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Individual differences in interrupted task performance: One size does not fit all[☆]

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ABSTRACT

Two experiments used a spatial navigation task to study the relationship between individual differences in working memory capacity and interrupted task performance. The results of experiment one show that participants with low working memory capacity (WMC) are more susceptible to the negative effects of interruptions than participants with high WMC. The results of additional analyses indicate that both groups differ in their strategies used to memorize material from the primary task. A second experiment manipulated memory strategy use for high and low memory span participants and found that low span participants performed at the level of high spans when using a strategy that is more typically used by high span participants. However, this performance improvement did not show during interrupted tasks. Overall, these results suggest that individual memory capacity differences affect performance during interrupted tasks by determining selection of memory strategies and by limiting performance of participants.

Working memory (WM) is crucial for performing cognitive tasks (Unsworth and Engle, 2007), and is highly correlated with general fluid intelligence (Engle et al., 1999; Jaeggi et al., 2008; Kane and Engle, 2002) and executive attention (Engle, 2002). Engle et al. (1999) define working memory capacity (WMC) as the ability to temporarily maintain representations activated in the face of distraction, e.g., interruptions. Sweller (1988) refers to information that is processed in working memory as cognitive load with increases in cognitive load utilizing a person's finite working memory capacity.

Interruptions increase cognitive load, often by requiring processing of information that is not relevant to the primary task. For example, when facing an interruption (e.g., a notification of required operating system restart) a person may suspend a primary task (e.g., creating a table in a document) in order to address the interruption. During that time, information relevant to the primary task needs to be kept active in WM in order to allow resumption of the primary task (Trafton et al., 2003). Information maintained may include steps of the primary task already performed (e.g., determining the number of columns and rows of the table, insertion of the table, entering some of the headers into the table), the step that was active at the time of interruption (e.g., formatting of the table), and how one had prospectively planned to proceed (e.g., adding borders to the table) (Boehm-Davis and Remington, 2009). Further, a person may have to store information about the interrupting task in WM until task completion (e.g., performing manual system restart). Failure of working or prospective memory will result in execution errors upon return to the primary task. Recent cognitive models of interruptions, e.g., Altmann and Trafton's (2002) memory for goals model, specify these cognitive processes involved in WM.

Another aspect of WM is that it is associated with controlled, but not automatic processing. Unsworth and Engle (2005) demonstrated significant differences between participants with high and low WM span scores in task performance of a difficult task that requires controlled processing. The authors found no differences between groups in automated tasks. However, interrupted task performance entails controlled processing because the disruption requires operators to decide whether to proceed with the interrupting task, rehearse completed steps, and prospectively encode goals. Thus, a difficult primary task, which requires controlled processing is more demanding and requires more cognitive control with the onset of an interruption. Consequently, interruptions will exacerbate any impact on primary task performance across different abilities of WM, and this impact likely increases with greater task difficulty.

A review of the interruption literature indicates that previous research predominantly investigated task and interruption characteristics, for example, timing (Adamczyk and Bailey, 2004), duration (Altmann and Trafton, 2002; Gillie and Broadbent, 1989), or complexity (Cades et al., 2008; Monk et al., 2008) of interruptions, or complexity of the primary task (Speier et al., 2003). Overall, research focused primarily on characteristics external to the person rather than

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on theoretical underpinnings of interruptions involving human cognitive processes (Biron et al., 2009). Thus, one of the limitations of this body of work is that it does not identify how interruptions differentially affect performance of individuals in their abilities to plan, recall, and execute tasks (although see Brumby et al., 2013). The goal of this work is to advance the research on interruptions by adding a complementary perspective to this research: How do characteristics of the individual affect performance during interruptions. An improved understanding of this impact would allow for more effective human computer interaction because by anticipating the user specific impact of interruptions, it would be possible to manage interruptions in such way that they have the least impact. For example, for some users interruptions could be completely blocked while interacting with the computer, for others only selected interruptions would be active, while for another group, no suppression of interruptions would occur.

Engle (2002) explains that individual differences in WMC are an important predictor for performance on higher-order cognitive tasks (e.g., problem solving, decision making and reasoning) (Just and Carpenter, 1992). Higher WMC is associated with better goal maintenance and increases resistance to the negative effects of interference. Kane and Engle (2000) note that people with low WMC are more susceptible to proactive interference under dual-task conditions compared to single task conditions. Other research demonstrated similar effects of retroactive interference on working memory (Hedden and Park, 2003). Based on these findings, it is likely that interruptions affect people with higher WMC less than those with lower WMC.

In addition, different cognitive abilities may also lead to differences in how a person plans how to deal with an interruption. Thus, higher WMC may lead to use of a more cognitively demanding strategy that increases WM requirements, whereas lower WMC may lead to the use of less cognitively demanding strategies.

1. Interruptions and error

One way that interruptions can cause errors is by increasing the cognitive demand on an individual. Capacity interference (Kahneman, 1973) occurs when there is too much information present for an individual to successfully process. During difficult tasks, a person's mental workload may be at or near capacity limits (Evaristo et al., 1995). In such a situation, the additional cognitive demands imposed by an interruption can overload the individual's processing limits (Speier et al., 1999) which decreases performance and increases error.

While performing a primary task (PT), a person often plans a sequence of steps necessary to accomplish that task (e.g., the steps required to create a table in a document). This can be cognitively demanding, especially if the PT requires accurate and efficient execution. In environments where interruptions are prevalent, a person's ability to plan effectively may be impaired even by the anticipation of an interruption (Loft et al., 2008). In these situations, a person must not only encode goals and steps, but also prepare for the possibility of interruption. Anticipation of an interruption can impede performance more than being surprised by an interruption (Loft et al., 2008). These findings suggest that preparation for an interruption requires additional cognitive resources. One potential outcome of a failure to mobilize additional resources during an interruption are post completion errors (Li et al., 2008), where the temporal proximity of an interruption to a post completion step increases the likelihood of error.

Above, it was argued that interruptions impair performance and contribute to error. Here we distinguish between two types of error: Planning errors and execution errors (Altmann, 2004; Altmann and Trafton, 2002). Planning errors occur during the encoding of necessary task steps in prospective memory. They manifest themselves in incorrect or sub-optimal intentions. Execution errors occur during the recall of previously encoded goals and steps. Execution errors may involve optimal planning, but memory failure results in incorrect recall of that plan. Planning errors and execution errors map into the distinction between mistake and slips (for more detail see Norman, 1983).

The present work investigates the question how individual differences in WMC affect task performance and error rates in interrupted tasks. We present the results of two studies with the first examining the impact of WMC on a person's ability to deal with interruptions, and the second exploring how strategy use affects performance in interrupted tasks.

2. Experiment 1

The goal of the first experiment is to investigate the contribution of WMC on interrupted task performance and error rates across varying WM spans. The prediction is that high spans have lower execution error rates during interrupted PT trials than low spans. In addition, we expect an interaction between WM span and difficulty of PT such that low spans will show greater increases in error rates due to interruptions over increasing difficulties of PT compared to high WM span participants. Finally, planning ability will be affected during trials following an interruption with high WM span participants having lower planning error rates. Similar to predictions for execution error rates, an interaction between WMC and primary task difficulty is expected, such that low span participants will have higher planning error rates over increasing difficulty of PT compared to high span participants.

2.1. *Methods*

2.1.1. *Participants*

104 participants (57 females and 47 males) ranging in age from 18 to 27 ($SD=2.48$) took part in the study. Absolute Aospan scores were used to group participants into four groups of WMC with participants with scores in the lowest quartile (scores less than or equal to 25) being categorized as low spans, and participants with scores in the highest quartile (scores greater than or equal to 53) being categorized as high spans. Participants outside these two categories were excluded from further analyses, leaving 51 participants (29 females and 22 males) ranging in age from 18 to 27 ($M=20.8$, $SD=2.48$). The mean absolute Aospan score for the high span group was 58.64 ($n=26$; $SD=3.98$) and the low span group had a mean score of 15.23 ($n=25$; $SD=5.51$).

All participants were undergraduate students at the University of Utah and randomly assigned to one of three PT difficulty conditions.

2.1.2. *Materials*

2.1.2.1. Spatial navigation task. For the purpose of this study we developed a task that included features that are common in many everyday tasks. The primary task (PT) involved spatial planning navigation, which required participants to plan, recall, and execute spatial movements in order to move a cursor to a specific goal (see Fig. 1a).

The navigation space contained the starting and goal position, movement obstacles and movement facilitators. A navigation problem was comprised of the successful movement of the cursor from the starting point to the goal using the smallest number of instructions possible. A problem consisted of six trials with each trial being divided into three phases (Fig. 2a).

During the *planning* phase participants saw the movement space (Fig. 1a) and the movement instructions (e.g., “Turn left”, “Forward 2”, “Turn right”, “Forward 3”, “Back up 1”, “Do nothing”, “Forward 1” and