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Time keeping and working memory development in early adolescence: A 4-year follow-up

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ABSTRACT

In this longitudinal study, we examined time keeping in relation to working memory (WM) development. School-aged children completed two tasks of WM updating and a time monitoring task in which they indicated the passing of time every 5 min while watching a film. Children completed these tasks first when they were 8 to 12 years old and then 4 years later when they were 12 to 16 years old. Time keeping in early adolescence showed a different pattern of outcome measures than 4 years earlier, with reduced clock checking and increased timing error. However, relative changes in WM development moderated these adverse effects. Adolescents with greater relative gains in WM development were better calibrated than participants with less developing WM functions. We discuss these findings in relation to individual and developmental differences in executive control functions and socioemotionally driven reward seeking.

Introduction

Time keeping concerns the coordination and synchronization of the subjective experience of time's passing with some type of standard and is intimately associated with complex goal-directed behavior. Time keeping often involves balancing the cost of monitoring against the cost of having inaccurate information about the environment (Atkin & Cohen, 1996; Ceci & Bronfenbrenner, 1985; Harris & Wilkins, 1982; see also Mäntylä & Carelli, 2006, for an overview). It also involves judging available resources accurately for selecting a realistic strategy. Furthermore, the monitoring strategy itself needs to be evaluated and updated. It also reasonable to assume that time keeping in complex task

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conditions (cf. multitasking or remembering multiple intentions) may reflect individual and developmental differences in executive control functions.

Mäntylä, Carelli, and Forman (2007) provided direct support for the notion that time monitoring is closely related to individual and developmental differences in executive control functions (see also Carelli, Forman, & Mäntylä, 2008; Mackinlay, Kliegel, & Mäntylä, 2009). In their study, school-aged children and young adults indicated the passing of time every 5 min while watching a DVD film. Participants also completed six experimental tasks that tapped three basic components of executive functioning: inhibition, updating, and mental shifting. Both children and adults showed accelerating monitoring functions, with low rates of clock checking during the early phase of each 5-min interval. However, compared with adults, children needed more clock checks for obtaining the same level of monitoring accuracy. Separate analyses of the executive functioning data yielded a two-factor solution for both age groups, with the updating and inhibition tasks constituting a common factor and the shifting tasks constituting a separate factor. Individual differences in executive functioning had selective effects on time-based prospective memory performance. In both children and adults, monitoring performance was related to the working memory (WM) component (i.e., updating and inhibition), but not to the shifting component, of executive functioning.

Mäntylä and colleagues (2007) interpreted these findings to suggest that the functional role of subjective sense of time is to initiate time keeping when more specific temporal information is needed closer to the deadline. Instead of relying on absolute duration estimates, even category-level temporal information (e.g., "not yet-soon-now") might be sufficient to minimize early clock checking and to reduce monitoring costs in most goal-directed tasks. This type of adaptive monitoring strategy might be mediated by processes related to the maintenance and updating of WM contents. Following the notion that updating and retaining dynamic event information in WM contributes to a sense of temporal continuity (Carelli et al., 2008; Jonides & Smith, 1997), individuals with efficient updating functions would be able to rely on this temporal information when monitoring deadlines. By contrast, individuals with difficulties in temporary maintenance and elaboration of WM contents may experience discontinuities in sense of time, leading to an increased dependence on external time keeping.

Following this line of reasoning, the aim of this study was to examine time keeping in relation to WM development in early adolescence. Past studies suggest a continuous increase in WM performance from early childhood to adolescence (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004; Luciana, Conklin, Hooper, & Yarger, 2005), and these functional developments have been linked to structural changes (e.g., Kwon, Reiss, & Menon, 2002; Luna, 2009; Sowell, Delis, Stiles, & Jernigan, 2001). However, knowledge about WM development in school-aged children is still limited, and the few existing studies are based on cross-sectional comparisons (see also Best, Miller, & Jones, 2009, and Garon, Bryson, & Smith, 2008, for overviews).

Taken together, past research suggests that WM and related higher order cognitive functions continue to develop even after late childhood and that individual and developmental differences in these control functions mediate complex goal-directed tasks such as time-based prospective memory. Following these observations, it is reasonable to hypothesize that both time keeping and executive functioning are more efficient (and "adult-like") in early adolescence than in childhood. Specifically, we expected that adolescents (with better WM functions than 4 years earlier) would show more efficient monitoring behavior with less frequent monitoring (and reduced monitoring costs) while maintaining the same level of response accuracy.

To examine WM development and its relation to time keeping, we report a 4-year follow-up to Mäntylä and colleagues' (2007) study. Specifically, school-aged children, who were 8 to 12 years old during the first test occasion and 12 to 16 years old during the second test occasion, completed two tasks of WM updating and a time monitoring task in which they indicated the passing of time every 5 min while watching a DVD film. The updating tasks were identical in both occasions except for differences in overall task difficulty. Specifically, because some of the children performed close to ceiling already 4 years earlier, it was necessary to use more demanding versions of the two updating tasks during the second test occasion. Consequently, instead of examining absolute changes in WM performance, our primary interest here was in relative changes. In addition to overall age effects, we hypothesized that children with more developed WM functions would show more efficient time keeping performance than children showing less development of the same. The time monitoring task was