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Bidirectional interference between timing and concurrent memory processing in children

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ABSTRACT

This study investigated the nature of resources involved in duration processing in 5- and 8-year-olds. The children were asked to reproduce the duration of a visual or auditory stimulus. They performed this task either alone or concurrently with an executive task (Experiment 1) or with a digit or visuospatial memory task (Experiment 2). The results showed that duration reproduction was systematically shorter in the dual-task condition than in the single-task one. Furthermore, timing an auditory stimulus decreased the proportion of accurate responses in the executive and digit memory tasks but not in the visuospatial memory task, whereas timing a visual stimulus decreased the proportion of accurate responses in the executive and visuospatial memory tasks but not in the digit memory task, at least to a lesser extent in the older children. This pattern of interference suggests that duration reproduction in children requires both the central executive and the slave memory system associated with the modality of the temporal stimulus.

Introduction

The underlying processes of time estimation have always intrigued psychologists (James, 1890), certainly because time is one of the dimensions that govern much of human behavior. Most timing researchers assume that humans possess an internal clock-like system that they can use to measure time (for a review, see Wearden, 2005). Moreover, recent studies have suggested that this internal clock is functional at a very early age (Brannon, Roussel, Meck, & Woldorff, 2004; Droit-Volet, 2003a; Droit-Volet, Clément, & Fayol, 2003; Droit-Volet & Wearden, 2001; see also Droit-Volet,

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2003b, for a review). Although the exact nature of this internal mechanism is still not fully understood, especially with regard to the brain structures involved (Lewis & Miall, 2003; Meck & Malapani, 2004), there is a general agreement that it involves an accumulator system. More specifically, in classic internal clock models (e.g., Gibbon, Church, & Meck, 1984), a pacemaker continuously emits pulses that are accumulated into an accumulator through an attention-controlled switch that opens and closes at the beginning and end of the estimated duration. The number of pulses accumulated during the event being timed is the internal representation of the event duration; the more pulses that are accumulated, the longer the perceived duration. However, time judgment also relies on memory and decisional processes. Indeed, the internal representation of the event duration is then stored in short-term working memory and can then be transferred into long-term reference memory, which stores important times (e.g., standard durations important for the current task). Final temporal judgment results from a comparison between the just-presented duration and the durations stored in reference memory.

According to this theoretical approach, duration is processed just like any other type of information. As such, its processing requires cognitive resources. This idea has been extensively supported by dual-task studies showing that parallel processing of a temporal task and a nontemporal task impairs duration estimation, leading participants to systematically underestimate durations (e.g., Brown & Merchant, 2007; Casini & Macar, 1997; Champagne & Fortin, 2008; Kladopoulos, Hemmes, & Brown, 2004; Predebon, 1996; Sawyer, 2003). This subjective shortening of perceived durations under dual-task conditions is widely taken as evidence that temporal processing requires working memory resources that are also needed by the concurrent nontemporal task. However, although it is well established that temporal information processing draws on working memory resources, much remains to be uncovered about the nature of these resources. Identifying the resources involved in time estimation is an important issue within the context of a multiple-resource memory model such as Baddeley and Hitch's (1974) original working memory model. According to this model, working memory comprises three components: the central executive, phonological loop, and visuospatial sketchpad. The latter two components are slave systems specializing in processing and handling limited amounts of verbal or visuospatial information-typical images. In contrast, the central executive is an attentional controller mechanism responsible for a range of high-level functions, including the sharing of attentional resources between the two slave systems and the coordination and scheduling of processes in dual-task situations.

In classic internal clock models, time refers to a continuous flow of information that can be tracked only by dint of constant attentional effort. Thus, we can logically expect the central executive component of working memory to play a role in temporal information processing. Recent studies have yielded empirical data that are consistent with this assumption (Brown, 1997, 2006; Brown & Frieh, 2000; Fortin, Champagne, & Poirier, 2007; Rammsayer & Ulrich, 2005). Brown (2006), for example, investigated bidirectional interference by pairing a timing task with an executive-level task. In his study, the timing task consisted in generating a series of 5-s temporal productions by pressing a button, whereas the central executive task consisted in verbally producing a continuous series of random numbers. In the dual-task condition, the adults' temporal productions were longer and more variable, and the randomization in the nontemporal task was poorer, compared with the single-task condition. Brown also suggested that adults' time estimation relies on executive-level resources rather than on resources dedicated to other specialized task demands such as visual and phonological processing.

However, recent data from adults raise questions about whether the processing of temporal information necessarily requires attentional control monitoring by the central executive. Franssen, Vandierendonck, and Van Hiel (2006) found that a task relying on the phonological loop without attracting attentional resources also affected time estimation. In their study, adults needed to reproduce or verbally estimate short tone durations (<4 s) in different phonological load-level conditions, namely no load, performing articulatory suppression, and listening to irrelevant speech, tones, or music. The results showed that articulatory suppression alone affected timing performance (i.e., the durations were systematically underestimated), suggesting that adults' time estimation is mediated by phonological working memory and the involvement of an active verbal rehearsal process. Nevertheless, the authors mentioned that it was still a matter of debate whether the concurrent active information processing in memory that leads to impaired time estimation also requires attentional