Chapter 11

Developmental Perspectives on the Psychology of Time

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> "What then is time? I know well enough what it is provided nobody asks me; but if I am asked and try to explain, I am baffled." (St. Augustine, 1961, p. 264)

St. Augustine's dilemma, familiar to anyone beginning to consider the nature of time, is rooted in large measure in the fact that a single word refers to may different things, including natural periodicities, temporal–causal relations, and the distinction between the past, present, and future. Even within psychology, the term *time perception* is often used to describe all of the perceptual and cognitive processes that contribute to our experience of time. But the experience of time is multifaceted, depending on many different processes to adapt to different temporal features of the environment. The multiplicity of temporal experience is perhaps most evident when one examines the development of children's adaptation to time. Different abilities emerge in early infancy, during childhood, during adolescence, and even later, making clear that our experience of time has many different parts.

This chapter was written to illustrate the diversity of humans' experience of time by providing examples of its components and the different ages at which they are found. It is also intended to provide a summary of the main findings from many of the approaches that developmental psychologists have taken. It is not a comprehensive review; the literature is too extensive in some areas for this to be practical in a single chapter. But many of the references can help the interested reader find additional sources in a particular area. In addition to summarizing findings, the concluding section provides some ideas about the reasons behind the developmental pattern.

The general perspective offered here is that the natural and social environments are rich in temporal information of various sorts and that the process of development is a matter of adapting to much of this information. Children experience a physical

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world that includes temporal–causal relations, coincidences of sounds and sights, natural periodicities, and many other kinds of temporal information. The sociocultural environment is also replete with temporal information: names for particular times, cultural tools for measuring time and representing natural and conventional patterns, tense and other ways of representing times relative to the present, schedules and routines, and others. Indeed, an important part of socialization is training children to conform to the temporal expectations of their culture. Children must learn to internalize schedules, coordinate their activities with others, and prepare for events that will occur at specific times in the future. The distinction between time in nature and conventional time is of little importance to children. What does matter is their ability to adapt to these different types of information, thereby allowing them to function effectively in their environment.

11.1. Review of the Development of Temporal Abilities

11.1.1. Perception in Infancy

Children begin the task of adapting to time with a biological head-start: mechanisms that allow them to attend to some kinds of temporal information and retain this information for at least brief periods of time. Even in the first months of life, infants are sensitive to the temporal structure of the auditory and visual stimuli that they experience (Lewkowitz, 1989, 2000). For example, infants of less than 6 months of age can discriminate between different temporal groupings of tones and pauses — what adults would experience as different rhythmic patterns (e.g., Demany, McKenzie, & Vurpillot (1977); Morrongiello, 1984). Researchers have also studied the ability to remember the sequence in which discrete events occur. Gulya, Galluccio, Wilk, and Rovee-Collier (2001) found that 3- and 6-month-old infants can remember something about the sequence in which they had interacted with particular mobiles a day earlier: A mobile was more likely to be recognized if they received its predecessor as a reminder. Lewkowitz (2004) demonstrated that 4- and 8-month-old infants who were habituated to the sight and sound of three different objects falling and striking a surface (e.g., in the order ABC) subsequently looked longer at displays in which the order had been changed (CAB). Even younger infants are sensitive to the order in which words are spoken in a sentence: 2-month-olds discriminate the sound of ‘‘cats would jump benches’’ from ‘‘cats jump wood benches’’ (Mandel, Nelson, & Jusczyk, 1996). Another kind of temporal information to which young infants are sensitive is the synchrony of sensations. Lewkowitz (2000) reviewed evidence demonstrating that this sensitivity is present from the first months of life, and he discussed the role that it might play in infants learning to make connections between different sensory modalities, such as vision and audition.

There is also evidence concerning infants' sensitivity to another kind of temporal regularity, one that adults usually take for granted. Many of the events that we witness day to day, such as an object falling or a cookie being broken into pieces, are temporally unidirectional. (Films of these events would seem anomalous if played in reverse.) These examples of perceptual "arrows of time" (Friedman, 2002a, 2003a) show that adults have mental representations of a variety of temporal–causal regularities. Studies of infants' looking times to videotapes of such events indicate that they respond differently to forward and backward versions of a number of gravity events by 8 months of age. Sensitivity to the temporal–causal information in separation events such as a breaking cookie apparently emerges at some as-yet-unknown time between 12 months and 3(1/2) years (Friedman, 2003a, c). It appears that humans only gradually learn about the temporal structure in the world, even on the very brief time scale of a few seconds.

Other evidence bearing on humans' sensitivity to temporal information is found in the literature on causal perception (Cohen & Oakes, 1993; Leslie, 1984; Leslie & Keeble, 1987; Oakes, 1994; Oakes & Cohen, 1990, 1995). For example, Leslie (1984; Leslie & Keeble, 1987) showed infants of about 6–8 months of age films of simple causal and noncausal events (such as a moving square that appeared to collide with and "launch" another square, on the one hand, or launching taking place without collision, on the other). After the infants habituated to one of the films, they were shown the same film in reverse. Leslie found greater recovery from habituation when the reversal was of a direct launch than when it was of a delayed launch. The results of studies like this one show the early ability to discriminate between dynamic stimuli that differ in how they unfold over time.

11.1.2. The Perception and Measurement of Duration

Time perception. From early infancy humans are also sensitive to the durations of events (at least when those durations are about 5 s or less), showing the presence of biological mechanisms that permit measurement of durations on these scales. Colombo and Richman (2002) presented 4-month-olds with eight alternating periods of light and dark visual fields. The light fields were 2 s in duration, and the dark fields were 3 s for some infants and 5 s for others. On the ninth trial, the light field did not come on. Measurements of the infants' heart rate revealed that they noticed the "missing" field within about one-half second; their heart rates began decelerating just after 3 or 5 s of the dark field. This allowed the researchers to conclude that the infants had developed rather precise temporally based expectations.

The presence of the early ability to form temporally based expectations should not be surprising in light of an extensive literature showing that animals can measure the lengths of intervals (see, e.g., Meck, 2003). The well-developed theories and techniques in the animal literature have provided the framework for some of the most sensitive tests of humans' capacity to measure amounts of time in early childhood and later. One of the techniques, called temporal bisection (see Chapter 2), involves training children to press one button for the briefer of two stimuli (e.g., 1 s) and another for the longer of the two (e.g., 4 s). During the test phase, they are presented with the durations on which they were trained and a number of durations in between (e.g., 1.5, 2, 2.5, 3, and 3.5 s) and asked to make the same long-or-short choice. Using this method, children as young as 3- to 5-year-olds have proved able to make the discrimination and to produce data roughly similar to those obtained in studies of animals and adult humans: The number of "long" responses increases systematically as test durations grow longer (Droit-Volet, 2003; McCormack, Brown, Maylor, Darby, & Green, 1999). Young children's judgments are not as differentiated as those of 8- or 10-year-olds', apparently because younger children produce more random responses and they have greater difficulty remembering the standard durations (Droit-Volet, 2003). However, despite their lower levels of sensitivity, young children's performance can be well described by the same theoretical models that successfully explain the performance of animals and adults, models that assume the existence of biological clocks.

In addition to the presence of biological clocks, developmental studies show that children experience some of the same illusions of time perception as adults do. For example, when we are engrossed in a task, a given interval of time seems to pass more rapidly than when we have little to do or to think about. By about 8 years of age, children are susceptible to some of the same illusions (Arlin, 1986; Zakay, 1992, 1993). In one of these studies, children who were asked to fill in dotted lines that make up geometric figures produced shorter estimates of 30- and 120-s intervals than those who had no task to perform (Zakay, 1993). Expecting a prize at the end of 30- and 120-s intervals makes them seem longer than if no prize is expected (Zakay, 1993), whereas distraction leads to shorter judgments of 3- to 10-s intervals (Zakay, 1992).

These findings can all be explained by attentional models of time perception (e.g., Zakay, 1989), which assume the division of attention between temporally related information (e.g., number of thoughts or external events or the output of an internal timer) and nontemporal information (e.g., the shapes of the geometric figures). When considerable attention is devoted to the nontemporal information, less is devoted to correlates of the passage of time, resulting in shorter time judgments (see Chapters 4 and 12). Clearly, cognitive factors, in addition to biological timekeepers, influence children's (and adults') experience of duration. The biological timers may be especially important when repeated events have a clear onset and end and are of a constant duration. In other situations, cognitive processes may be more important in determining our impressions of amounts of time.

Although it has not been studied, other cognitive factors probably make young children's temporal experience quite different from adults'. Adults' ability to cope with a boring or unpleasant situation depends in part on their understanding of what is happening and the amount of time they will probably have to wait until it is over. Young children who do not understand what is happening or the reasons for the wait — and who lack an understanding of time measurement, the next topic — are likely to experience the same interval as being interminable.

Studies of time perception in children involve the perception of brief intervals, typically 10 s or less. But there is evidence that children learn and remember information about the durations of much longer events in their everyday lives. In one study (Friedman, 1990), children were taught to use a drawing (a line with a small sandglass at one end and a large one at the other) to indicate different amounts of time. The tester used labels such a "very short" and "very long" to label points on the continuum and then asked the children to use the representation to judge the durations of a number of familiar activities. By 4 years of age, mean judgments were perfectly rank-ordered according to the true durations of the five events. For example, 4-year-old and older children judged drinking a glass of milk as taking less time than watching a cartoon show and a cartoon show as taking less time than sleeping at night. These results indicate that young children have formed mental representations of familiar events that contain information about their durations.

Measurement. Whenever measurement of time is possible, adults subordinate their impressions of an interval of time to its measured length (for which reason they are prevented from consulting watches or clocks in studies of time perception). Piaget (1969) found that this is not true of children younger than about 7 or 8 years, who believe that the lengths of two intervals that are shown to be equal (e.g., by measuring them with a stopwatch) differ if one is filled with actions performed at a rapid pace and the other with slower actions (see Levin, 1992, for a discussion of this and related research). In addition, few children younger than about 7 or 8 years spontaneously count in order to measure durations in time-perception tasks (Espinoza-Fernádez, Vacas, García-Viedma, García-Gutiérez, & Colmenero, 2004; Wilkening, Levin, & Druyan, 1987). But children as young as 5-year-olds will count in these tasks if a metronome is provided (Wilkening et al., 1987) or if they are instructed to count (Clément & Droit-Volet, 2006). It appears that the basic idea that time is measurable develops before children understand that measurement supersedes other sources of information about the interval (such as the number of events that occurred).

11.1.3. Event Representations

We saw earlier that young infants detect a change in the order in which three objects appear to drop onto a surface and make a sound. Researchers have used another method, imitation of actions, to study the development of memory for the temporal sequence of more complex events — and over longer retention intervals — during infancy and early childhood (e.g., Barr & Hayne, 1996; Bauer & Mandler, 1989, 1992; Bauer & Thal, 1990). In this method, infants and young children are shown demonstrations ranging from two to eight actions in a particular order. For example, they might witness the unfamiliar sequence of an adult putting a crosspiece on a supporting stand, hanging a piece of metal from the crosspiece, and hitting the metal with a mallet. The ability to reproduce acts in the modeled order has been assessed after various retention intervals. In a summary of her research using this method, Bauer (1996) concluded that 11-month-olds are very accurate in their immediate imitation of two-event sequences, and progressively longer sequences can be reproduced through 30 months of age. By 13 months of age, infants show impressive recall over very long retention intervals: 13-month-olds who have seen event sequences modeled twice in 2 weeks show significant recall of the order of the events 8 months later. These studies show that by about 1 year of age, infants have the ability to form representations of brief, novel events — representations that incorporate much of the temporal information in the events and that are preserved over long periods of time.

By 3 years of age, and probably earlier, children can use these abilities to learn about the order of events that unfold over even longer periods of time. Nelson and her colleagues (1986, and see Hudson, Fivush, & Kuebli, 1992) have interviewed young children about familiar events, such as having lunch, baking cookies, or eating in a restaurant. Using prompts such as "What happens when…?" they have found that even 3- and 4-year-olds can describe these events in ways that preserve much of the true order of their constituents. For example, many 4-year-olds can explain what happens when you make cookies (e.g., you put chocolate chips in the dough, place the cookies in the oven, take them out, put the cookies on the table, and then eat them). Young children's descriptions show that they possess representations of familiar events that preserve much of the temporal order of the events. The fact that they describe the events using the timeless present (e.g., "You put them in the oven…") shows that they are referring to general events, not a specific occurrence.

11.1.4. The Representation of Transformations in Early Childhood

Children's knowledge about the temporal organization of familiar events continues to develop in the years after infancy. By 3 to 4 years of age, they are aware of what happens when a variety of familiar transformations (including wetting, melting, breaking, and cutting) take place (Das Gupta & Bryant, 1989; Gelman, Bullock, & Meck, 1980; Goswami and Brown, 1989). For example, when shown an initial state (e.g., a whole apple) and a mediator (a knife), they can select a picture representing the correct end-state (a cut apple) from a number of alternatives (Gelman et al., 1980). Another study focused on sensitivity to a particular subset of arrows of time, ones involving increases in entropy (Friedman, 2001). Three- through eleven-year-old children were asked to judge whether randomizing forces, such as the wind blowing on plastic utensils and paper plates, could make a neat set disordered or, on other problems, a disordered set neat. By 4 to 5 years of age, children showed an awareness that increasing disorder is more likely than increasing order in the face of such forces. Finally, research indicates that young children understand that physical causes precede their effects (Bullock, Gelman, & Baillargeon, 1982; Shultz, 1982).

Another set of studies, on children's biological concepts, shows that by early childhood there is an understanding that growth is progressive and that this property is specific to living things (e.g., Inagaki & Hatano, 1996; Rosengren, Gelman, Kalish, & McCormick, 1991). Young children also know that animals grow larger but not smaller (Rosengren, Kalish, Hickling, & Gelman, 1994). In both cases children reveal knowledge about processes that occur on very long time scales, ones that cannot be continuously observed. (See Montangero & Pownall, 1996, for research on older children's conceptualizations of changes on long time scales.)

11.1.5. The Past and the Future

Adults have a compelling sense of where they are in time and of when particular past and future events have occurred or are expected to occur. Although the past–present–future distinction appears to most adults to be a basic feature of the real world, Nelson (1996) has argued that it is a social construction, one which children must learn. Developmental research shows that the distinction takes years to master, supporting her view (Friedman, 2003b, 2005).

Language measures. One approach to studying children's acquisition of the past–present–future distinction is to examine their production and comprehension of words referring to these categories. Studies of children's spontaneous productions indicate that by the second or third year of life, they refer to events that actually occurred in the past or will occur in the future (Harner, 1982a; Nelson, 1996; Sachs, 1983; Weist, 1989). Two- and three-year-old children begin marking these temporal categories through the use of tense and later use temporal adverbs, such as *yesterday*, *last night*, or *this afternoon*. However, when children of this age first produce these forms, they are seldom used correctly, and errors may persist for several years (Nelson, 2001).

In other studies children's competence was assessed by directing children's attention to past and future events (e.g., some actions that were completed and others that were impending) and eliciting descriptions from the children. Depending on the particular language, correct tense use has been found in many or most children by 2(1/2) to 3(1/2) years of age (Harner, 1981; Weist, Wysocka, Witkowska-Stadnik, Buczowska, & Konieczna, 1984). These studies show that children of these ages can distinguish actions that have just occurred from ones that are expected to occur in the immediate future.

A third method involves measuring children's comprehension of words that refer to past and future times (Harner, 1975, 1976, 1980, 1982b; Weist, 1983), using the terms *before* and *after*, and *yesterday* and *tomorrow*. These studies show that 3-year-olds' performance sometimes exceeds levels that would be expected by chance, and 4-year-olds are very accurate. When future forms are used to refer to the immediate future, they are understood at earlier ages than when the forms refer to the next day. However, past forms are about equally well understood when referring to the immediate past and the preceding day.

Together, the studies using language measures show that young children link linguistic markers of pastness and futurity to times that adults consider to be past and future. But the use of very supportive contexts and brief time scales in these studies means that we cannot generalize the findings to children's ability to discriminate the past–future status of everyday events (Friedman, 2003b).

Differentiation within the past. Other researchers have been interested in children's ability to differentiate the times of events within the past and within the future (Friedman, 2003b). When adults try to remember when past events occurred, they rely on several kinds of information, including when in some time pattern the event occurred (called *location* information) and how long ago the event occurred (called *distance* information) (Friedman, 1993, 1996, 2001b). Research suggests that the main way of remembering locations is to reconstruct when the event must have occurred by relating what is remembered about it to general knowledge of personal, natural, and conventional time patterns. To a more limited extent, adults are also able to use direct impressions of the ages of memories (distance information) to discriminate their times.

Children as young as 4 years of age can link past events to temporal locations, but this does not imply that they share adults' understanding of when the locations occurred. In one study children from 4 to 9 years of age were asked to report something that happened yesterday, last weekend, last summer, and on a number of holidays from the past year (Friedman, 1992). The results showed that even 4- and 5-year-olds could retrieve memories of events that had taken place at many of these temporal locations, often recounting content that was specific to the most recent occurrence of a given time. However, throughout the age range, children had difficulty judging which of a pair of times (e.g., their birthday or Easter) was a longer time ago. It appears that locations are initially like "islands of time" and that only at later ages are children able to use representations of annual time patterns to relate the times of events on such long time scales.

But 4-year-olds are able to use their general knowledge of parts of the day to reconstruct when a particular event must have happened. In one study (Friedman, 1991), 4- to 8-year-olds were asked to remember the time of an event that had happened 7 weeks earlier. They responded by pointing to positions in a row of cards representing the seasons and a row representing the daily activities: waking, eating lunch, eating dinner, and going to bed. Only older children were accurate on the season scale, but 95% of 4-year-olds indicated that the event had happened in the morning (the time that their nursery class met). The ability to reconstruct locations appears to be limited by semantic knowledge about time patterns, knowledge that changes substantially from early to middle childhood.

Other findings show that children as young as 4-year-olds are able to use impressions of the ages of memories (a kind of distance information) to judge the times of past events with some accuracy. Children of this age can judge which of two distinctive events was more recent, one that had occurred 1 week before testing or one that had occurred 7 weeks before the test session (Friedman, 1991). In another study (Friedman, Garner, & Zubin, 1995; and see Friedman & Kemp, 1998), children from 3 to 12 years of age were asked to compare the recency of their birthday and Christmas. This problem is trivially easy for adults, who can use their mental representations of the months of the year (see Section 11.1.7). In contrast, errors were common in children as old as 9-year-olds, again demonstrating that the ability to use representations of annual time patterns to relate the times of events develops in late middle childhood. However, even children less than 6 years of age could answer correctly when one of the events had occurred within the preceding few months and the other had happened much longer ago. Under limited circumstances (when the temporal distance of the nearer of two events to be compared is a small ratio of the distance of the farther event), preschool-age children can use distance information to differentiate the times of past events.

Differentiation of the times of future events. A number of researchers have investigated young children's ability to delay gratification or to plan future activities (e.g., Hudson, Shapiro, & Sosa, 1995; Thompson, Barresi, & Moore, 1997), but little is known about children's understanding of the times of future events beyond the next day or so. A series of studies using spatial representation of the future provides information about the development of a differentiated sense of the future on longer time scales. In these studies children judged the future distances of events by pointing to places on a picture of a road that begins near the viewer and recedes towards distant mountains. In one study 4-, 7-, and 10-year-old children judged the future distances of a daily event, a day of the week, and several annual events by pointing to a spot on the road and by responding to questions such as ‘‘How long is it until…?’’ (Friedman, 2000). The results showed that 4-year-olds produced largely undifferentiated judgments on both the road task and on the verbal tasks. However, about half of 4-year-olds correctly responded that a holiday was coming soon if it actually was within about the next 2 months, and many children of this age correctly judged that other events would not happen for a long time. Probably these young children are retrieving from memory propositions that they have heard from parents and teachers that some events are near and some are distant. Seven-year-olds showed some ability to differentiate future distances of this set of events, apparently by distinguishing two categories of near and far events. Ten-year-olds produced very accurate judgments throughout the range of times, and they used conventional units in answering the verbal questions. A follow-up study of judgments of annual events showed changes within the 4- to 6-year age range: 4-year-olds again failed to distinguish the future distances, 5-year-olds distinguished two categories of near and far events, and 6-year-olds distinguished three categories.

Although one might think that a differentiated sense of the future is a monolithic achievement, findings show that children learn to differentiate future times separately for the parts of the day, days of the week, and parts of the year and that different processes are used for different contents. In the previous study, many 7-year-olds had only a few future-distance categories on the scale of the year but could tell the exact number of days until the weekend. This shows that representations of days of the week could be used before representations of the months. In another set of studies (Friedman, 2002b, 2003b), children judged the future distances of daily events, such as lunch and going to bed. It was found that many 4- and 5-year-olds can differentiate future distances within the day. Interestingly, two problems are common in this age range but diminish over the next several years. First, many children have difficulty adopting the present, rather than the start of the day, as the reference point. Second, many judge the immediately preceding event, breakfast to lie in the near future. Another study showed that those 6- to 8-year-olds who adopted the present as their reference point for judging parts of the day made more differentiated judgments on this time scale than in judging the future distances of annual events. From about 4 to 8 years of age, children appear to judge the future times of the daily events using mental representations of times within the day, whereas they rely on propositions (e.g., "soon," "not for a long time") to distinguish the future distances of annual events.

Past–future confusion. The tendency that many 4-year-olds show to judge a recent event, breakfast, as coming soon is similar to an error that appears when young children judge the past or future distance of annual events (Friedman, 2003b). For example, many children less than 6 years of age responded that their birthday was more recent than Christmas when it was actually longer ago than the holiday but would happen within the next few months (Friedman, Gardner, & Zubin, 1995). Similarly, many 5-year-olds judged Valentine's Day to be coming soon when they were tested shortly after the holiday (Friedman, 2000). Confusion regarding the past–future status of events has also been found when children are given a clear choice between the two. In several studies (Friedman, 2003b), children of about 4 to 5 years of age were shown a horizontal road, with a car half way across it and trained to point to the side behind the car for past times such as *yesterday* and to point ahead of the car for times such as *tomorrow*. When tested about a week before Valentine's Day, 80% correctly pointed to the side representing the future. But about a week after the holiday, only 60% pointed to the side representing the past. In the morning at school, children also had difficulty judging the past–future status of the daily activity breakfast, although they were quite accurate in assigning lunch to the future.

These examples of past–future confusion could stem from the fact that with cyclic content, where events belong to both the past and the future, both answers are actually correct. In another study 4- and 6-year-olds made the same type of judgment for a series of noncyclic events: unusual or unique events that their parents had said had occurred at each of several distances in the past or would occur at each of those distances in the future (Friedman, 2003b). Even the 4-year-olds performed at levels beyond chance expectations, but their accuracy was rather poor: 0.64 correct for the past events and 0.67 correct for the future events. (The values for 6-year-olds were 0.88 and 0.84.) There is some evidence that the changes that take place between 4 and 6 years are related to a growing conceptual understanding of the ways that the past and future relate to the present (Friedman, 2003b). Progress in overcoming past–future confusion also probably follows from the development of increasingly flexible representations of time patterns, such as the parts of the day and times of the year (see Section 11.1.7).

11.1.6. Reasoning about Succession, Simultaneity, and Duration

Other important developmental achievements concern children's ability to draw logical conclusions from information about the order and durations of events. Studies have shown that children understand terms expressing succession and simultaneity by about 4 years of age (Blewitt, 1982), suggesting that these are salient concepts by early childhood. We have also seen that 3-year-olds can discriminate brief durations, and 4-year-olds are aware that different events take different amounts of time. A considerable body of research, much of it inspired by Piaget's (1969) work on the topic, has focused on the development of the ability to reason about these types of information.

Drawing conclusions from the order of two past events. Evidence reviewed in an earlier section shows that even young children represent the order of some causal transformations and are aware that an event can be the consequence of something that happened before but not after it. But some researchers have questioned whether young children have a similar understanding that the order of past events can tell us what information is likely to be current (McCormack & Hoerl, 2005; Povinelli, Landry, Theall, Clark, & Castille, 1999). For example, if an object was recently placed in location A and then moved to location B, it is more likely to be in location B now. When they directly observe such events, very young children can solve this sort of problem by successively updating their knowledge of the location of the object. But if the order information is presented in a more abstract way (e.g., *telling* children the order in which things took place), children in the early preschool years are unable to reason from this information. Using quite different methods, Povinelli et al. (1999) and McCormack and Hoerl (2005) found that children younger than 5 years were unable to reason about the relation between the order in which recent events took place and what the current state must be. Five-year-olds are able to solve such problems.

Reasoning about the relations between duration and succession, distance, and speed. If two runners begin a race at the same time, and one crosses the finish line before the other, adults can infer that the one who came in second ran for more time and ran at a slower speed. The development of the ability to make such inferences was investigated in an ingenious series of studies by Piaget (1969). Most of his methods involved presenting preschool and school-age children with two toys that moved at different speeds and asking them to make temporal comparisons between the events. Piaget found that prior to about 7 years of age children asked to judge the successions and durations of events were usually misled by distance and/or speed information. For example, if shown two toy snails that started and stopped at the same time but moved at different speeds, young children often concluded that the one that went faster (and covered more distance and ended up farther along the table) also moved for a greater amount of time. From these studies Piaget (1969) concluded that young children's understanding of time differs from adults' in a number of respects. First, young children fail to understand that time passes uniformly in different places (and for successive motions; see Section 11.1.2). Second, they are unable to use the logical relations between succession and duration that allow adults to solve the problem of the two runners. Third, they fail to properly separate temporal information (about succession and duration) from information about space and speed. Piaget believed that all of these limitations are overcome as children progress into his stage of concrete operations, at about 7 or 8 years.

Researchers who have used other methods have been able to provide a detailed description of many of the component abilities (see Levin, 1992, for a review).

They have also found that some important abilities are present by early childhood but that others are not predominant until adolescence, if ever. The relevant developments have come to appear more gradual and piecemeal than Piaget theorized them to be.

By 5 years of age, children can correctly compare two durations using information about succession *if* they do not have to deal with differences in spatial displacements of the two objects. Levin (1977) presented children with tasks involving the durations that two dolls slept. The dolls went to bed and woke up at the same time, went to bed simultaneously but woke successively, or went to bed successively and woke up simultaneously. She also presented logically identical problems involving two moving objects (as in Piaget's tasks). Levin found that the youngest children, 5-year-olds, were accurate in comparing durations in the sleeping-doll task, but they failed the task with moving objects. In fact, even at third grade, most children thought that a car that travels farther takes more time, even when information about succession and simultaneity leads to a different conclusion. Another type of integration of succession and duration remains difficult until about seventh grade: If object A begins and stops moving before object B by the same amount of time, the durations are equal (Levin, 1992).

Many of the errors that Piaget and later researchers found stem from confusing temporal information (such as start and stop times or duration) with spatial information (such as the locations where an object started and stopped or the distance it traversed) or from confusing duration with speed (Levin, 1992). A number of researchers have systematically investigated the development of children's understanding of the relations between duration, distance, and speed, (see Levin, 1992, for a review). This development can be illustrated by a study by Matsuda (2001). In her study children from about 4 to 11 years of age were asked to predict the duration, speed, or distance that a train would move when provided with information about a second dimension (and told that the third dimension is held constant). There were three distances, three speeds, and three amounts of time the train could move. To illustrate one of the six problem types, children were told which of the three speeds the train would move and then asked which of three buttons, each producing a different duration of motion (and a whistle blowing for the corresponding duration), should be pressed to get the train to the farthest station. This method allowed Matsuda to assess children's understanding of the physical relations between the three dimensions: (1) when speed is held constant, greater duration is associated with greater distance (as in the example), (2) when duration is held constant, greater speed is associated with greater distance, and (3) when distance is held constant, greater speed is associated with a shorter duration. The first two relations are direct and the third is an inverse one, and this distinction was important in understanding the results.

Matsuda (2001) found that children as young as 4-year-olds make judgments concordant with the first two direct relations (between duration and distance and between distance and speed). Four-year-olds' success with these two relations may stem from a general tendency to link more of any one dimension with more of any other: Children of this age also think that longer durations are associated with more sounds or pictures in an interval or brighter or larger light bulbs (Levin, 1992).

But this "more-is-more" tendency leads to problems with the inverse relation: 4- and 5-year-olds in Matsuda's study incorrectly linked longer durations with faster speeds when distance was held constant. In the following years, between 5 and 8, she found large gains in children's application of the inverse relation between duration and speed. Interestingly, it was not until about 11 years that about half of children referred to the third dimension (the one that was held constant) in explaining their answers to particular problems, leading Matsuda to conclude that it is not until this age (or later) that an integrated understanding of the relations between the three dimensions is achieved. Other studies, using more complex displays with pairs of motions (as in Piaget's tasks), have found confusion between duration and spatial cues well into adolescence, and they have revealed that a quantitative understanding of the relation between duration, distance and speed (e.g., speed = distance/time) eludes even most adolescents (Levin, 1992).

It is apparent from these findings that children's understanding of the relations between duration and succession and between duration, speed, and distance develop over a considerable period of time. By 4 years of age, children correctly expect longer durations to be associated with more distance covered. By 5 years they are able to correctly compare the durations of nonspatial events (such as dolls going to bed and waking) using information about the succession or simultaneity of the starts and endings of the modeled actions. But young children's duration judgments are incorrectly influenced by spatial information (e.g., endpoint or distance covered) and by speed and other quantities. Although considerable progress is seen from early to middle childhood in understanding the relation between speed and duration in relatively simple problems (e.g., Matsuda, 2001), the fragility of these concepts through adolescence is shown by the fact that duration judgments are often swamped by endpoints and speed in more complex displays involving two motions.

11.1.7. Representations of Time Patterns

We have seen that by 3 years of age, children possess representations of familiar activities, such as baking cookies, which incorporate information about the order in which the component actions unfold. Adults, of course, know about much longer time patterns, from daily to annual cycles and even longer temporal regularities. Developing representations of such patterns, which far exceed spans of time that allow continuous attending, would seem to present a formidable challenge, and indeed the development extends from early childhood through adolescence (Friedman, 2005).

The pattern of daily activities and the clock. By 4 to 5 years of age, children not only know about the order of events that transpire over several hours at nursery school (Friedman & Brudos, 1988) but are able to place in order a set of cards representing main events from the waking day (e.g., waking, lunch, dinner, and going to bed at night) (Friedman, 1977, 1990). By 6 years children possess sufficiently flexible representations of the pattern of daily activities that they are able to think about the *backward* order of these events (e.g., if it's dinner time, which was more recent, lunch or waking?) (Friedman, 1990). These representations probably develop at such an early age because 4-year-olds are likely to have thought about where they are within the day hundreds of times.

Although discussions with parents and teachers about past and upcoming activities must also play a role in the development of representations of daily activities, children do not need formal tuition to learn about the order of daily activities. In contrast, conventional time patterns require systematic instruction (Nelson, 1996). Learning about one such cultural tool, the clock, is a protracted process. Seven-year-olds bring to the task some knowledge of the times at which particular activities usually take place, but it is only in the following years that children learn to read the full range of times on analog clocks, and performing some operations (e.g., adding 30 min to the time 4:23) remains difficult through 11 years of age (Friedman & Laycock, 1989).

Longer time patterns. During the elementary-school years, adults also expect children to learn about the days of the week, seasons, and months of the year. Most 6- and 7-year-olds in the populations that have been studied can correctly order a set of cards representing the seasons (Friedman, 1977), and 7- and 8-year-olds, respectively, can recite the days of the week and months in order (Friedman, 1986). But the ability to recite the days and months does not mean that children are able to think flexibly about relative times of occurrence within the week and the year. Only in mid-adolescence does it become possible to solve backward-order problems similar to those that 6-year-olds can solve for daily activities (e.g., "If it's Saturday and you go backward in time, which will you come to first, Thursday or Tuesday?"). A number of findings indicate that adolescents develop mental images of the days of the week and months of the year that allow them greater flexibility in detecting relations between the days or months than the verbal-list representations they initially acquire (Friedman, 1986).

The developmental pattern is different when children learn calendar systems that number the days and months instead of assigning them nonnumerical names. In China, the names of the days of the week (except Sunday) include numbers, as do the names of the months. Kelly, Miller, Feng, and Feng (1999) conducted a study with Chinese and American second and fourth graders and adults to determine whether the presence of numbers in names for times leads to the use of different strategies than that were found in Friedman's (1986) study. Participants were asked to name the day or month that is a particular number of units before or after a stimulus day or month. The results showed that although some Chinese second and fourth graders used the verbal-list process that predominates at these ages in American children — activating and counting each intervening day or month — most used calculation strategies. For example, if the task was to find the month that is seven months after January, they would add seven to one to arrive at month eight as the answer. The availability of numerical names led to faster and more accurate responses by the Chinese than the American children. These findings show that the tools a culture provides to structure time have a strong influence on the representations and processes that children use to adapt to these time patterns.

In addition to mastering the main features of the calendar, adolescents also understand the ages at which some major life events usually take place (Nurmi, 1989, 1991; Nurmi, Poole, & Kalakoski, 1994). For example, when asked to report their hopes and dreams and then to judge the ages at which they expected them to be realized, adolescents chose ages in their 20s that reflected the normative sequence of finishing one's education, getting a job, and getting married. (Interestingly, hardly any adolescents expressed hopes that they expected to attain after age 30.) Although we do not know the nature of the underlying representations, it is clear that adolescents are able to think about times of life over about the next decade.

11.2. Understanding the Developmental Pattern

The variety of topics discussed in this chapter shows that children's adaptation to time involves a wide range of abilities, from perception of the durations and order of very brief events to the representation of annual cycles and even the lifespan. St. Augustine's question cannot be answered in a simple way, because time never becomes an integrated concept. From a psychological point of view, time is many different things: sequences of events; natural and conventional time patterns; the distinction between the past, present, and future; and relations between duration and succession, speed, and distance; to name only a few (see Chapter 1). We have also seen that the process of adaptation to temporal features of the natural and cultural environments is a protracted one, with some abilities present in early infancy and others emerging in adolescence or later.

Despite the paucity of relevant evidence, it may be worth sketching some ideas about why particular temporal abilities appear when they do. I will propose a distinction between psychological mechanisms that have been shaped by evolution to process temporal information and other more general-purpose cognitive processes that children learn to apply to time.

11.2.1. Biologically Based Temporal Abilities

A number of the temporal abilities that appear early in human development are also found in other species, and they probably depend on specific biological mechanisms. One is the ability to develop expectations about the lengths of brief, repeated durations. In the section on time perception, we saw that infants and young children form representations of durations on the order of several seconds, representations that influence infants' visual expectancies and that young children can use to make explicit judgments. It was also noted that there is an extensive literature showing similar timing abilities in other animals. In the animal literature, these abilities have been attributed to special biological mechanisms that measure intervals and retain the measurements. It seems very likely that the same mechanisms are operational early in human development.

We also saw that infants and young children attend to the order of brief events, such as sequences of words, audiovisual displays of objects falling, and sequences of modeled actions. Recent research has shown that rats are also to remember the order of brief experiences, in their case the sequence of a series of odors (Eichenbaum, Fortin, Ergorul, Wright, & Agster, 2005). Humans' sensitivity to the order of auditory stimuli may be rooted in mechanisms adapted to the processing of linguistic input, but the capacity to represent the sequences of actions and other visual events may rely on separate order-encoding mechanisms, perhaps ones related to those that allows rats to remember the order of a sequence of odors.

A third ability, found at least by early childhood, was described in the section on children's differentiation of the past: the capacity to discriminate the ages of events on the order of days to months in the past (called distance information). Studies with a bird species, scrub jays (e.g., Clayton & Dickinson, 1998; De Kort, Dickinson, & Clayton, 2005), have revealed what may be a related ability. Clayton and her colleagues have found that jays can discriminate between different ages of events (e.g., ones that happened 4 h versus 5 days earlier), the hiding of particular foods. It seems unlikely that humans' and jays' abilities to discriminate ages on these long time scales depend on the same interval-timing mechanisms that underlie perception of durations on the order of seconds. We do not yet know what brain processes create information about the ages of memories, but it may be that humans' and jays' discriminations on these long time scales rely on similar neural mechanisms (Friedman, 2007).

11.3. General Cognitive Mechanisms Applied to Time

Representations and processes. Nontemporal cognition depends on a rich array of cognitive, linguistic and other processes, and many of these same processes are used to adapt to temporal features of the environment. Included in this category are the representation of word meanings (and semantic memory in general), episodic memory, and imagery. The ages at which these processes are applied to time probably depend on the intrinsic development of the processes themselves, social influences, and individuals' histories of temporal problem solving.

By early childhood linguistic and semantic-memory processes enable children to begin to acquire temporal adverbs (e.g., *tomorrow*, *last night*) and to learn basic facts about time (e.g., that summer is hot). Young children also can retain for days or weeks adults' statements about which events are coming soon and which will not occur for a long time (e.g., that their birthday is coming soon, or that Christmas is not for a long time), contributing to an early, partially differentiated sense of the future. Of course, these same representations and processes underlie the acquisition of new information throughout later development (e.g., the number of months in the year, the meaning of *Daylight Savings Time*). Furthermore, the meanings of particular words change over time: They become freed from the particular contexts in which they were first acquired and often become linked to representations of time patterns. A child might learn early that Sunday is pancake day but only later develop representations of the days of the week that allow her or him to understand when Sunday occurs relative to other days.

A different language-related ability is also applied to different contents at different ages. Through repeated practice humans can memorize long word sequences. When parents and teachers encourage such practice, even young children learn ordered strings of many words, such as counting numbers and letters of the alphabet. Although the same basic abilities apply, children in Western societies do not usually learn the order of the days of the week and months of the year until middle childhood. The capacity is present by early childhood, but the timing of direct teaching determines the ages at which these verbal-list processes are applied to particular temporal contents.

Another basic cognitive process is mental imagery. As we have seen, children appear to use imagery to represent the relative times of occurrence of main daily activities by about 5 years. But it is not until about 15 years of age that we find evidence for the use of images of the relative times of the days of the week and of the months of the year. Here, there is no reason to think that direct teaching is responsible for the developmental pattern, because most children are probably not taught to represent the parts of a day, days of the week, and months in this way. The ages at which imagery emerges for these contents may be better explained by individual children's history of mental operations and the form of mental representation — imagery — that best captures the structure of the content (Friedman, 1986, 1989, 1990). As noted earlier, temporal orientation within the day probably occurs hundreds of times in early childhood. In contrast, it is not until much later that a similar number of instances of orientation within the week and year are likely to have been accumulated. Adults' repeated requests that children recite the days of the week and months may even delay the development of more flexible, image representations. Imagery may eventually prevail for many kinds of temporal problem solving because of its advantage in capturing information about the relative times of occurrence of the elements of temporal patterns. In general, individuals' representations and processes seem to develop towards forms that are effective in solving repeatedly encountered problems.

A variety of general attentional and memory processes also contribute to humans' adaptation to time (see Chapters 4 and 12). Impressions of amounts of time are available to children by early childhood, as seen in 4-year-olds' ability to judge the duration of familiar events. Studies of duration perception show that at least by 8 years of age, impressions of durations are influenced by manipulations that affect attention, supporting the conclusion that attention to internal and external changes provides children with information about amounts of time. Another example is that the processes underlying episodic memory provide children, like adults, with some of the raw materials they need to reconstruct the times of remembered events. Children as young as 4-year-olds can begin to use their memories of the contents of events (e.g., where they occurred) to infer in what part of the day they happened, and older children can use memory for context to reconstruct times on longer time scales. Here, the developmental timing seems to be influenced by age changes in children's semantic knowledge about time (Friedman & Lyon, 2005).

The gradual development of concepts. Although we would like to be able to answer questions about when children acquire a particular concept with a single age, developmental research shows that most important concepts develop over many years (Siegler, 1991). In the case of time, there are numerous examples of concepts that children begin to acquire in early childhood but that are substantially enriched over the succeeding years. Children begin to recognize the past–present–future distinction in early childhood, but a conceptual understanding does not appear until at least 6 years, and differentiation of the times of past and future events continues well into middle childhood. By 5 years children can compare two durations using start and stop times in simple situations, but it is not until middle childhood or later that they recognize these as the crucial items of information when there are conflicting spatial cues.

What is responsible for the protracted development of such concepts? In some cases one temporal concept cannot develop fully until children possess adequate representations of time patterns. This is true for children's differentiation of the past and the future, where learning about long conventional time patterns provides a framework for structuring a child's own past and future. We have also seen how a child's history of mental operations can influence developmental timing: It may take many years of thinking about given types of problems for concepts to attain forms that are flexible, free of internal contradictions, and applicable to a broad range of contexts. It is very likely that a third factor, the complexity of the concepts and their interaction with age-related limits in children's brain development and information-processing capacity, also contributes to the ages at which children understand particular aspects of time. Such changes might explain why children grasp the direct relations between duration and distance and between distance and speed before they can systematically relate all three dimensions. In any case it is clear that children do not wait until they have the capacity to understand all of the complexities of the temporal environment before they begin to learn about them. From infancy onward, the social and physical environments are rich sources of temporal information, and children attempt to adapt to them.

Uncited References

Block, Zakay, and Hancock (1999); Harner (1982); Nelson (1986).

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