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Time perception in children: A neurodevelopmental approach

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ABSTRACT

In this review, we discuss behavioral studies on time perception in healthy children that suggest the existence of a primitive "sense" of time in infants as well as research that has revealed the changes in time judgments that occur throughout childhood. Moreover, a distinction is made between implicit and explicit time judgments in order to take account of the different types of temporal judgments that emerge across ages. On the basis of both the neurobiological model of the internal clock proposed by Matell and Meck (2000), and of results of imaging studies in human adults, we then try to identify which of the neural structures underlying this primitive sense of time mature faster and which mature more slowly in order to explain the age-related variance in time judgments. To this end, we also present the small number of timing studies conducted among typically and non-typically developing children that have used functional magnetic resonance imaging (fMRI) as well as those that have assessed the cognitive capacities of such children on the basis of various neuropsychological tests.

A la poursuite du temps!

Influenced by the philosophical conception of time, psychologists initially suggested that time is not a primitive dimension that can be directly perceived, but rather one which is inferred from the coordination of movements in space (Piaget, 1946). However, numerous studies have gathered data demonstrating that animals (rats or pigeons), which have no sophisticated reasoning capacities, are able to estimate temporal intervals accurately (e.g., Catania, 1970; Dews, 1970; Stubbs, 1968). In addition, their perception of time conforms to Weber's law as does the perception of certain other sensory dimensions. Time estimates are on average accurate (mean accuracy) and the variability in estimates (S.D.), i.e., sensitivity to time, increases linearly with the length of the intervals to be timed (scalar property). Since the publication of these results on animal timing, most researchers have come to agree that human beings and animals must all share a "sense" of time together with its hallmark characteristic: the scalar property. The ability to estimate time is therefore thought to be universal. In this review, we will discuss behavioral studies on time perception in healthy children suggesting the existence of a primitive "sense" of time in infants, and those showing the changes in time judgments that occur throughout childhood. Then, on the basis of the neurobiological model of the internal clock proposed by Matell and Meck (2000, 2004) and the results of imaging studies in human adults, we will try to identify which of the neural structures underlying this primitive sense of time mature earlier and which mature later in order to explain age-related variance in time judgments. To this end, we will present the small number of timing studies that have been conducted in typically and non-typically developing children using functional magnetic resonance imaging (fMRI), as well as those that have assessed such children's cognitive capacities on the basis of various neuropsychological tests.

1. Behavioral studies on time perception in children

1.1. Infants' timing abilities

From the moment of their birth, infants are immersed in time. Everything that they see or do evolves in time. Every day, they therefore experience the dynamic temporal structure of a wide variety of events and actions. For example, they experience the temporal dynamic of social interaction with their mother. They experience the period needed for the mobile hanging over their bed to stop moving. Using a variety of paradigms, researchers have thus been able to demonstrate that infants are able to learn the temporal intervals between two events as well as the durations associated with events.

The first studies showing infants' abilities to time temporal intervals used behavioral learning procedures based on temporal conditioning (for a review, see Pouthas, Droit, & Jacquet, 1993). The most frequently cited study in this domain is that conducted by Brackbill and Fitzgerald (1972) in infants aged 1 month. In this study, the infants were placed in a dark environment in which every

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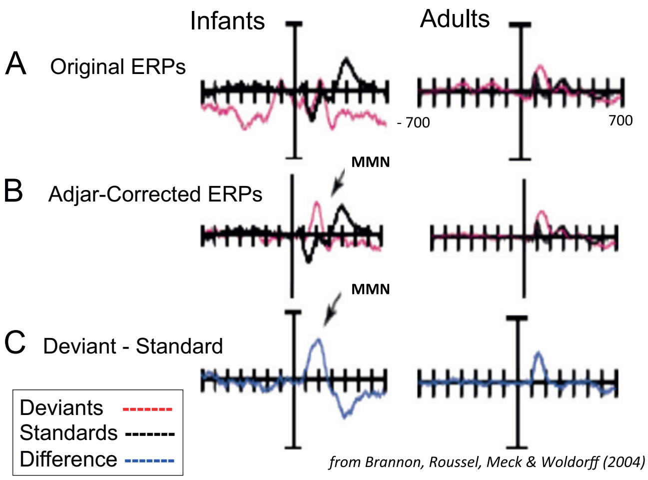

Fig. 1. The infant brain's reaction to temporal deviants. Data are from electrode FZ. Negative potentials are plotted upward. Each tickmark represents 100 ms. A. Responses to tones that followed the deviant (red) and standard (black) ISI for infants (left) and adults (right). Note the prestimulus distortion in the infant deviant waveform. (B) Deviant and Standard waveforms after Adjar correction. Note the relatively quiet prestimulus baseline. (C) Difference between deviant and standard waveforms. The MMN is visible between 100 and 200 ms. (Reproduction of Fig. 1 from Brannon et al. (2004)).

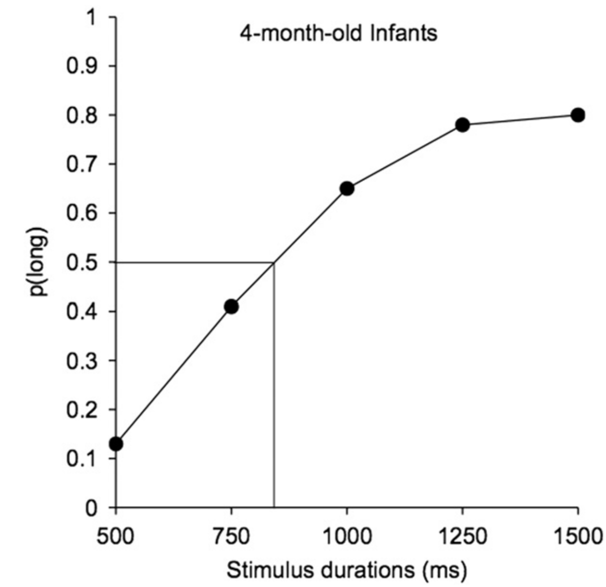

Fig. 2. Time bisection in 4-month-old infants. Proportion of long responses plotted against stimulus duration (from Provasi et al. (2010)).

20 s, the light was switched on for 4 s. This light change produced an autonomic pupillary constriction reflex. After a learning phase, Brackbill and Fitzgerald introduced test trials without light change and observed that pupillary constriction continued to occur at the 20-s interval. This temporal conditioning of the pupillary reflex demonstrates that infants are able to learn a given temporal interval between two events. Other studies have since shown that infants' heart rates slow down each time a stimulus is omitted in a sequence of repetitive stimuli (Clifton, 1974; Colombo & Richman, 2002). More recently, Brannon, Roussel, Meck, and Woldorff (2004) have shown that an infant's brain reacts in exactly the same way as an adult's brain to temporal deviations in a repetitive sequence of auditory stimuli. Fig. 1 shows the event-related potentials (ERPs) recorded in 10-month-old infants and adults for a standard inter stimulus interval (ISI) of 1.5 s and certain deviant ISIs of 0.5 or 0.75 s. As illustrated in Fig. 1, infants, like adults, exhibit a clear mismatch negativity (MMN), i.e., an ERP component of negative polarity that peaks between 120 and 200 ms after the onset of deviance. In addition, Brannon, Libertus, Meck, and Woldorff (2008) tested infants with different ratios between the standard and the deviant ISI (e.g., 0.5 vs. 1.5 s, 0.75 vs. 1.5 s or 1.0 vs. 1.5 s), and found that the amplitude of the MMN increased as the disparity between these two intervals grew, in conformity with the scalar property. Overall, these results show that infants automatically detect temporal irregularities in a repetitive sequence of stimuli.

Using conditions of learning by habituation in infants aged 6 and 10 months, VanMarle and Wynn (2006) and Brannon, Suanda, and Libertus (2007) have also succeeded in showing that infants are able to estimate the duration per se of an event. In their studies, the authors recorded the time infants spent looking at an event displayed for a standard duration (e.g., 2 s), e.g., a Sylvester the cat figure that moved his head from right to left while producing a sound of a given duration (first study), or a cow puppet that opened and closed its mouth for a given duration (second study). In these two studies, once habituation had occurred, as evidenced by a significant decrease in looking time, the infants were presented with the same events for either the same (2 s) or a different duration (4 s). An increase in looking time was then observed only for the new event duration. In other words, the infants reacted to the new duration, thus indicating that they had learned the duration associated with the event. In addition, this reaction to the new duration occurred for different ratios between durations regardless of their absolute values (i.e., 0.5 vs. 1 s, 2 vs. 4 s and 1.5 vs. 3 s). This clearly demonstrates that the ability of infants to discriminate durations obeys Weber's law and is proportional rather than absolute.

More recently, Provasi, Rattat, and Droit-Volet (2010) adapted the well-known temporal bisection task, extensively used in animals and human adults (Allan & Gibbon, 1991; Church & Deluty, 1977; Wearden, 1991), for use with infants aged only 4 months. The infants in this study were initially presented with two sounds, one short (S=0.5 s) and one long (L=1.5 s), and were trained to look to the right or left side of a screen after S and L, respectively. In this training phase, a correct response (e.g., looking to the right for S) resulted in the immediate appearance of a picture (reinforcement) on the corresponding side of the screen. During the test phase, the infants were then presented with non-reinforced intermediate sound durations (0.75, 1.0, 1.25 s) as well as the standard durations followed by the reinforcement after an interval of 3 s. The first look to the right, to the left, or elsewhere, and the time spent by the infants looking in these directions for the period of 3 s were recorded. In this adapted temporal bisection task, the 4-month-olds exhibited orderly psychophysical functions with the proportion of long responses increasing with the target duration (Fig. 2) in the same way as been observed in animals and human adults. In line with the idea that timing is a basic ability that is indispensable for learning and for adaptation to our environment, there is thus ample evidence that infants can time temporal intervals at an early age or, in other words, that they possess a "primitive sense" of time. Consequently, it seems reasonable to suppose that the cerebral mechanism underlying this sense of time matures early or/and is functional at an early age. The question that we will address below relates to the nature of this neural mechanism.

1.2. An improvement in time sensitivity during childhood

Despite the fact that children have a primitive sense of time which exhibits scalar properties (mean accuracy, scalar variance), numerous studies have observed an improvement in time judgments throughout childhood (for a recent review, see Allman, Pelphrey, & Meck, 2012; Droit-Volet, 2011; and for a meta-analysis, see Block, Zakay, & Hancock, 1999). Studies that have