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Distinct developmental trajectories for explicit and implicit timing

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ABSTRACT

Adults and children aged 5 and 8 years were given explicit and implicit timing tasks. These tasks were based on the same temporal representation (the temporal interval between two signals), but in the explicit task participants received overt instructions to judge the duration of the interval, whereas in the implicit task they did not receive any temporal instructions and were asked only to press as quickly as possible after the second signal. In addition, participants' cognitive capacities were assessed with different neuropsychological tests. The results showed that temporal variability (i.e., the spread of performance around the reference interval) decreased as a function of age in the explicit task, being higher in the 5-year-olds than in the 8-year-olds and adults. The higher variability in the youngest children was directly linked to their limited cognitive capacity. By contrast, temporal variability in the implicit timing task remained constant across the different age groups and was unrelated to cognitive capacity. Processing of time, therefore, was independent of age in the implicit task but changed with age in the explicit task, thereby demonstrating distinct developmental trajectories for explicit and implicit timing.

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Introduction

There is now ample evidence of an improvement in time judgment throughout childhood (Allman, Pelphrey, & Meck, 2012; Droit-Volet, 2011, 2016; McCormack, 2015). Developmental studies have shown an increase in temporal sensitivity from the age of 3 years to young adulthood, with temporal sensitivity approaching that of adults at around 8 to 10 years. Although young children's time judgments are accurate, with mean estimates close to the target duration, they are indeed significantly more variable (i.e., greater trial-by-trial variability in time estimates). The greater variability of temporal performance in young children has been recently associated with age-related differences in cognitive abilities. In a series of neuropsychological studies, Droit-Volet and Zélanti assessed children's cognitive capacities in terms of working memory, attention, and information processing speed. They systematically found significant correlations between these cognitive capacities and sensitivity to time; the lower the cognitive capacity, the higher the temporal variability (Droit-Volet & Zélanti, 2013a, 2013b; Zélanti & Droit-Volet, 2011, 2012). In addition, it appears that working memory and attentional capacity are better predictors of developmental differences in sensitivity to time than is age. The improvement in executive control processes during childhood, thus, plays a critical role in age-related differences in time judgment.

The critical role of cognitive capacity in time judgment can be explained in great part by the types of timing task used with children, that are directly derived from those used in adults. In these tasks, participants receive explicit instruction to process temporal information. For example, in the temporal generalization task, they are presented with a reference duration and are taught that they must learn this duration. They are then presented with probe durations (shorter, longer, or equal) and are instructed to compare these durations with the memorized representation of the reference duration to overtly judge whether or not they are the same. In explicit timing tasks, thus, participants are made consciously aware of the temporal aspects of the task and are required to process time intentionally. Consequently, they deliberately allocate attention to the passage of time during stimulus presentation and consciously recall the reference duration for comparison purposes. In other words, executive control functions are required for the conscious processing of temporal information (Cleeremans & Jiménez, 2002; Kahneman & Treisman, 1984; Reber, 1992). Consequently, the reported changes in sensitivity to time during childhood may be largely due to age-related improvement in cognitive capacities involved in the conscious monitoring of temporal information in working memory. The voluntary manner by which temporal information is processed in these tasks, and its underlying cognitive mechanisms, therefore, is likely to influence the developmental course of time judgments.

Unlike explicit time judgment tasks, participants are unaware of processing time during implicit timing tasks. For example, when participants experience the temporal regularity of a sensory input, they can spontaneously adapt their behavior to its temporal structure (e.g., clapping along to the beat). The temporal regularity allows them to build a temporal template of the repeated interval, which can be used to predict the time at which the next event will appear. Thus, there is an acquisition of temporal knowledge that is independent of awareness. This has also been widely demonstrated in studies of animals and infants who are capable of estimating temporal intervals despite a lack of temporal reasoning ability. For example, in classical temporal conditioning paradigms, infants automatically react (e.g., pupillary dilatation, heart rate deceleration) to the omission of an event presented at regular intervals (e.g., Brackbill & Fitzgerald, 1972; Colombo & Richman, 2002). Other studies using the standard habituation procedure have also observed infants' reactions to differences in the presentation duration of events (Brannon, Libertus, Meck, & Woldorff, 2008; Brannon, Roussel, Meck, & Woldorff, 2004; De Hevia, Izard, Coubart, Spelke, & Streri, 2014; VanMarle & Wynn, 2006). Thus, infants are able to automatically process temporal intervals, enabling them to predict and anticipate incoming events. Therefore, there is a primitive form of temporal processing that emerges very early in development. However, the tasks used in infants are very different from those used in adults and verbal children, and they reflect the functional distinction between implicit and explicit timing, respectively (temporal prediction of regular events vs. overt temporal judgment) (Ameqrane, Pouget, Wattiez, Carpenter, & Missal, 2014; Coull & Nobre, 2008; Merchant, Zarco, Bartolo, & Prado, 2008; Spencer & Zelaznick, 2003; Zelaznik, Spencer, & Ivry, 2002). Explicit and implicit timing tasks also recruit distinct neural