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Time flies faster if a person has a high working-memory capacity ☆

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ABSTRACT

Attention affects the perception of time, and the ability to control attention is reflected in measures of working-memory capacity. Individuals with low working memory capacity have more difficulty maintaining focus on a task than high-capacity individuals, particularly when faced with contextual distracters. This experiment examined the effect of working-memory capacity on the perception of temporal duration while performing a cognitive task. We predicted that low-capacity participants would be more likely to direct attention away from the cognitive task and towards the contextual distraction of time, and consequently perceive temporal duration more accurately, and perform the cognitive task less accurately, than high-capacity participants. The results showed that when performing both tasks simultaneously, low-capacity participants were less accurate than high-capacity participants on the cognitive task, but were more accurate on the timing task. High-capacity participants, conversely, were more accurate in the non-temporal cognitive task at the cost of monitoring duration.

1. Introduction

Maintaining a sense of time's passing often occurs while working on a cognitive task, particularly when given a specific duration of time to complete a task (e.g., an examination). However, when working on a cognitive task, monitoring the passage of time represents a secondary task and can be a potential distraction. If attention is directed to monitoring time's passing throughout a cognitive task, performance on the task is negatively affected (Brown, 2006). Conversely, if one is immersed in the cognitive task, duration may go relatively unmonitored. It is well established that the allocation of attention affects the awareness of time's passage, particularly during a cognitive task (Block, 1990; Block, Hancock, & Zakay, 2010; Block & Zakay, 1996; Brown, 2006; Brown & Stubbs, 1992; Zakay & Block, 1997).

A widely accepted model of time perception during cognitive tasks is the *attentional-gate model*, which posits that attention to time's passage affects the accuracy of time perception. Like most theories of time perception based on a scalar expectancy theory (Gibbon, Church, & Meck, 1984), the attentional-gate model assumes that an internal pacemaker (see also Treisman, 1963) sends temporal pulses to a counter that records them. Temporal judgments are made by comparing the pulses accumulated by the counter to reference memories for known durations. While the amount of temporal pulses sent by the pacemaker remains constant, the number of pulses counted by the counter is gated by attention. Allocating attentional resources towards the passage of time increases the number of pulses passed through this attentional gate, and results in a subjective lengthening of time. Conversely, when an individual is focused on a non-temporal task, fewer pulses pass through the gate (Zakay & Block, 1997), resulting in a subjective shortening of time. Consequently, when attention is directed towards a cognitive task, “time flies”, whereas when attention is directed towards time when doing such a task, “time drags” (Zakay & Block, 1997).

Attention is particularly influential when making prospective judgments of time, or time estimations when one is required to attend to time (e.g., when one is taking a timed test; Block, 1990; Block et al., 2010; Block & Zakay, 1996; Brown, 1985, 1997, 2006; Zakay & Block, 1997). In temporal perception research, prospective time judgments are commonly measured in the context of duration production tasks. For example, participants may be told to work on a task for a given duration (usually ranging in the seconds) and then estimate when the duration has passed. Duration production has been shown to be highly sensitive to workload, such that a higher workload results in participants taking longer to report the passing of a given duration, suggesting that less attention is devoted to time under these conditions (Block et al., 2010; Zakay & Shub, 1998).

Studies of prospective temporal perception (and importantly, research on the attentional-gate model) are typically conducted using durations that extend up to several seconds. However, given the focus of the current study, longer durations were of interest. Many real-world cognitive tasks (particularly in academic contexts) involve maintaining focus on task demands for a period of several minutes, if not longer. This type of attentional focus requires that individuals not be distracted by contextual factors, such as the passage of time. Moreover, the cognitive mechanisms inherent to models of prospective temporal perception (e.g., gating of the temporal pacemaker) are likely relevant

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to tasks involving relatively longer durations. Brown and Boltz (2002), for example, used durations of up to approximately 1 min, and found typical prospective temporal results (i.e., participants perceived a shortening of time under cognitive load).

We posit that a bi-directional relationship exists between performance on a prospective temporal perception task and performance on concurrent cognitive task. Specifically, simultaneously monitoring the passage of time and completing a non-temporal cognitive task can cause bi-directional interference between the two tasks (Brown, 1997; 2006; Macar, Grondin, & Casini, 1994). As people devote more attentional resources to a cognitive task and away from time, performance on the cognitive task will improve at the expense of temporal perception accuracy. On the other hand, if individuals direct their attentional resources to the passage of time, they will perceive a lengthening of time, resulting in compromised cognitive task performance. There is some evidence for this bidirectional relationship between attention towards time or a cognitive task. When cognitive tasks are relatively challenging, such as mental arithmetic (Brown, 1997) or a word-counting task (Macar et al., 1994), attention towards time can negatively affect cognitive task performance, and attention towards a cognitive task can negatively affect accuracy of temporal perception.

We contend that avoiding the distraction of the passage of time while engaging in a cognitive task requires attentional control, which is strongly correlated with working-memory capacity (Broadway & Engle, 2011; Conway, Cowan, & Bunting, 2001; Engle, 2001, 2002; Kane, Bleckley, Conway, & Engle, 2001; Kane et al., 2007; Kane & Engle, 2003). Engle has argued that working-memory capacity represents a “domain-free limitation in the ability to control attention” (Engle, 2002, p. 19). Therefore, working-memory capacity and attentional control may affect both temporal perception and performance on cognitive tasks.

Individual differences in working-memory capacity have been shown to influence accuracy in prospective time judgments. Broadway and Engle (2011) identified high and low working-memory capacity participants using the Operation Span Task (OSPAN; Turner & Engle, 1989) and symmetry span texts for visual–spatial information. Importantly, performance on the OSPAN test is correlated to attentional control (Engle, 2002). High-and low-capacity participants were asked to reproduce durations of relatively brief events (the duration of a light that ranged from 500 to 5500 ms). The temporal reproductions of high-capacity participants were consistently more accurate than low-capacity participants across the different durations. In contrast, low-capacity participants tended to overestimate short durations and underestimate longer durations, consistent with Vieorodt's Law (Brown & Boltz, 2002; Woodrow, 1951). This is one of the first studies to demonstrate that individual differences in working-memory capacity are related to perception and memory of the passage of time.

In the present study, we addressed a different set of issues regarding the relationship between working-memory capacity and the prospective perception of the passage of time. Specifically, we explored potential tradeoffs that can occur between performance on a primary cognitive task and attending to the passage of time over relatively long durations, as would occur in activities such as an academic task (e.g., working on homework,). Consistent with the assumption of a bi-directional tradeoff between cognitive and temporal tasks, we predict that when individuals are able to effectively direct their attentional resources to a cognitive task, they are consequently less aware of time's passing. Conversely, if individuals have poor attentional control and become distracted by the passage of time, performance on a cognitive task may be compromised.

In the current study, participants engaged in a math task for varying durations (2 or 4 min). At any time during the task, the participants could indicate when they felt the duration had passed. This task can be conceptualized as a dual-processing cognitive load task (e.g., Block et al., 2010). From the participant's perspective, the math task was the primary task and the duration task was the secondary task. Math task difficulty was manipulated because individual differences in working-memory capacity tend to be revealed in more challenging tasks (e.g., Just & Carpenter, 1992). Additionally, Block et al. (2010) showed cognitive load tasks that vary in difficulty affect prospective judgments such that time-estimations shorten as difficulty increases. Individual differences in working-memory capacity were assessed with the OSPAN task (Turner & Engle, 1989).

We used duration judgment ratios to measure prospective time judgments (Block et al., 2010). Duration judgment ratios are computed by dividing the objective duration (i.e., the duration the participant is told to produce) by the subjective production (i.e., how long the participant takes to indicate the end of the duration). If a participant's production is longer than the requested duration, the duration judgment ratio will be less than one, whereas it will be greater than one if the production is shorter than the requested duration. Previous research shows that these ratios are lower when a concurrent non-temporal task requires a high processing load, reflecting less attention devoted to the passing of time (Block et al., 2010).

A *working-memory capacity hypothesis* assumes that individuals with high working-memory capacity are better to maintain attentional focus on a cognitively demanding task in the face of potential contextual distractions, such as time. As such, one would expect that high working-memory capacity participants would take longer to signal the end of duration than low-capacity participants, and consequently be less accurate in their temporal judgments. This hypothesis may seem to contradict the findings from Broadway and Engle (2011), but it is important to note that their experimental task did not involve a concurrent cognitive processing load (see Block et al., 2010), and their studied durations were significantly shorter. As such, they did not explore the potential trade-off between attention towards a cognitive task and attention towards the passage of time over longer durations. Under these conditions, we assume that high-capacity individuals will be more apt to stay attentionally focused on the primary cognitive task (e.g., Engle, 2002).

This hypothesis leads to a duration × working-memory capacity interaction for the duration judgment ratios. Vierordt's Law predicts that the temporal productions will shorten with increasing duration (i.e., leading to higher ratio scores), but we predict that working-memory capacity will moderate this effect.[1] Thus, we expect the slopes to be steeper for low working memory-capacity participants compared to high working-memory capacity participants, and that differences in duration judgment ratios between the two groups will be larger at 4 min than at 2 min. Such results would likely be due to differences between the two groups in allocating attentional resources to either the cognitive or temporal task, and these differences should increase as time passes.

We also we predict a working memory × duration interaction for performance on the math task such that the slopes over the two durations will be different for high and low-capacity participants. Specifically, there will be a decline in performance for low-capacity participants, but not for high-capacity participants. Additionally, the difference in performance will be greater at 4 min than at 2 min.

2. Methods

2.1. Participants

100 Northern Illinois University undergraduates were recruited for participation. One participant was dropped because he/she performed very poorly on the math task, indicating non-compliance with the instructions.

[1] Vierordt's Law is typically explained in terms of regression towards the mean.