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The differential contribution of executive functions to temporal generalisation, reproduction and verbal estimation

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ABSTRACT

Evidence from dual-task studies suggests that executive resources are recruited during timing. However, there has been little exploration of whether executive recruitment is universal across temporal tasks, or whether different temporal tasks recruit different executive resources. The current study explored this further by examining how individual differences in updating, switching, inhibition and access affected performance on temporal generalisation, reproduction and verbal estimation tasks. It was found that temporal tasks differentially loaded onto different executive resources. Temporal generalisation performance was related to updating and access ability. Reproduction performance was related to updating, access and switching. Verbal estimation performance was only related to access. The results suggest that executive resources may be recruited when monitoring and maintaining multiple durations in memory at the same time, and when retrieving duration representations from long-term memory. The findings emphasise the need to consider timing behaviour as the product of a wide range of complex, integrated, cognitive systems, rather than as the output of a clock in isolation.

1. Introduction

Recent research has demonstrated that working memory, attention and executive functions are critical to temporal perception (Block, Zakay, & Hancock, 1998; Brown, 2006, 2014; Brown, Collier, & Night, 2013; Droit-Volet & Zélanti, 2013; Fortin, Schweickert, Gaudreault, & Viau-Quesnel, 2010; Mioni, Mattalia, & Stablum, 2013; Ogden, Salominaite, Jones, Fisk, & Montgomery, 2011; Perbal, Droit-Volet, Isingrini, & Pouthas, 2002; Pouthas & Perbal, 2004; Rattat, 2010; Wearden, Wearden, & Rabbitt, 1997; Zakay & Block, 2004; Zélanti & Droit-Volet, 2011, 2012). There remains, however, a lack of clarity regarding specifically which working memory and executive functions are involved in timing, and the extent to which their involvement is common to all temporal tasks. Consequently, this study aimed to explore how executive functions may be differentially involved in different timing tasks.

Research examining the involvement of executive resources in timing has generally used an interference paradigm in which performance on timing and non-timing tasks is compared under single and dual-task conditions (see Brown, 2006 for review). In a typical experiment a participant would complete a timing task, such as serial interval production, and an executive task, such as serial subtraction of sevens, alone and concurrently under dual-task conditions. Of key interest is bidirectional interference between the two tasks. Poorer performance on both tasks under dual than single-task conditions indicates that both tasks are competing for the same limited resources (Navon & Gopher, 1979). Such experiments have demonstrated bidirectional interference, confirming that timing is to some extent dependent on executive resources (Brown, 2006, 2014; Brown et al., 2013; Ogden, Salominaite, et al., 2011; Rattat, 2010).

Recent theoretical models of executive function suggest that the central executive is not a unified construct and is instead made up of different components (Fisk & Sharp, 2004; Miyake et al., 2000). Miyake et al. (2000) identified three component processes of the central executive; updating, inhibition and switching. Updating refers to an individual's ability to monitor incoming information and to update the contents of working memory accordingly. Inhibition refers to an individual's ability to inhibit a dominant or automatic response when it is inappropriate. Switching refers to an individual's ability to switch their attention between different tasks or different elements of the same task. Fisk and Sharp (2004) added a fourth component, access, which reflects the efficiency of access to semantic memory. The fractionation of the central executive into these component processes is supported by neuroimaging studies. For example, updating tasks

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activate the dorsolateral prefrontal cortex (DLPFC; Goldman-Rakic, 1996), inhibition is associated with prefrontal cortex activity (Casey et al., 1997; Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998), switching produces anterior cingulate (Posner & Raichle, 1994) and left frontal lobe activity (Rogers et al., 1998), and access to semantic memory is associated with left PFC activity (Kolb & Whishaw, 1985). In addition, the maintenance of working memory as a whole is related to the integrity of the PFC (Miyake et al., 2000). Recent research has sought to establish which of these component processes is recruited during timing (Brown et al., 2013; Ogden, Salominaite, et al., 2011), and the results are summarised below.

1.1. Updating

Brown and Frieh (2000) and later Ogden, Salominaite, et al. (2011) suggested that because updating requires the online maintenance, temporal tagging and replacing of information in working memory, updating resources are likely to be recruited during timing. This suggestion is generally supported (Brown & Frieh, 2000; Brown et al., 2013; Droit-Volet & Zélanti, 2013; Ogden, Salominaite, et al., 2011; Zélanti & Droit-Volet, 2011, 2012). Ogden, Salominaite, et al. (2011) explored how updating, inhibition, switching and access were involved in timing. A dual-task paradigm was employed in which participants completed serial production and executive tasks under single and dual-task conditions. Updating was assessed by Serial Subtraction of Sevens (SSS) in which participants have to serially deduct 7 from 385 or 368 (counterbalanced for single vs. dual-task), verbalising their response. Bidirectional interference was observed; when concurrently timing and performing SSS, temporal productions became longer and more variable and there were significantly fewer correct subtractions in the SSS task. Ogden, Salominaite, et al. (2011) therefore concluded that interval production requires updating resources.

Brown et al. (2013) and Brown and Frieh (2000) found partial evidence for bidirectional interference between timing and updating tasks. Brown et al. (2013) used a modified version of the Mental Counters task (Larson, Merritt, & Williams, 1988) in which participants had to monitor the presentation of a series of geometric shapes and report how frequently certain shapes occurred. The Mental Counters task and serial production of 5 s were performed under single and dual-task conditions. In addition, participants were instructed how to share their attention between the two tasks; with either 75%, 50% or 25% of attention being dedicated to the updating task. Relative to single-task conditions, dual-task timing became more variable and productions lengthened as decreasing attention was paid to time. Timing only impaired updating performance when attention to the updating task was low (25%), resulting in slower response times. Partial bidirectional interference was also reported between serial production and a running memory task in Brown and Frieh (2000). Timing only interfered with running memory performance when the running memory task was easy (recall the last 3 items presented) but not when it was difficult (recall the last 5 items presented). It should be noted however that performance was equally poor on the difficult task under single and dual-task conditions, perhaps reflecting a ceiling effect, and the importance of assessing simple span in such tasks prior to running span.

1.2. Switching

Brown et al. (2013) suggest that shifting resources are likely to be recruited during timing because our day to day interactions with the environment require people to shift between timing and non-timing tasks. Partial support for this suggestion is provided (Brown et al., 2013; Wearden, O'Rourke, Matchwitck, Min, & Maeers, 2010; Zakay & Block, 2004). Brown et al. (2013) observed bidirectional interference between serial interval production and the Local–Global task (a switching task requiring shifting attention between attention to individual items of a stimulus or the stimulus as a whole). Interval productions became longer and more variable under dual-task conditions. Response times in the Local–Global task were also greater under dual-task conditions, indicating that switching resources are recruited during timing. Interestingly, Wearden et al. (2010) observed interference between task-switching and timing without using a dual-task paradigm. The experiment involved conditions in which participants only completed a timing task (estimation and production) and other conditions in which participants switched from an addition task to a timing task. When switching from addition to timing, duration estimations became shorter than in conditions where only timing was performed. Wearden et al. (2010) suggested that task switching may have reduced attention to time, resulting in shorter perceived durations.

Interference between switching and timing is not however a universal finding (Fortin et al., 2010; Ogden, Salominaite, et al., 2011). Ogden, Salominaite, et al. (2011) observed that relative to single-task conditions, interval production became more variable when performed concurrently with the plus–minus task which requires participants to switch their attention between adding and subtracting from a list of 2-digit numbers. Concurrent interval production did not, however, affect the switch-cost (the time difference between the switch vs. no switch conditions). Similarly, Fortin et al. (2010) reported four experiments requiring participants to produce intervals whilst performing a memory search task, or switching between performing a memory search and digit classification task. Switching did not affect interval production. Both Ogden, Salominaite, et al. (2011) and Fortin et al. (2010) therefore concluded that switching resources are not always recruited during timing.

1.3. Inhibition

The role of inhibition in timing is presently unclear. Studies in which timing and the Stroop task are performed concurrently consistently report that perceived time is shorter under dual than single-task conditions; however, examination of bidirectional interference is rare. Brown et al. (2013) explored bidirectional interference between concurrent performance of the Stroop and serial 5-second production. Bidirectional interference was observed: relative to single-task conditions, interval productions became longer and more variable under dual-task conditions, with the greatest effects observed when attention to time was low (25%). Concurrent timing also lengthened response times on the Stroop task with greater effects when less attention was paid to the Stroop task (25%). Bidirectional interference was also reported by Brown (2006) using Random Number Generation (RNG). Ogden, Salominaite, et al. (2011) however, did not observe bidirectional interference between timing and concurrent performance of Random Letter Generation (RLG). Whilst RLG made interval production more variable, timing did not influence RLG. The disparity between Ogden, Salominaite, et al. (2011) and Brown's (2006) findings can perhaps be explained by varying levels of task difficulty; Brown (2006) required participants to produce numbers at a faster rate (every 0.86/s) than Ogden, Salominaite, et al. (2011) who required participants to produce letters once every second. Indeed, the linear relationship between attention to the Stroop task and Stroop interference, reported in Brown et al. (2013), supports the suggestion that inhibitory resources are perhaps only required for timing when task demands are high.

1.4. Access

The role of access to semantic memory in timing is rarely explored. Ogden, Salominaite, et al. (2011) provide the only exploration of bidirectional interference between timing and access. Participants completed serial interval production alone and concurrently with the Controlled Oral Word Association (COWA) task. The COWA task requires participants to retrieve as many words as possible beginning with a given