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Spatial memory guides task resumption

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Previous research examining how people resume a task following an interruption has focused primarily on pure memory processes. In this paper, we focus on the perceptual processes underlying task resumption and show that spatial memory guides task resumption. In Experiment 1, fixation patterns suggest participants were able to resume remarkably close to where they were in the task prior to interruption. In Experiment 2, a spatial interruption disrupted resumption performance more than a nonspatial interrupting task. Together, these results implicate spatial memory as a mechanism for resumption.

When resuming an interrupted task, there are often time costs associated with the resumption process (Altmann & Trafton, 2002, 2007; Hodgetts & Jones 2006a, 2006b); it takes people time to "gather their thoughts" to determine what they were doing before being interrupted. What cognitive and perceptual processes underlie resumption of a primary task?

Previous work on interruptions has focused primarily on memory processes during resumption. Memory for Goals, an activation-based theoretical framework, (Altmann & Trafton, 2002, 2007) is a prominent theory in the interruptions domain. This theory suggests that the current most active goal directs behaviour and the activation levels of goals decay over time. When interrupted, the current primary task goal is suspended and the activation level of this goal decays. Upon resumption, the time required to begin work on the primary task reflects the process of retrieving the suspended goal. The higher the activation level of the suspended goal, the

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more easily that goal can be retrieved. There are several constraints which determine the activation level of the suspended goal. First, the history of the goal (i.e., frequency and recency of goal retrieval) impacts goal activation. Second, the environmental context and cues may provide priming of the goal and increased activation.

Several empirical studies have examined the predictions of the Memory for Goals theory, generally using fairly complex primary tasks with a hierarchical goal structure. Hodgetts and Jones (2006b) and Monk, Trafton, and Boehm-Davis (submitted) have provided support for the decay of goals overtime. There is also support for the constraints in the theory. Trafton, Altmann, Brock, and Mintz (2003) showed that to prevent or slow down goal decay, it is possible to rehearse the retrospective or prospective goal. Trafton, Altmann, and Brock (2005) provided support for the role of environmental cues in facilitating goal retrieval. Finally, Altmann & Trafton (2008) have shown that each task relevant goal in the goal hierarchy is associatively linked to future goals in the hierarchy. Thus, retrieval of one task goal provides priming for the next task goal. Together, the Memory for Goals theory and these empirical studies provide a broad understanding of the memory processes underlying primary task resumption.

Interestingly, the perceptual processes involved in resuming complex tasks are not as well understood. However, in the visual search domain, there have been several studies examining how people resume interrupted visual search tasks (Lleras, Rensink, & Enns, 2005, 2007; Shen & Jiang, 2006). Lleras et al. (2005) showed that resuming an interrupted visual search task was faster than initially beginning a visual search task, suggesting that some information about the search display is kept in memory during the interruption. Shen and Jiang (2006) also explored interruptions during visual search tasks, finding that unfilled temporal delays did not affect search performance; short (4 s) search tasks disrupted search performance, and long (3 min) search tasks eradicated search memory. Additionally, they suggested that relative spatial location (spatial configuration) of the search display is retained during the interruption.

These two bodies of literature have different theoretical accounts for the resumption process. The Memory for Goals framework, which is focused on more complex tasks, lacks a spatial memory component and does not account for the perceptual processes when resuming. The visual search research that focuses on resumption has shown that a spatial representation of a search display is maintained; specifically, spatial configuration is important. However, these visual search papers have relied solely on reaction time to demonstrate these effects. Thus, it is unclear how this spatial representation is used to resume. In this paper we combine these two approaches to show that spatial memory needs to be integrated into the Memory for Goals theory and to show that the spatial representation that is maintained during the interruption can be used to accurately return to a specific spatial location.

To accomplish this goal we used a task with a visual search component, but that was more complex and goal oriented than traditional visual search tasks. This task had a sequential order of operations allowing for a direct measure of where in the task people resume in relation to where they were prior to being interrupted. Experiment 1 focused on the general perceptual processes used when resuming an interrupted task; we show that participants are quite accurate at returning to the specific spatial location of where they should resume. In Experiment 2, we show that a spatial interrupting task is more disruptive than a nonspatial interrupting task, suggesting that memory for spatial location is a key component in the resumption process.

EXPERIMENT 1

Empirical papers examining interrupted visual search tasks (Lleras et al., 2005, 2007; Shen & Jiang, 2006) suggest that people are able to maintain some kind of spatial representation of the primary task over a delay. It is not clear how the spatial information facilitates search—it could be more accurate spatial location memory, less time orienting, fewer fixations to return, or something else. In contrast to the findings in visual search, researchers in the interruptions domain have shown that participants sometimes restart their primary task following interruption (Czerwinski, Cutrell, & Horivitz, 2000; Miller, 2002), as if they have no memory for where to resume. The difference between these two perspectives may be due to task, complexity, or paradigm. The goal of this experiment was to examine the pattern of eye movements upon resumption to determine whether a spatial representation is maintained and whether this representation allows for one to return close to the specific resumption point. If participants start the task over, the majority of fixations should land on the first step of the primary task. If participants maintain an accurate representation of spatial location, the majority of fixations should land close to where they left off prior to interruption.

Method

Participants. Thirteen George Mason University (GMU) students participated for course credit.

Materials. The primary task consisted of columns of numbers; each column contained 11 numbers ranging from 100 to 999 (Figure 1). Fifteen

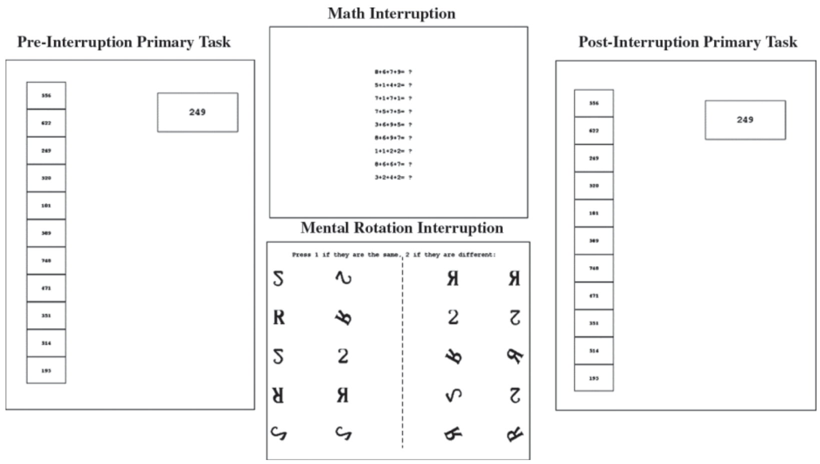

Figure 1. Primary and interruption tasks from Experiments 1 and 2.

unique templates containing slots specifying which numbers were to be even or odd and the location of these numbers were used to generate the columns of numbers used in the experiment; each template contained a minimum of five odd numbers. Based on the templates, two sets of 15 columns of numbers were randomly generated for each participant. Each number subtended 0.6° of visual angle, each cell subtended 2.9°, and each number was separated by 2.3°.

The interrupting task lasted 15 s and consisted of 10 addition problems, each containing four randomly generated addends ranging from 1 to 9.

Design. A within-participants design was used; one set of 15 columns were interruption trials and one set were control trials resulting in a total of 30 trials per participant. The presentation order was randomized. Each interruption trial contained a single interruption which occurred equally among different positions in the task (early, middle, and late).

Procedure. Participants were seated 50 cm from the monitor. Stimuli were presented using E-Prime (Schneider, Eschman, & Zuccolotto, 2002). In the primary task, participants were instructed to type odd numbers from the primary column (on the left) into a copy box (on the right; Figure 1). Participants started at the top of the primary column working their way to the bottom. The spacebar was used to advance to the next trial.

On the interruption trials, the interrupting task immediately appeared and fully occluded the primary task. Participants answered as many addition problems as possible. Upon resumption of the primary task, the number that was last entered in the copy box was still displayed.

Measures. Two reaction time measures were calculated. The inter-action interval, calculated for control trials, was the average amount of time between entering odd numbers. The resumption lag (Altmann & Trafton, 2004), calculated for interruption trials, was the time from the end of the interruption to the first action back on the primary task (i.e., entering an odd number). Eye track data were collected using a Tobii 1750 operating at 60 Hz. A fixation was defined as a minimum of five eye samples within 10 pixels (approx 2° of visual angle) of each other, calculated in Euclidian distance. The primary column cells and the copy box were defined as areas of interest. For descriptive purposes, the primary column cells were sequentially numbered 1 to 11.

Results

Reaction time data. The resumption lag ($M = 4511.4$ ms) was significantly longer than the inter-action interval ($M = 1893.6$ ms), $F(1, 12) = 167.1$, $MSE = 366495.9$, $p < .001$, suggesting that the interruption was disruptive to primary task performance. Participants took more than twice as long to respond following an interruption than the average time between responses in the control condition.

Eye movement data. If participants were starting the task over again, participants' first fixation on the primary column should have been to the first cell. Thus, the average first fixation location should be approximately one, reflecting this process. The postinterruption first fixation location ($M = 4.01$) was statistically different from one, $t(12) = 5.1$, $p < .001$, suggesting that participants were not starting over.

To determine whether spatial memory was used to resume and to determine the accuracy of participants' spatial memory, we compared participants' pre- and postinterruption fixation locations in the primary column. A difference score was calculated between the two cell values that corresponded to the pre- and postfixations as a gauge of resumption accuracy. For example, if a participant fixated on cell 5 prior to being interrupted and then returned to cell 4 after the interruption, this difference of -1 would indicate that the participant returned 1 cell back from the preinterruption location. A value of 0 would indicate perfect spatial memory. Figure 2 shows the distribution of difference scores, which is centred on -2, indicating that participants were conservative in where they resumed. Over

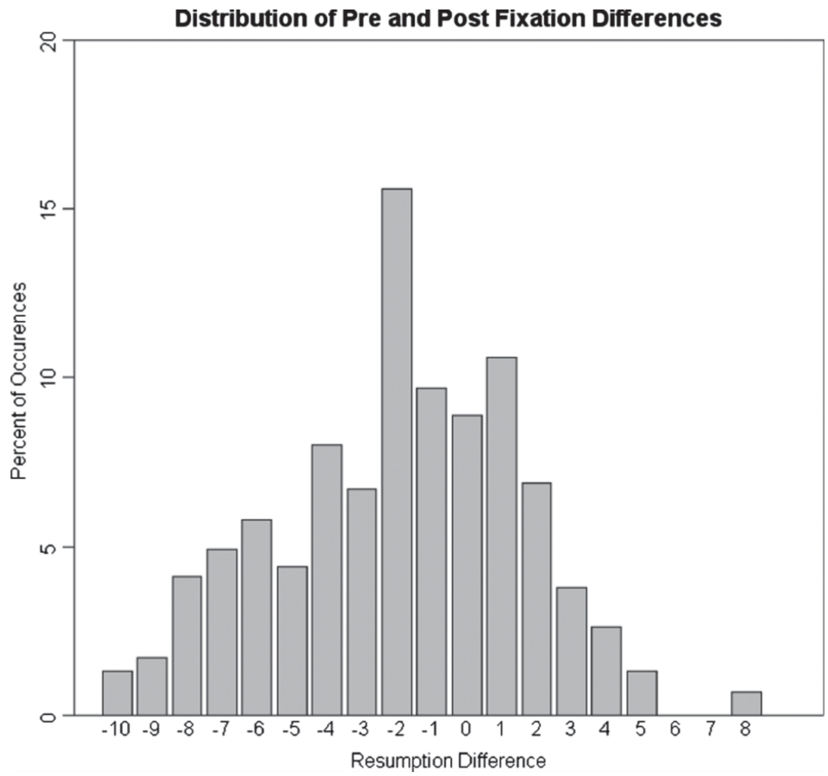

Figure 2. Distribution of pre- and postinterruption differences from Experiment 1.

50% of the time, participants returned to within two cells of where they left off.

Discussion

The reaction time measures showed that the interruption was disruptive to primary task performance; this is consistent with several other studies showing the immediate disruptive effects of interruptions. The eye movement data showed that participants were not starting the task over again, but were using spatial memory to resume. The distribution of difference scores demonstrated that participants were quite accurate at returning to where they last were prior to being interrupted, although their spatial memory was not perfect. This finding extends Shen and Jiang's (2006) work by showing that a spatial representation is maintained for a more complex task and that this representation can be used to guide one back to a specific spatial location. The use of spatial memory is not consistent with the Memory for Goals theory.

EXPERIMENT 2

In this experiment we sought to directly implicate spatial memory in the resumption process by attempting to disrupt people's spatial memory for where to resume. To do this we introduced a mental rotation task as an interruption which requires spatial working memory resources (Baddeley, 1986; Logie, 1995). If spatial memory is used to maintain a representation of the primary task during the interruption and spatial memory guides resumption of the primary task, disrupting spatial memory should negatively impact the resumption process. The spatial interruption should affect resumption in two ways. First, resumption lags following a spatial interruption should be longer than a nonspatial interruption. Second, participants should be more inaccurate at returning to where they last were in the primary task column following the spatial interruption.

Method

Participants. Thirty-six GMU students participated for course credit.

Materials. The primary task materials were the same as Experiment 1. There were two types of interruption tasks: Nonspatial and spatial. The nonspatial interruption was the addition task used in Experiment 1. The spatial interruption was a mental rotation task (Cooper & Shepard, 1973). Participants were presented with pairs of letters ("R"s) or numbers ("2"s) that were upright or mirror reversed and rotated in one of six orientations (Figure 1). For each pair the participant had to determine whether the stimuli were the same orientation (i.e., both upright or both mirror reversed) or different orientations (i.e., one mirror reversed and one upright). During each interruption 10 pairs of randomly generated stimuli were presented.

Design. Spatial ($N = 18$) and nonspatial ($N = 18$) interruptions were manipulated between participants; participants were randomly assigned to either condition. The number of trials and the frequency and location of interruptions was the same as Experiment 1.

Procedure. The primary task procedure was the same as Experiment 1. During the 15 s interruption, participants answered as many addition or rotation problems as possible. Participants responded to the rotation problems by entering 1 for same or 2 for different.

Measures. The measures were the same as Experiment 1.

Results

Reaction time data. In the spatial condition, the resumption lag ($M =$ 4505 ms) was significantly longer than the inter-action interval ($M =$ 1828.1), $F(1, 17) = 270.8$, $MSE = 238181.5$, $p < .001$. In the nonspatial condition, the resumption lag ($M = 3982.2$ ms) was significantly longer than the inter-action interval as well ($M = 1679$ ms), $F(1, 17) = 454.6$, $MSE = 105030$, $p < .001$. Critically, the spatial condition resumption lag ($M = 4505$ ms) was longer than the nonspatial resumption lag ($M = 3982.2$ ms), $F(1, 34) = 4.9$, $MSE = 506480.1$, $p < .05$. The inter-action intervals were not significantly different, $F(1, 34) = 1.1$, $MSE = 175020.3$, $p = .3$.

Eye movement data. To determine whether the spatial interruption directly affected participants' spatial memory participants' pre- and postinterruption fixation locations were examined. Similar to Experiment 1, a resumption accuracy measure was calculated by taking the difference score between the cell numbers that corresponded to the pre- and postinterruption fixation locations. We examined the absolute value of the difference scores to directly compare resumption accuracy across conditions. Participants were more inaccurate at resuming in the spatial condition ($M = 3.5$) than the nonspatial condition ($M = 2.6$), $F(1, 34) =$ 10.1, $MSE = 0.8$, $p < .01$.

One possible explanation for this finding is the difference in the layout of the two interrupting tasks. The position of the eyes just prior to resuming may have been different in each condition, influencing the time required to reorient to the primary task interface. Upon resumption, in over 99% of the trials participants first fixated on the copy box. To rule out the eye position and reorientation explanation the amount of time from the offset of the interruption until this first fixation was examined. There was no difference in the time required to fixate on the copy box following the spatial ($M = 342.8$ ms) and nonspatial ($M = 371.2$ ms) interruptions, $F(1, 34) = 0.09$, $MSE =$ 78675, $p = .76$. This suggests the resumption accuracy differences were not driven by the different layouts of the interrupting tasks.

Interrupting task performance. A second possible explanation for the difference in resumption between conditions is that the spatial interrupting task was more difficult than the nonspatial task. Participants answered more (not less) mental rotation ($M = 6.8$) problems than math problems ($M = 3$), $F(1, 34) = 84.2$, $MSE = 1.2$, $p < .001$. Additionally, there was no difference in accuracy on spatial ($M = 91.9\%$) and nonspatial ($M = 91.2\%$) interruptions,

$F(1,\ 34) = 0.14$, $MSE = 31.24$, $p = .7$. These data strongly argue against an interruption difficulty explanation.

Discussion

When the interrupting task required spatial working memory resources, the spatial representation of the primary task was disrupted, which disrupted resumption. The spatial interruption resulted in longer resumption lags and less accurate resumptions. Although the resumption lag differences between conditions may seem small ($\sim$500 ms) relative to the total resumption lag ($\sim$4000 ms), previous research examining the components of the resumption lag (Brudzinski, Ratwani, & Trafton, 2007) suggests that this difference is a substantial portion of the cognitive components of the task. These findings show that memory for spatial location is an important process in resuming an interrupted task and that disrupting this spatial memory negatively impacts resumption.

GENERAL DISCUSSION

These experiments have clearly shown spatial memory is a mechanism that is used to resume an interrupted task. This mechanism should be integrated into the Memory for Goals theory to make this theory more complete. One straightforward way of integrating spatial memory would be to use the same priming mechanism that is used for environmental cues (Altmann & Trafton, 2002; Trafton et al., 2005). Spatial memory may be one way that specific environmental cues are identified. Memory for spatial location may guide task resumption by allowing one to return to the appropriate environmental cue, which in turn provides the priming required to retrieve the task level goal that was suspended.

Our results also have implications for the interrupted visual search studies. Shen and Jiang (2006) found that unfilled temporal delays and passive viewing tasks did not affect search performance, whereas short search tasks disrupted search performance and long search tasks completely eradicated search memory. Our results show that specific spatial location information is used to resume and that if you engage spatial working memory processes during the interruption, memory for spatial location will be disrupted on the primary task. This finding may account for Shen and Jiang's results. The unfilled temporal delays and passive viewing tasks did not require spatial working memory; consequently, this did not affect search performance. The interrupting visual search task may have required spatial memory resources and consequently search performance was disrupted.

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