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Cognitive abilities explaining age-related changes in time perception of short and long durations

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ABSTRACT

The current study investigated how the development of cognitive abilities explains the age-related changes in temporal judgment over short and long duration ranges from 0.5 to 30 s. Children (5- and 9-year-olds) as well as adults were given a temporal bisection task with four different duration ranges: a duration range shorter than 1 s, two duration ranges longer than 3 s (4–8 s and >15 s), and an intermediate duration range (1.25–2.5 s). Their cognitive abilities were also assessed using a series of neuropsychological tests. The results showed that temporal sensitivity improved with age for each duration range but that this improvement occurred earlier for the short durations than for the long durations. Furthermore, the results revealed that the age-related improvement in time sensitivity for the durations shorter than 1 s was explained by the development of short-term memory span, whereas that for long durations was explained by the development of attention/executive functions. To summarize, the development of the abilities required to process long durations seems to be explained mainly by the development of attentional resources.

Introduction

Time is a fundamental dimension of everyday life that children experience at an early age. Recent studies have shown that, as of 4 months of age, infants are able to discriminate event durations (Brannon, Suanda, & Libertus, 2007; Provasi, Rattat, & Droit-Volet, 2010; VanMarle & Wynn, 2006) and to detect a temporal deviation in the rhythmical presentation of sounds (Brannon, Libertus, Meck, & Woldorff, 2008; Brannon, Wolfe, Meck, & Woldorff, 2004). At 3 years of age, children's behavior also exhibits

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the fundamental properties of time perception found in human adults and animals, that is, mean accuracy and the scalar property of variance (Droit-Volet, Clément, & Wearden, 2001; Droit-Volet, Meck, & Penney, 2007; Droit-Volet & Wearden, 2001). Indeed, their estimates vary accurately in line with real time, and the variability of these estimates (i.e., standard deviation) grows proportionally with the duration value. Consequently, the coefficient of variation of estimates—the Weber ratio (*WR*)—remains constant for different duration ranges, demonstrating that young children's perception of time obeys Weber's law. Overall, these results suggest that the neural mechanism (i.e., clock system) that enables children to estimate time is functional as of an early age (Brannon et al., 2008; Droit-Volet & Wearden, 2002).

However, the idea that the neural clock system is able to function at an early age is not incompatible with age-related variations in the processing of time. Indeed, temporal judgments result not only from an internal clock but also from the complex interaction among several different cognitive processes. Recently, a number of researchers have even suggested that time might be an emergent property of the neural dynamics of the brain and might not be dependent on a dedicated timing mechanism (Ivry & Schlerf, 2008; Mauk & Buonomano, 2004; Wittmann, 1999). In the scalar timing models, which are the most influential models of timing, temporal judgment is considered as the outcome of an interaction among an internal clock, memory abilities, and decisional processes (e.g., Gibbon, Church, & Meck, 1984; Treisman, 1963). According to these models, the raw material for duration comes from an internal clock that accumulates pulses emitted by a pacemaker during the stimulus to be timed. Memory processes then retain the current duration and store significant durations in reference memory, whereas decisional processes compare these two durations to provide a temporal judgment. In addition, the processing of time has been demonstrated to demand attentional resources. When attentional resources are diverted away from the processing of time, fewer pulses are accumulated and the duration is judged to be shorter (e.g., Brown, 1997; Coull, Vidal, Nazarian, & Macar, 2004). To summarize, changes in any of the cognitive components—memory, decision, or attention—may result in age-related variations in time discrimination.

However, a debate is currently under way concerning the distinct cognitive processes involved in the estimation of short and long durations, with the idea being that attention is primarily involved in the processing of long durations during which it is necessary to expend greater mental effort in order to keep track of the passage of time. Although the debate is still unresolved, an outline consensus according to which the boundary lies at approximately 1 s has emerged (e.g., Ivry & Schlerf, 2008; Lewis & Miall, 2009; Rammsayer, 1994). Fraisse (1984) and Pöppel (1997) placed the boundary between the temporal processes at a longer duration of approximately 2 to 3 s, below and above which they talked about time perception (psychological present) and time estimation, respectively. Whatever the case, the processing of short durations seems to be more automatic and less dependent on attentional capacities. For instance, Rammsayer and Lima (1991) showed that short durations (500 ms), unlike longer durations, were not affected by a concurrent cognitive task. Neuroimaging studies have also shown that the prefrontal cortex (right hemispheric dorsolateral prefrontal cortex), which plays a fundamental role in high-level cognitive capacities, is specifically activated during the processing of durations longer than 1 s (Ivry & Schlerf, 2008; Lewis & Miall, 2006; Meck, Penney, & Pouthas, 2008). Therefore, the purpose of the current study was to investigate what dimensions of cognitive development assessed by neuropsychological tests explain the age-related variations in the discrimination of short and long durations.

Recently, the development of temporal discrimination has been examined systematically using the temporal bisection task, which is a task that is easy to use in young children and has been used extensively both in animals (Church & Deluty, 1977) and in human adults (Allan & Gibbon, 1991; Wearden, 1991). In the temporal bisection task, children are initially presented with short (*S*) and long (*L*) anchor durations. They are then presented with comparison durations (*t*) that either are the same as or lie between the anchor durations. Children's task is to categorize *t* as more similar to *S* or to *L*. In this task, the results are represented in the form of a psychophysical function, with the proportion of long responses, *p*(long), being plotted against the comparison durations. The psychophysical functions that have been found in young children are orderly (i.e., *p*(long) increases with the stimulus duration value), thereby revealing their ability to discriminate time (Droit-Volet, 2008; Droit-Volet & Izaute, 2009; Droit-Volet, Tourret, & Wearden, 2004; McCormack, Brown, Maylor, Darby, & Green, 1999). However, they appear to be flatter in younger children (3- and 5-year-olds). The associated *WR* value