important.

Critically, the Western picture of time is not universal, and often differs from views about time held by pre- and non-industrialized communities (Gell, 1992). Indeed, the great variety of beliefs and attitudes about time across the world and throughout human history make this domain a particularly fertile one for exploring how potentially innate factors like duration and event representation interact with learned, cultural factors to shape adult-like concepts of time. With this in mind, I explore the development of American children's temporal concepts, particularly in the years prior to their becoming fluent in the use of the clock and calendar system, which is couched in systems of mathematical knowledge (e.g., multiplication by 60) that can take 10 years of more to acquire.

Many proposed solutions to the problem of how abstract, uniquely-human thought is possible posit that we start with a set of primitive representations and combine them in such a way that we end up with ideas that are richer than the sum of their parts (e.g., Locke 1689; see Wagner, Tillman, & Barner, 2016, for discussion). More recently, alternatives to this building-block view of abstract concept acquisition have also emerged, though in many cases these theories have focused on conceptual domains other than time. One such theory, known as "Quinian bootstrapping," holds that from early in development, abstract concepts, such as number word meanings, are defined by their *inferential roles* within semantic structures (see Carey, 2009; Wagner, Tillman, & Barner, 2016). Carey's view nevertheless posits that early language-based "placeholder" structures for representing abstract relations are "grounded" in perceptual primitives, such as approximate number representations. A more recent proposal by Barner (2017) posits that perception plays a more limited role, simply providing a phenomenon to be explained by symbolic systems, rather than their foundation. While the psychology of time is fascinating in and of itself, this case study also provides a new testing ground for these more general theories about abstract word learning and conceptual development.

In the case of time, several evolutionarily-ancient "building blocks" are available to human infants, and could plausibly form a foundation for the acquisition of abstract temporal concepts. For example, infants in the first months of life are sensitive to elapsed time (e.g., Columbo & Richman, 2002). By 4 months of age, infants can also discriminate stimuli on the basis of their duration (Brannon et al., 2007; Provasi et al., 2011). In the first six months of life, infants can reproduce single actions from memory (e.g., Barr et al, 1996), while older infants can imitate multi-step sequences of events with increasingly higher accuracy over longer delays (Bauer & Mandler, 1989; Bauer & Mandler, 1992; Mandler & McDonough, 1995).These findings suggest that infants mentally represent both the temporal structure of events and the temporal relations between them in memory. Further, infants are surprised when presented with impossible causal chains of events, including those with apparent breaks in temporal continuity (Cohen et al., 1998), suggesting that they have an intuitive understanding of the link between temporal order and causality. Infants also appear to spontaneously associate longer spatial magnitudes with longer temporal durations (de Hevia et al., 2014; Lourenco & Longo, 2010; Srinivasan & Carey, 2010), which has been taken as evidence for an innate link between representations of time and space.

While some temporal primitives are in place from infancy, the ability to represent time in language and via other symbolic systems develops slowly. Natural languages express time at several levels of representation, including morpho-syntax, lexical items, and narrative structure. In English, the past-tense marking "*–ed*" is one of the first grammatical inflections children produce, as early as the first year of life (Brown, 1973; DeVilliers & DeVilliers, 1973). Time words like "day" and "minute" are also highly frequent (Kucera & Francis, 1967), and early to appear in the child's lexicon (e.g., Ames, 1946). However, although children begin to produce many time words by age 3, they do not use these words in adult-like ways for several years (Brown, 1973; Busby Grant & Suddendorf, 2011; Busby and Suddendorf, 2005).

Relevant to the question of how time concepts develop, children's early errors with time words suggest that they may have partial meanings before acquiring adult definitions (e.g., Harner, 1975; Shatz et al., 2010). For example, past work has shown that 4-year-olds respond to questions about duration with duration words, despite using them inaccurately (Shatz et al., 2010) – suggesting that they already know these words denote durations. Three-year-olds contrast both "tomorrow" and "yesterday" with "today" – suggesting that they know these words refer to non-present times (Harner, 1975). Furthermore, anecdotal reports of within-category speech errors, such as over-extending "yesterday" to refer to any past event (e.g., Harner, 1981), also suggest partial knowledge of their meanings. Nonetheless, while it is clear that children struggle with time words, past work has revealed less about precisely what children do and do not know about them, which is the topic of Chapters 1 and 2. Examining children's first interpretations of temporal words, and how they change over time, provides a window into the development of temporal concepts, as well as the sources of knowledge children use to acquire them.

In addition to representing time linguistically, societies across the world and throughout history have developed means of spatial representing time, including clocks, calendars, charts, and timelines (Gell, 1992; Rosenberg & Grafton, 2013). Spatial metaphors for time (e.g., *the past is behind me*) are also widespread across languages (Haspelmath, 1997; Grady, 1999), and the practice of reading text habitually associates progress in time with process along a particular spatial path. A large body of research suggests that adult speakers of English and other languages written from left-to-right organize temporal sequences using an implicit left-to-right "mental timeline" (MTL) from the past to the future (for a review, see Bonato et al., 2012). However, it remains unclear whether cultural tools and practices linking space and time draw upon pre-existing, potentially-innate spatial representations of time in the mind, or, alternatively, if engaging in these cultural practices *causes* space and time to become mapped in the mind.

While several studies in infants indicate that language and culture are not required to associate duration and length (de Hevia et al., 2014; Brannon et al., 2007; Laurenco & Longo, 2010; Srinivasan & Carey, 2010), and some researchers argue that the MTL is innate (Chatterjee, Southwood, & Basilico, 1999; Vicaro et al., 2007), cross-cultural comparisons in adults and school-children show that the direction of space-time mappings varies widely, suggesting that they are a learned convention (Bergen & Lau, 2012; Boroditsky, 2001; Boroditsky et al., 2011; Boroditsky & Gaby, 2010; Brown, 2012; Fuhrman & Boroditsky, 2010; Lai & Boroditsky, 2011; Miles et al., 2011; Ouellet et al., 2010; Nachson, 1983; Nunez & Sweetser, 2006; Tversky, Kugelmass, & Winter, 1991). If the MTL is a result of a biological predisposition, English-speaking preschoolers, like adults, should spontaneously represent time linearly from left-to-right. Alternatively, if cultural conditioning is necessary for the deployment of the MTL, this behavior should emerge only after children begin to receive instruction on reading and spatial artifacts for time. These hypotheses are tested in Chapter 3.

3. Children's acquisition of duration words

Tillman & Barner (2015), *Cognitive Psychology*

Children use time words like *minute* and *hour* early in development, but take years to acquire their precise meanings. Chapter 1 investigated whether children assign meaning to these early usages, and if so, how. To do this, I tested their interpretation of seven time words: *second, minute, hour, day, week, month,* and *year.* Across 3 experiments, I found that although preschoolers infer the orderings of time words (e.g., *hour* > *minute*) before they can use them accurately, they have little to no knowledge of the absolute durations these words encode. These results suggest that knowledge of absolute duration is learned much later in development – many years after children first start using time words in speech – and in many children does not emerge until they have acquired formal definitions for the words. I conclude that associating words with the perception of duration does not come naturally to children, and that early intuitive meanings of time words are instead rooted in relative orderings, which children may infer from their use in speech.

Experiment 1 tested 3- to 6-year-old children's knowledge of the ordering of duration words, e.g., that an hour is longer than a minute. Children performed a forced-choice task, deciding which of two verbally described events was longer – e.g., "jumping for a minute" vs. "jumping for an hour." We found that, by age 4, children were able to correctly identify the longer duration more often than would be predicted by chance, indicating that they have partial knowledge of these words, even at an age at which they frequently use them inaccurately. However, against the hypothesis that individual terms are mapped to approximate durations, children's performance was not driven by the specific time words included in the comparison, and accuracy was not higher on trials in which the ratio between durations was greater (e.g., second vs. year).

In Experiment 2, I further probed children's knowledge of the approximate durations of time words by adding number words to the comparisons, e.g., "3 minutes" vs. "2 hours." Despite their high performance in Experiment 1, even 6-year-old children were often stumped by trials in which the larger number word was paired with the smaller duration word. Thus finding indicates that, although they have early knowledge of the ordering of these words, young children have little knowledge of *how much* larger, e.g., an hour is than a minute. Again, this pattern of results is inconsistent with the hypothesis that duration words are first learned by mapping them to approximate durations. In contrast, it is consistent with the hypothesis that children rely primarily on speech input. For example, contrastive usages, such as "you can't stay in bed for an *hour*, because school starts in a just a few *minutes*!" typically contain information about the relative ordering of time words, but lack information about their precise durations.

Finally, in Experiment 3, I used a timeline paradigm to test children's ability to map duration words to a spatial representation of time. While 5-year-olds were able to both order familiar events like "washing hands," "eating lunch," and "going to the zoo" along the timeline, and to space them out appropriately to represent larger differences in duration, even 7-year-old children struggled to represent the relative differences in duration (but not the order) of words like "second," "minute," and "day."

Furthermore, age-related differences in children's ability to represent the relative durations of time words were completely accounted for by their knowledge of the adult definitions of these words (e.g., hour = 60 minutes).

Together, all 3 experiments in Chapter 1 indicated that, although children learn the relative ordering of time words (which can be inferred from linguistic input) early, they do not map them to perceptual representations of duration (which are potentially available from birth) until many years later.

4. Children's acquisition of deictic time words

Tillman at al. (2017), *Cognitive Psychology*

Deictic time words like "yesterday" and "tomorrow" pose a unique challenge to children not only because they are abstract, and label periods in time, but also because their denotations vary according to the time at which they are uttered: Monday's "tomorrow" is different than Thursday's. As with duration words, although children produce these words as early as age 2, they do not use them in adult-like ways for several subsequent years. In Chapter 2, I explored whether children have partial but systematic meanings for these words during the long delay before adult-like usage. I asked 3- to 8-year-olds to represent these words on a bidirectional, left-to-right timeline that extended from the past (infancy) to the future (adulthood). Critically, this method allowed me to independently probe knowledge of three separate facets of these words' meaning: their deictic status (e.g., "yesterday" is in the past), their relative ordering (e.g., "last week" was before "yesterday"), and their remoteness from the present (e.g., "last week" was about 7 times longer ago than "yesterday"). I found that adult-like knowledge of deictic status and order emerge in synchrony, between ages 4 and 6, but that knowledge of remoteness emerges later, after age 7. These findings suggest that children's early use of deictic time words is not random, but instead reflects the gradual construction of a structured lexical domain.

Importantly, different theories of how abstract words are acquired make different predictions about how English-speaking children's knowledge of the deictic status, order, and remoteness of time words might emerge over development. For example, a *syntactic bootstrapping* account predicts early acquisition of deictic status (but not order and remoteness), because this facet of time is also encoded syntactically, in verb tense (e.g., Gleitman et al, 2005). On the other hand, an event-mapping hypothesis, on which children learn time words by associating them with remembered or anticipated experiences (e.g., "last year" is approximately as long ago as the last birthday party) predicts that both deictic status and remoteness knowledge would emerge early and in tandem, because both are encoded in event representations.

The timeline method enabled me to test these hypotheses by extracting information about children's knowledge of each of these three facets of meaning separately from the others. Children used colored pencils to mark where several events or deictic time words belonged on a linear representation of time. To assess knowledge of deictic status, I tested whether children placed each term to the right or left of the midpoint of the line ("now"). To assess knowledge of order, I tested whether children put each term to the right or left of the term on the previous trial. Finally, to test knowledge of remoteness, I assessed the relative spacing of all the terms across each timeline (factoring out understanding of order). In a series of analyses, I measured (1) children's accuracy on each measure separately, (2) the order of acquisition of the three facets, and (3) the contingencies between knowledge of individual facets in a given child. Each analysis provided convergent evidence for a developmental trajectory in which children acquire knowledge of both deictic status and order early, beginning at age 4. This parallels the early order knowledge of duration words we observed in Chapter 1. On the other hand, similar to their lack of knowledge of the approximate durations encoded by duration words, children did not exhibit knowledge of the approximate remoteness of deictic terms until several years later. Again, this pattern is inconsistent with the theory that time words are learned via association with nonverbal representations of events, and consistent with the view that they are learned via inference about their relations within a structured lexical class, using cues that are readily available in the structure of language (e.g., grammatical tense and order-of-mention in discourse).

5. The gradual construction of the mental timeline

Tillman et al. (2018), *Developmental Science*

When reasoning about time, English-speaking adults often invoke a "mental timeline" stretching from left to right (LR). Although the direction of the timeline varies across cultures, linear representations of time have been argued to be ubiquitous and primitive. On this hypothesis, we might predict that children also spontaneously invoke a spatial timeline when reasoning about time. However, little is known about how and when the mental timeline develops, or to what extent it is variable and malleable in childhood. In Chapter 3, I used a sticker placement task (adapted from Tversky, Kugelmass, & Winter, 1991) to test whether preschoolers and kindergarteners spontaneously produce linear representations of temporal events (breakfast, lunch, and dinner) and deictic time words (*yesterday*, *today*, *tomorrow*), and to what degree those representations are adult-like. I found that, at age 4, preschoolers were able to make linear mappings between time and space with minimal spatial priming. However, unlike kindergarteners and adults, most preschoolers did not adopt linear representations spontaneously, in absence of priming, and did not prefer left-to-right over right-to-left lines. Furthermore, unlike most adults, children of all ages could be easily primed to adopt an unconventional vertical timeline. These findings suggest that mappings between time and space in children are initially flexible, and become increasingly automatic and conventionalized in the early school years.

I found that both (conventional) Horizontal and (unconventional) Vertical priming were highly effective at prompting preschoolers and kindergarteners to adopt linear representations of time, suggesting that space-time mappings are intuitive for children. Following Horizontal Priming, like adults, both kindergarteners and preschoolers showed a significant bias toward representing time from left-to-right. However, when no priming was given, only about a third of preschoolers produced any type of linear representation, and there was no LR bias among those who did so. In contrast, both kindergarteners and adults often made LR representations of time even without priming. This result is at odds with the view that the LR mental timeline is a result of innate space-time associations, and instead suggests that it is a result of experience in childhood, and that both its automatic deployment and its LR direction may be linked to cultural practices introduced in elementary school. Our findings in the Vertical Prime condition further suggest that the MTL is shaped for many years. Unlike adults, who often created conventional LR representations of time even after experiencing a vertical prime, both preschoolers and kindergarteners virtually always created unconventional vertical representations of time. These findings show that the direction of the MTL is highly flexible until at least age 6, which is also at odds with the view that there is a strong biological default of LR.

6. Discussion

Because time perception is highly subjective, the necessity of coordinating activities across large groups of people has led diverse cultures to create external symbolic systems to precisely encode the passage of time. Although humans have basic capacities for time perception from birth, these formal systems take many years to learn, and are not universal. In this dissertation, I explored how 3- to 8-year-old children first acquire duration words (Chapter 1), deictic time words (Chapter 2), and linear representations of time (Chapter 3). The results of each study indicated that children begin to construct abstract systems to represent and communicate about time as early as age 4. However, in each case, I argued that primitives available from infancy – including perceptual representations of duration, events, and spatial magnitudes – play a limited role in this process.

Our findings regarding the acquisition of time words have implications for general theories of abstract word learning. They are inconsistent with classic "building block" views of conceptual development, and more consistent with proposals in which abstract words are defined by their *inferential roles* within semantic structures (Carey, 2009), and perception plays little if any role (Barner, 2017). These ideas have previously been discussed primarily in the context of the domain of number, and this dissertation broadens their scope to another central domain of human cognition.

The present work also has important practical implications for education. Although teaching time is one of the hardest challenges school teachers face, research on this topic in the educational literature is scarce (Burny et al., 2009; Kamii & Russell, 2012). Knowledge of the meanings of time words is a prerequisite for successful clock use (Burny et al., 2009; Friedman & Laycock, 1989), and children's difficulty in calculating elapsed time may stem from inability to coordinate units (Kamii & Russell, 2012). In order to deploy appropriate scaffolding for the acquisition of temporal terms, was must take into account children's understanding *before* instruction begins, which is described by the current studies. This work also indicates that children are capable of representing time linearly by the age of 4, and that timelines may be effective learning aids even in preschool.

Time has long been an important domain of inquiry in many of the cognitive sciences – particularly psychology, philosophy, linguistics, and anthropology – as well as other disciplines as diverse as physics and literature. Studying children's cognitive development offers a new window into the fundamental problem of how time is represented in the mind.

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