Journal of Experimental Psychology: Applied
2011, Vol. 17, No. 2, 97–109

1076-898X/11/$12.00 DOI: 10.1037/a0023497

Mitigating Disruptive Effects of Interruptions Through Training: What Needs to Be Practiced?

David M. Cades and Deborah A. Boehm-Davis
George Mason University

J. Gregory Trafton
Naval Research Laboratories

Christopher A. Monk
George Mason University

It is generally accepted that, with practice, people improve on most tasks. However, when tasks have multiple parts, it is not always clear what aspects of the tasks practice or training should focus on. This research explores the features that allow training to improve the ability to resume a task after an interruption, specifically focusing on task-specific versus general interruption/resumption-process mechanisms that could account for improved performance. Three experiments using multiple combinations of primary tasks and interruptions were conducted with undergraduate psychology students. The first experiment showed that for one primary and interruption task-pair, people were able to resume the primary task faster when they had previous practice with the interruption. The second experiment replicated this finding for two other sets of primary and interruption task-pairs. Finally, the third experiment showed that people were able to resume a primary task faster only when they had previous practice with that specific primary and interruption task-pair. Experience with other primary and interruption task-pairs, or practice on the primary task alone, did not facilitate resumption. This suggests that a critical component in resuming after an interruption is the relationship between two tasks. These findings are in line with a task-specific mechanism of resumption and incompatible with a general-process mechanism. These findings have practical implications for developing training programs and mitigation strategies to lessen the disruptive effects of interruptions which plague both our personal and professional environments.

Keywords: interruptions, training, practice, human-computer interaction

Interruptions are generally disruptive to the performance of a primary task in terms of both completion time (Eyrolle & Cellier, 2000; Hodgetts & Jones, 2006; Monk, Boehm-Davis, & Trafton, 2004; Trafton, Altmann, Brock, & Mintz, 2003) and accuracy (Cutrell, Czerwinski, & Horvitz, 2001; Edwards & Gronlund, 1998; Ratwani, McCurry, & Trafton, 2008). Although much of this work has focused on why interruptions are disruptive, comparatively little work has looked at how experience or practice can improve how people handle interruptions.

It is well known that the more people practice a given task, the better they are able to perform that task (Newell & Rosenbloom, 1981). It would, therefore, make sense to reason that the more that people experience or practice with interruptions, the better they will become at dealing with and recovering from them. In fact, research examining the effects of repeated exposure to interruptions supports this view. For example, Shinar, Tractinsky, and Compton (2005); Detweiler, Hess, and Phelps (1994); Hess and Detweiler (1994); and Trafton et al. (2003) found that people performing a task while experiencing interruptions over several sessions showed improved performance, either in quicker resumption of the primary task or improved performance on either the primary or secondary task.

However, these studies do not address the source of the improved performance, and these performance improvements may result from several sources. For example, they may arise from improvements in performance of the primary task alone, leading to reduced cognitive demand. They may also result from improvements in performance of the specific primary-interrupting task pair. Finally, they may result from a more general learning process, where exposure to any type of interruption leads to improvement at handling them.

This article was published Online First April 25, 2011.

David M. Cades, Deborah A. Boehm-Davis, and Christopher A. Monk, Psychology Department, George Mason University; J. Gregory Trafton, Intelligent Systems, Naval Research Laboratories.

David Cades is now at Exponent Failure Analysis Associates and Christopher Monk is now at the Federal Highway Administration.

Portions of the data from Experiment 1 in this manuscript have been published previously in Cades, D. M., Trafton, J. G., & Boehm-Davis, D. A. (2006). Mitigating disruptions: Can resuming an interrupted task be trained? In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, October 16–20 (pp. 368-371), San Francisco. Specifically, the untransformed raw timing data were used for analysis in this previous conference publication. We thank Raja Parasuraman, Carryl Baldwin, and other members of the Arch Lab who provided comments on earlier versions of this article. This work was supported by Grants N00014-05-1-0438 and 55-8122-06 from the Office of Naval Research. The first author's time is supported by Grant NNX08AR78H from the NASA Graduate Student Researchers Program.

Correspondence concerning this article should be addressed to David M. Cades, Exponent, 185 Hansen Court, Suite 100, Wood Dale, IL 60191. E-mail: dcades@exponent.com

If improvements arise from learning of the primary task, they may be specific to the task that is learned. For example, it has been shown that as people gain expertise in chess, they may be able to remember large numbers of boards and positions simultaneously. However, their superior working memory capacity for chess does not transfer to other games or even randomly arranged chess boards (Gobet & Simon, 1996; Salomon & Perkins, 1989; Simon & Chase, 1973). It may be, however, that experience with the primary task alone is insufficient for improved performance. Instead, it may be necessary to practice with specific primary and interrupting task pairs to see later improvements. Finally, it is possible that what is being learned is not specific to the individual tasks but arises from practice in resuming the primary task after any interruption.

Support for Improvement Based on Practice With the Primary Task

Oulasvirta and Saariluoma's (2004, 2006) application of Long-Term Working Memory (LTWM) (Ericsson & Kintsch, 1995) to interrupted task performance suggests that the handling of interruptions can be improved through practice on the primary task alone. Ericsson and Kintsch (1995) suggest that with sufficient practice or expertise on a task, people are able to use specialized encoding to store information in a type of protected memory—LTWM—that is long-lasting, has a large capacity, and allows for fast and accurate retrieval. The development and use of this type of encoding is thought to improve gradually as people gain more experience with specific tasks. In other words, with increased exposure to a given task, the ability to encode and retrieve information about that task will become protected, faster, and more accurate.

Oulasvirta and Saariluoma (2004, 2006) showed that when participants were able to encode the primary task—reading an essay on a variety of topics—into LTWM, they scored higher on comprehension tests after interruptions than if they were not able to use the LTWM store. This work suggested that participants were able to use LTWM when the pace of the primary task was slower or matched the participants' encoding speed and that this encoding speed became faster with increased exposure to the task. As long as participants were able to encode the information of the primary task, they did not suffer any negative effects associated with being interrupted. Thus, their work suggests that improvements at handling interruptions should be seen over time as people gain expertise with the primary task. Additionally, given sufficient time to encode the primary task, decrements associated with interruptions should be minimized.

A Memory for Goals Explanation of Improvement Based on Experience With the Primary Task

The Memory for Goals model (Altmann & Trafton, 2002, 2007) is a computational theoretical framework that has been used to account for the interruption and resumption process. This model provides a theoretical mechanism by which the LTWM hypothesis may be explained. Memory for Goals is an activation-based model instantiated in the ACT-R (Anderson et al., 2004) cognitive architecture which suggests that the most active current goal drives behavior, where activation is a measure of the strength of a goal in memory.

When an interruption occurs, the goal associated with the primary task must be suspended; once suspended, the activation level associated with this goal decays. Once the interruption is complete, the goal associated with the primary task must be retrieved from memory to return to that specific task. The time to complete the retrieval process and the accuracy of retrieval reflects the activation level of the suspended goal. In other words, the time it takes to retrieve the goal of the suspended primary task (the resumption lag) and the probability that the retrieval will be correct are directly related to the activation of the goal at the time of retrieval, with lower activation being associated with longer resumption times and lower accuracy, and higher activation with faster resumption times and higher accuracy.

In addition to the memory decay function, Altmann and Trafton (2002) identify certain constraints that influence the activation level of the primary goal. One of these constraints, strengthening, explains how the development of LTWM can lead to improved performance at resuming from an interruption with increased exposure to the primary task alone. The strengthening constraint suggests that both the frequency and recency with which that specific goal has been retrieved affect its activation level. In other words, if a goal is retrieved quite often, either through rehearsal or through use, its activation will increase and it will be faster and easier to retrieve. Thus, as people practice the primary task, its representation in memory gains activation through strengthening. The "stronger" the activation of the primary task, the easier it will be to retrieve quickly and accurately. This constraint takes into account time spent on a specific task and how recently that task was performed. Therefore, maximum strengthening would be achieved when a primary task was practiced without interruptions. That is, interruptions would reduce the recency of exposure to the primary task, leading to less strengthening. Thus, strengthening can be viewed as a mechanism by which expertise on a task and the ability to use the specialized encoding and retrieval structures of LTWM are attained. This also provides a mechanism to explain improvements in dealing with interruptions through practice with the primary task only.

Support for Improvement Based on Practice With Specific Primary-Interrupting Task Pairs

Interrupted task performance bears some similarities to the performance of multiple (in this case two) discrete tasks. However, unlike traditional multitasking, where the goal is to complete the set of tasks, when we talk about interrupted task performance, we imply that the completion of one task has priority over completion of the other task. Further, we assume that when the primary task is interrupted by a secondary task, the performer has the desire to return to the primary task as soon as possible after being interrupted (Wickens, 2008). Thus, interrupted task performance can be viewed as the performance of a larger, multipart task composed of smaller individual tasks with a priority to complete one of the tasks. Viewed in this light, the literature on part-task training may be instructive in understanding the source of improvements in interrupted task performance.

The evidence from this domain suggests that part-task training is not uniformly effective in improving performance on the whole task. For example, a set of experiments examining the training of proceduralized tasks suggests that no form of part-task training is as good as direct replication of the entire task (Johnson, 1981). However, when the "critical components" of task performance can be identified, training on those components alone can improve whole task performance. For example, part-task training concentrating on previously identified critical components led to similar levels of performance as whole-task training in experiments examining skill acquisition on a flight simulator (Goettl & Shute, 1996).

However, it can be challenging to identify what the critical components of a task are. Goettl and Shute (1996) used a transfer of training approach to identify the critical components of the flight simulator task in their experiments. They exposed different groups of people to different parts of the flight simulator task and then had everyone perform the whole task to evaluate which components led to the best performance. Wightman and Lintern (1985) caution that when using this approach, it is essential to decompose the original task systematically to identify the most important aspects of the task. Mané, Adams, and Donchin (1989) effectively applied this approach to identify the critical components of a command and control video game. The part-task training program they developed based on their task analysis actually proved to be more effective than a whole-task training approach.

What is clear from these studies is that practice involving the critical components of an interrupted task should lead to improvements at handling the interruptions. Further, this literature suggests that the critical components appear to be aspects of the specific tasks being performed and not general processes. For example, Whaley and Fisk (1993) found that it was training on the specific items to be remembered and not simply training on remembering things that led to successful part-task training. Applying the findings from the part-task literature to the improvement of interrupted task performance lends support to a task-specific mechanism of improvement. In other words, this research suggests that the critical components of interrupted task performance are in the specific tasks themselves and not the general process of switching between any two tasks. Thus, according to this view, only practice that includes specific task pairs should lead to improvement.

A Memory for Goals Explanation of Primary-Interrupting Task Pair Specific Improvement

As with the primary task improvement explanation discussed above, the Memory for Goals model (Altmann & Trafton, 2002, 2007) provides a mechanism that can help explain how task pair specific improvements may be realized. Recent instantiations of Memory for Goals have been used to predict performance on sequential tasks. For example, Altmann and Trafton (2007) built a model to predict performance on the task used in their first experiment; this model used the associative linking mechanism of ACT-R. In this model, each step provides associative priming to the next correct step in the sequence, increasing the likelihood of the correct step being retrieved from memory. Trafton, Altmann, and Ratwani (2009) have also used an instantiation of the Memory for Goals model which formed episodic traces of sequential tasks when the model knew what step to perform next. Episodic memory traces have slightly higher activation than normal declarative memory chunks and show speeded retrieval of well-learned information when compared with novel information. These instantiations of Memory for Goals (Altmann & Trafton, 2007; Trafton, Altmann, & Ratwani, 2009) suggest that people's performance on sequential tasks would improve only when they perform those tasks in the same sequence over time. This application of the Memory for Goals model would predict that the critical components of interrupted task performance lie in the transition between the primary and interrupting task and that only practice of specific task-interruption pairs over time would receive the benefit of faster resumption time associated with the use of episodic traces.

Support for Improvement Based on Improved Resumption Processes

One other possible explanation of how people improve at dealing with interruptions over time is that they simply learn how to recover from interruptions in general. In other words, it does not matter what the specific tasks are; rather, what is important is that they are experiencing the act of being interrupted and subsequently resuming. There is currently no evidence in the literature to either support or refute this possibility; however, if this type of improvement is observed, the Memory for Goals model (Altmann & Trafton, 2002, 2007) does provide the mechanisms by which this could occur.

Memory for Goal Explanation for Improved Resumption Processes

It could be that there are more general goals associated with the interruption resumption process (e.g., resume previous goal) as opposed to task-specific goals (e.g., resume VCR task). If the goals were more general, the strengthening constraint would suggest that every time a person is interrupted and then resumes, a general goal of handling an interruption would gain activation. As this general process goal gained strength over time, people would be able to resume more quickly after an interruption regardless of the actual content of the task. This explanation suggests that improvement at resumption would be facilitated by mere exposure to the general process of interruptions and resumptions but would not necessarily be observed with exposure to the primary task alone.

Experiment Rationale

Previous studies examining training in interrupted task performance were not designed to provide critical tests of whether improvements seen were attributable to improvement in the general process of resuming, improvement in the primary task regardless of interruptions, or improvement in resuming a specific primary task from a specific interruption. These studies only used one primary and interrupting task pair, and all participants had equal exposure to both the primary and interrupting tasks (Detweiler, Hess, & Phelps, 1994; Hess & Detweiler, 1994; Trafton et al., 2003). To evaluate the plausibility of the process-specific view of improvement, people must experience multiple primary and interrupting task pairs over time to see whether exposure to interruptions and resumptions in general leads to improved performance.

The following three experiments are designed to help determine both how and why people improve at dealing with interruptions over time. The goal of Experiment 1 is to examine whether the task-specific view of improvement requires that the primary and interrupting task pairs be trained with interruptions, as suggested by a critical components (Goettl & Shute, 1996) explanation using associative priming (Altmann & Trafton, 2007) and the formation of episodic traces (Trafton, Altmann, & Ratwani, 2009), or whether practice with the primary task alone will lead to improved performance, as suggested by a LTWM (Ericsson & Kintsch, 1995) explanation and the strengthening constraint from the Memory for Goals model (Altmann & Trafton, 2002, 2007). Experiment 2 looks to extend these findings to other task pairs, and finally, Experiment 3 investigates whether the improvement is task pair-specific (i.e., improvement only occurs for specific task pairs) or whether the improvement is in the general process of resuming (i.e., improvement occurs with exposure to the interruption and resumption process).

The theories described from studies on both interruptions and part-task training in conjunction with the various constraints and mechanisms of the Memory for Goals model (Altmann & Trafton, 2002, 2007) provide the rationale to explain performance increments attributable to either primary task exposure alone (LTWM), exposure to specific primary-interruption task pairs (critical components), or practice with the general process of resuming from interruptions (strengthening of general process goals). If we can understand how people improve handling interruptions with training, then we can tailor training programs and systems to take advantage of this improvement and reduce the disruptiveness of interruptions.

Experiment 1

A primary task view of improvement through training suggests that exposure to a specific primary task over time will improve performance (Oulasvirta & Saariluoma, 2004, 2006). However, because an interrupted task paradigm necessarily involves two tasks—the primary and interrupting tasks—it is unclear whether exposure to only the primary task or both the primary and interrupting task is necessary for improved interrupted task performance under the task-specific view. Thus, we designed an experiment in which participants had different amounts of training with the primary task before being interrupted. In this experiment, participants were interrupted in the last of three sessions, in the last two of three sessions, or in all three sessions.

If exposure to the primary task alone is sufficient for improved performance with interruptions, resumption times will decrease across sessions regardless of whether participants were interrupted in previous sessions; we would expect the resumption times to be equal for all three groups in Session 3. Alternatively, if exposure to both the primary and interrupting tasks together is required for improved performance with interruptions, we would expect resumption times to decrease only when participants trained in the presence of interruptions. In this case, the decrease in resumption times should be proportional to the number of interrupted sessions each participant completed rather than the total number of sessions each had completed.

Method

Participants. Fifty-seven undergraduates (30 females and 27 males) with an average age of 20 years from George Mason University participated for class credit. All were randomly assigned to one of three conditions.

Task and materials. The primary task, the Tank Task (see Figure 1a), was a complex desktop computer-based resource management and strategy task (Brock & Trafton, 1999). Participants were responsible for managing a set of 20 tanks (10 heavy-duty and 10 light-duty). The interface consisted of a number of windows that allowed the operator to equip the tanks with munitions and fuel with a constraint that the tank had to stay under a certain weight. Once outfitted, the tanks were sent on missions with the

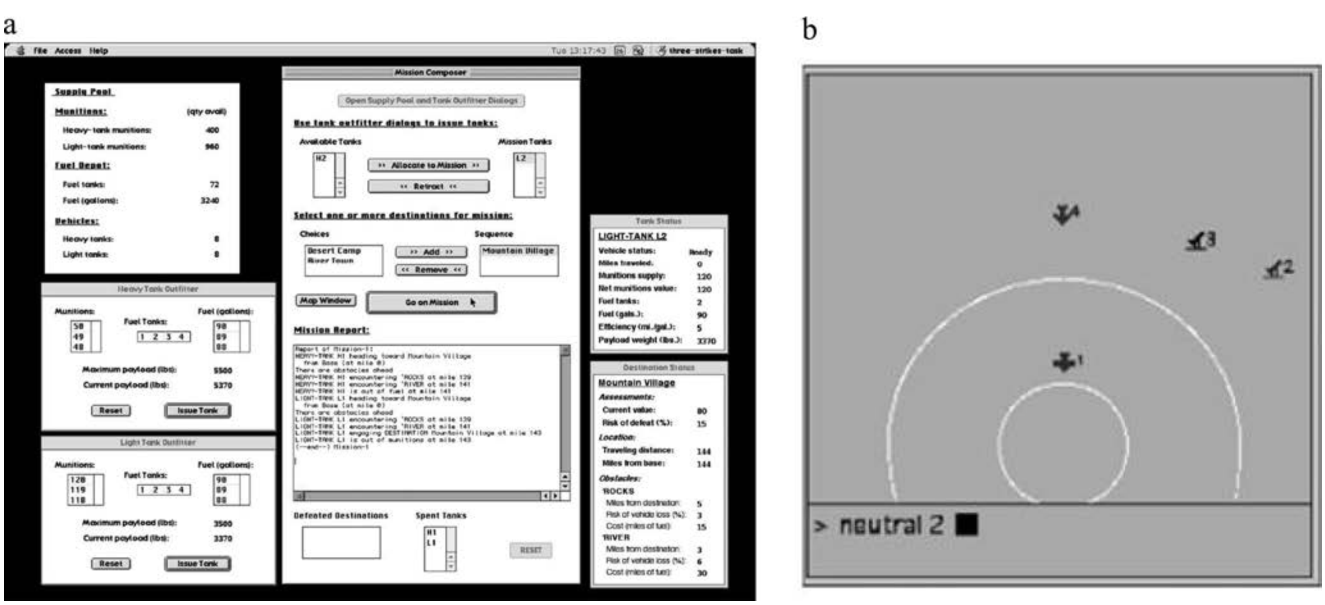

Figure 1. The task interfaces from Experiment 1. 1a, Tank Task; 1b, Radar Task.

goal of destroying the three target cities. Each target had a number of hit points that had to be reduced to zero for it to be destroyed, and each tank had an amount of damage it could do based on the amount of munitions and whether it was a light-duty or heavy-duty tank. In addition, each target city had a victory probability associated with it that specified the percentage of the time in which an attacking tank would be destroyed outright without doing any damage.

The three target cities were located at fixed distances that required the tanks to use a certain amount of fuel. If at any point a tank ran out of fuel or munitions, that tank was considered destroyed and no longer able to do damage. Participants had the option of allocating any number of tanks (1–20) at any given time and could attack the cities in any order they wanted. Double-clicking on any tank or city would bring up a status window showing the health, fuel remaining, and probability of defeat where appropriate. Mission updates were given via a text display in the middle screen after each attack to allow the participant to track the success or failure of the overall mission. This task ended when all three cities were destroyed, when no more fuel was available, when no more munitions were available, or when all 20 tanks had been destroyed. Participants were given a score at the end of each round to allow them to assess their performance.

The secondary task, the Radar Task (Figure 1b), was a tactical assessment task (Ballas, Kieras, Meyer, & Brock, 1999). In this task, objects appeared on the screen and had to be coded as either neutral or hostile before they flew off the bottom of the screen. Three types of objects were classified depending on their color and a set of rules regarding the speeds and flight patterns. All objects started as gray when they appeared on the screen and then turned to blue, red, or yellow. If they turned blue, they were automatically neutral and if they turned red, they were automatically hostile. If they turned yellow, then the participant needed to use the rules to classify them as hostile or neutral. The fighters and missile sites were to be classified as hostile if they were moving toward the center of the screen and neutral if they were staying on the sides of the screen. The airplanes were hostile if they were fast-moving and neutral if they were slow-moving.

Each object on the screen was numbered, and participants keyed in their responses by selecting the neutral or hostile button (labeled on the number pad) followed by the object number. Once classified, objects turned white and could be ignored. There was no distinction made between correct and incorrect classifications. The goal was merely for the participant to classify all of the objects on the screen. These two tasks were displayed sequentially and were never on the screen at the same time. All tasks were performed on a Macintosh G4 computer with a 17-inch (43 cm) VGA monitor.

Design and procedure. Each participant completed three sessions performing the primary task. One-third of the participants experienced interruptions only in the last session; one third experienced interruptions in the second and third sessions; the remaining third experienced interruptions in all three sessions. Before the first session, participants were trained on the primary and secondary tasks individually and then were given practice performing the primary task with one interruption from the secondary task. During an interruption session, participants were interrupted with the secondary task 12 times. Each interruption lasted approximately 30 seconds, and all interruptions occurred directly after a mouse click. At interruption onset, the Tank Task disappeared and was replaced with the Radar Task. Upon completion of the interruption, the Radar Task disappeared and the Tank Task reappeared with the mouse in the same location it was in just before the interruption onset.

Measures. Each mouse click in the primary task was recorded for all participants. Mouse clicks from the secondary task were not recorded. We calculated interaction intervals (IAI) for the primary task by taking the time difference between successive actions, defined by mouse clicks.

A special type of interaction interval called the resumption lag (RL) was measured for each of the 12 interruptions in the interruption sessions. Resumption lag is defined as the time it takes to resume the primary task after the cessation of the interruption (Altmann & Trafton, 2002; Trafton et al., 2003), measured in this task as the time between when the Tank Task is redisplayed after an interruption and the participants' first action (mouse click) on the Tank Task. This metric has been shown to quantify reliably the disruptive effects of interruptions (Monk, Trafton, & Boehm-Davis, 2008; Ratwani, 2008; Trafton et al., 2003).

Results and Discussion

Reaction time data were log transformed to better approximate a normal distribution. Furthermore, the log transformed data were converted to standardized *Z* scores (see Table 1 for untransformed means and standard errors for Experiment 1). This was done to remove effects attributable to the specific tasks used (Experiment 1: Tank and Radar, Experiments 2 and 3: VCR, Tracking, Shadowing) and to allow for accurate comparisons across conditions and experiments (Ratcliff, 1993).

Interaction intervals. We first wanted to examine the extent to which performance improved on the primary task overall, regardless of whether or not people were interrupted. As expected, a linear contrast showed that the mean IAIs decreased from Session 1 to Session 3 for all participants collapsed across number of

Table 1
Means and Standard Error for Inter-Action Intervals and Resumption Lags in Milliseconds in Experiment 1

Condition	Measure	Session 1	Session 2	Session 3
3 Interruption	RL	5555 (434.56)	5313 (933.24)	4624 (443.80)
	IAI	1491 (105.89)	1418 (106.04)	1264 (86.09)
2 Interruption	RL	NA	5033 (426.85)	5106 (678.67)
	IAI	1601 (87.53)	1378 (108.57)	1247 (77.21)
1 Interruption	RL	NA	NA	5794 (381.89)
	IAI	1764 (152.47)	1649 (122.63)	1382 (98.92)

interrupted sessions, $F(1, 54) = 45.10$, $MSE = .026$, $p < .001$, $\eta_p^2 = .46$. This suggests that over time, people were able to perform the primary task faster.

Resumption lags. We next wanted to see the extent of improvement in the participants' ability to resume when they were interrupted in all three sessions. A linear contrast showed that RLs decreased across sessions, $F(1, 18) = 6.76$, $MSE = .215$, $p < .05$, $\eta_p^2 = .27$ (see Figure 2) when participants were interrupted in all three sessions. Consistent with previous research (Trafton et al., 2003), this finding showed that people's ability to resume improved over time with repeated exposure to interruptions.

To evaluate the differential effects of practice with the primary task alone versus practice with interruptions, we compared the resumption lags across participants in Session 3. In this session, all participants were completing their third session of the primary task; however, one third of the participants were experiencing interruptions for the third time, one third were experiencing them for the second time, and one third were experiencing interruptions for the first time. Differences between the three conditions in the third session can, therefore, be attributed to experience with interruption and not experience with the primary task as all groups had performed three sessions of the primary task at this point. To examine this effect, we conducted a one-way ANOVA with linear contrast on Session 3 RLs across all three conditions. This analysis revealed a linear decrease in RLs, $F(1, 54) = 7.06$, $MSE = .366$, $p < .05$, $\eta_p^2 = .88$, with the slowest resumption lags for participants who were experiencing interruptions for the first time and the fastest RLs for participants who were experiencing interruptions for the third time (see Figure 2). This provides support for either a task-pair-specific (Goettl & Shute, 1996) or a general-resumption-process (Altmann & Trafton, 2002) mechanism of improvement. It still could be that practice with the general process of resuming is enough to facilitate improvement or that practice with specific task pairs is necessary for faster resumption.

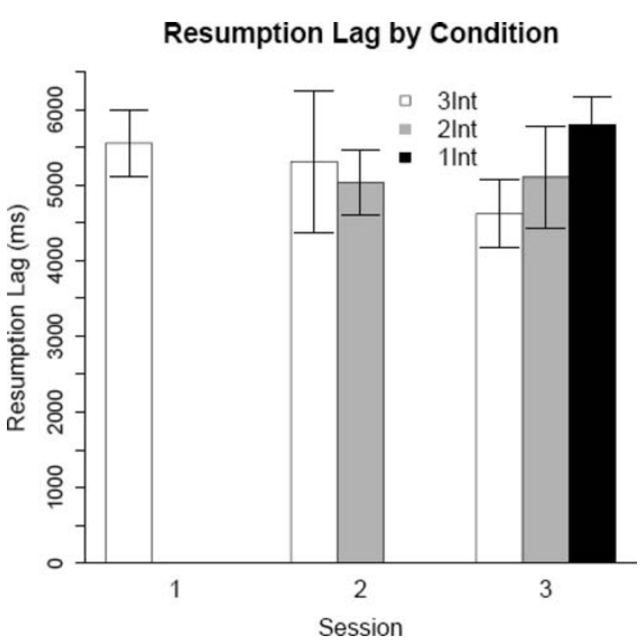

Figure 2. Mean resumption lags (untransformed) by condition and session for Experiment 1. Error bars are standard error of the mean.

We performed a final analysis to determine whether training on the primary task alone, as suggested by LTWM (Oulasvirta & Saariluoma, 2004, 2006), is sufficient to lead to improvement in the interruption resumption process. A one-way ANOVA on the RLs of the first interrupted session in each condition (i.e., Session 1 for participants interrupted in all three sessions, Session 2 for participants interrupted in the second and third sessions, and Session 3 for participants interrupted in only the third session) revealed no differences in the RLs between any of the groups ($F < 1$) (see Figure 2). This finding suggests that added exposure to the primary task before first experiencing interruptions does not improve the ability to resume after the first interruption.

Experiment 1 demonstrated that, although people become faster at performing a task overall (i.e., interaction intervals) with more training, they only improve at resuming from interruptions if they practice with interruptions (i.e., resumption lags in Session 3 were shortest for participants with the most experience with interruptions).

Experiment 2

Consistent with both a task-pair-specific and a general-resumption-process view of improvement, Experiment 1 showed that training on a task with interruptions improves performance only if that training provides exposure to both the primary and interrupting tasks together. However, it is not clear whether all task pairs require this level of task specificity to show improvement or whether this effect was specific to the task pair used (i.e., Tank Task and Radar Task). To investigate this question, Experiment 2 used a new primary task paired with one of two types of interrupting tasks. Participants again were interrupted in one, two, or all three of the sessions. Interrupting task type was a between-subjects manipulation, so each participant only experienced one of the two interrupting tasks.

We expected that, as in Experiment 1, participants would improve at resuming across sessions (as indicated by RLs) only when they were interrupted in previous sessions and that resumption times would be equivalent the first time participants were interrupted, whether it was in Session 1, 2, or 3 for the primary task paired with either of the two interrupting tasks. Lastly, we expected no performance differences between the two interrupting tasks, as long as exposure to each was equivalent.

Method

Participants. Seventy-two undergraduates (29 females and 43 males) with an average age of 20 years from George Mason University participated for class credit. All were randomly assigned to one of six conditions.

Task and materials. The primary task required participants to program a VCR using a simulated VCR built in Macintosh Common Lisp. The VCR interface (Figure 3a) was designed for experimental use (Gray, 2000). Programming a show consisted of four tasks: entering the show's start time, end time, day of week, and channel number. Two of these four tasks were broken down further into subtasks. There were three subtasks for the start time (start-hour, start-10min, and start-min) and three for the end time (end-hour, end-10min, and end-min). The day of week and channel tasks contained no subtasks; these tasks were therefore considered to be equivalent to the subtask level rather than the task level. To

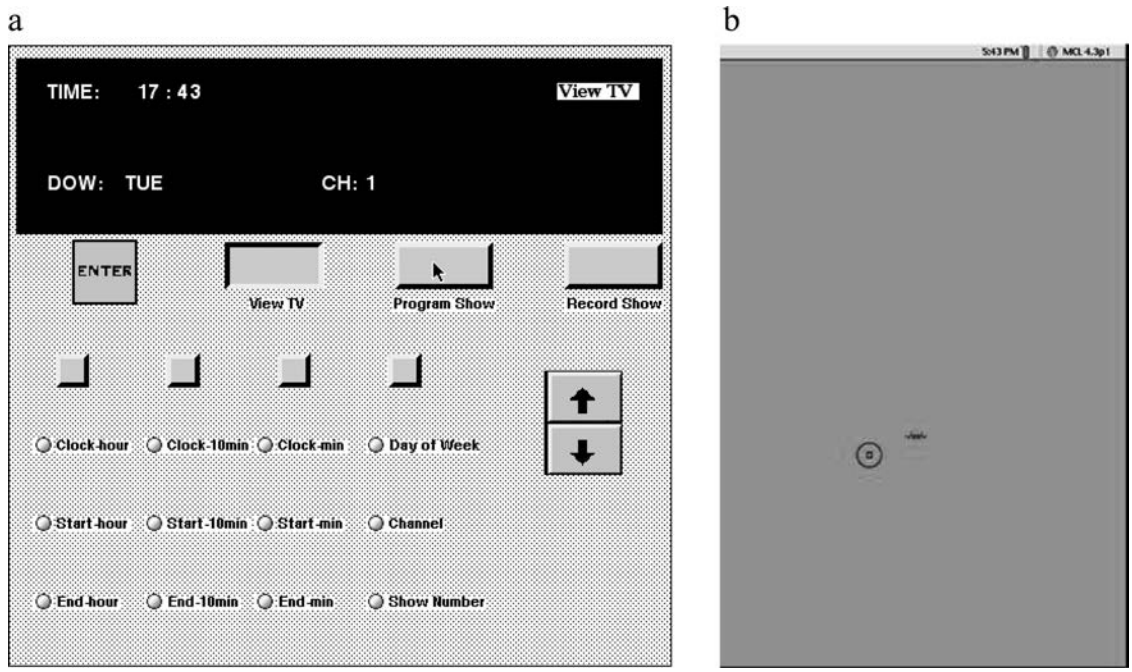

Figure 3. The task interfaces for Experiments 2 and 3. 3a, VCR Task; 3b, Tracking Task.

better understand the steps involved in carrying out these subtasks, consider the subtask of entering the start time. To enter the start time, the participant first clicked the column button above the hour buttons (the left-most square button). This signifies the beginning of the start-hour subtask. The participant then clicked the start-hour button and clicked on the up or down arrow multiple times until the displayed hour number reached the target. Next, the participant clicked on the enter button to save the start-hour setting. Finally, to end this subtask, the participant clicked the column button again (to "deselect" it) before moving onto the next subtask. The participant was required to repeat the same steps for the start-10min and start-min settings to complete the start-time entry. The same process was completed for the end time, day of week, and channel number entries. The VCR display was blank when no setting was selected. The participants had access to target show information (the show name, start time, end time, day of week, and channel number) at all times, as the information was posted to the right of the monitor on a 3- × 5-inch (7.6- × 12.7-cm) index card.

There were two types of interruption tasks. The first was a pursuit-tracking task and the second was a shadowing task. The tracking task interruption (Figure 3b) required the participant to track an airplane (target) moving around the screen in a random pattern with the mouse. For the shadowing interruption task, the screen went blank and the participant was required to listen to a series of one-digit numbers read aloud by the computer in a random order. For each number, participants simply had to repeat the number out loud. During both types of interruptions, the VCR task was blanked out during the interruption. It reappeared with the mouse cursor repositioned to the last location before the interruption at the end of the 30-second interruptions.

The VCR and interruption tasks were presented side by side on a Macintosh G4 computer with a 17-inch (43-cm) VGA monitor. The VCR task was on the left side of the monitor and the tracking task was on the right side. Both tasks required only the computer mouse, and only one of the tasks was visible at a time.

Design and procedure. As in Experiment 1, participants were trained on the primary and secondary tasks, first individually and then together before the experimental trials began. Sessions (1, 2, and 3) were once again the within-subjects factor, while the number of interrupted sessions (1, 2, or 3) and secondary task type (pursuit tracking or shadowing) were between-subjects factors. Participants were only trained on the secondary task corresponding to the condition to which they were randomly assigned. Each session lasted approximately 15 minutes and consisted of three VCR trials (or shows). In noninterrupted sessions, participants performed only the VCR task; during interruption sessions, they performed both the primary and secondary tasks and were interrupted an average of 11 times per session. Each interruption lasted 30 seconds, and all interruptions occurred directly after a mouse click. Upon interruption onset, the VCR task disappeared. For the tracking task, the VCR was replaced with the moving airplane (target). For the shadowing task, the VCR was replaced with a blank screen. At the end of the interruption, either the tracking task or blank screen disappeared and was replaced with the VCR with the mouse cursor in the same position it was in just before the start of the interruption.

Measures. The measures were identical to Experiment 1. The time between any two mouse clicks was considered an interaction interval. Resumption lags once again corresponded to the time between the end of the interruption and the first mouse click back on the primary task.

Results and Discussion

As in Experiment 1, all reaction time data were log transformed and then converted to standardized *Z* scores (see Table 2 for untrans-

Table 2
Means and Standard Error for Inter-Action Intervals and Resumption Lags in Milliseconds in Experiment 2

Condition	Measure	Session 1	Session 2	Session 3
3 Interruption	RL	2664 (124.59)	2392 (101.65)	2270 (92.10)
	IAI	933 (31.77)	777 (23.28)	756 (28.73)
2 Interruption	RL	NA	2580 (126.20)	2353 (139.76)
	IAI	760 (29.88)	829 (35.48)	751 (29.59)
1 Interruption	RL	NA	NA	2661 (125.44)
	IAI	760 (19.76)	647 (17.32)	761 (24.21)

formed means and standard errors for Experiment 2). There were no differences between the interaction intervals (all conditions, $F < 1$) or resumption lags (all conditions, $F < 1$) across secondary task type (pursuit-tracking or shadowing). This suggests that the overall pattern of results was unaffected by secondary task type, even though previous research has found effects of primary and interrupting task similarity (Detweiler, Hess, & Phelps, 1994; Gillie & Broadbent, 1989; Oulasvirta & Saariluoma, 2004). Because there were no effects of interrupting task, data were collapsed across both interrupting tasks to form three groups: those who were interrupted in all three sessions, those who were interrupted in only the second and third session, and those who were interrupted in only the third session. Half of the participants in each group performed the tracking interruption and the other half performed the shadowing interruption.

Interaction intervals. The interaction intervals in Experiment 2 showed a different pattern than in Experiment 1. In the first experiment, the interaction intervals decreased linearly across sessions for all participants regardless of the number of interrupted sessions they performed. In Experiment 2, however, the IAIs showed a different pattern. Interaction intervals decreased only when two successive sessions were performed either with or without interruptions. Furthermore, IAIs actually increased for the first session performed with interruptions, when it followed the performance of an uninterrupted session. Because of this unexpected pattern of data, we did not collapse across number of interrupted sessions for analysis of IAIs as in Experiment 1.

We first examined the IAI data for participants who were interrupted in all three sessions. As in Experiment 1, a contrast revealed that IAIs decreased linearly across sessions, $F(1, 23) = 19.26$, $MSE = .009$, $p < .001$, $\eta_p^2 = .46$.

Participants who were interrupted in the second and third sessions did not show a linear decrease in IAIs across sessions ($p = .43$). A quadratic contrast, however, was significant, $F(1, 23) = 8.81$, $MSE = .066$, $p < .01$, $\eta_p^2 = .28$, reflecting the increase in IAIs from Session 1 to Session 2 and the decrease from Session 2 to Session 3 (see Figure 4). Least Significant Difference post hoc comparisons from the omnibus ANOVA, $F(2, 46) = 3.51$, $MSE = .011$, $p < .05$, $\eta_p^2 = .13$, revealed that all three sessions were significantly different from one another ($p < .05$). This suggests that the onset of the interruptions in the second session led to a performance decrement on the primary task as evidenced by increased IAIs. By the third session, participants were faster than in either of the two previous sessions.

For participants interrupted in only Session 3, a quadratic contrast revealed a decrease in IAIs from Session 1 to Session 2 and an increase from Session 2 to Session 3, $F(1, 23) = 16.76$, $MSE = .009$, $p < .001$, $\eta_p^2 = .42$ (see Figure 4). Least Significant Difference post hoc comparisons from the omnibus ANOVA, $F(2, 46) = 8.81$, MSE .008, $p < .01$, $\eta_p^2 = .28$, showed a significant decrease from Session 1 to Session 2 ($p < .01$), corresponding to consecutive sessions without interruptions, and a significant increase from Session 2 to Session 3 ($p < .01$), corresponding to the first exposure to interruptions in Session 3. There was no difference in IAIs between Session 1 and Session 3 ($p = .65$). When exposed to interruptions for the first time in the third session, performance on the primary task deteriorated to the levels in Session 1 when they were first exposed to the task. The first exposure to interruptions disrupts primary task performance, as shown by the third group, interrupted in only the last session, which showed a decrease in IAIs from Session 1 to Session 2 as they performed the primary task uninterrupted in consecutive sessions, and then showed an increase in IAIs in the third session when interruptions were first introduced.

Overall, this pattern of results suggests that for these combinations of tasks (i.e., VCR & Tracking or VCR & Shadowing), faster performance on the primary task results only from successive

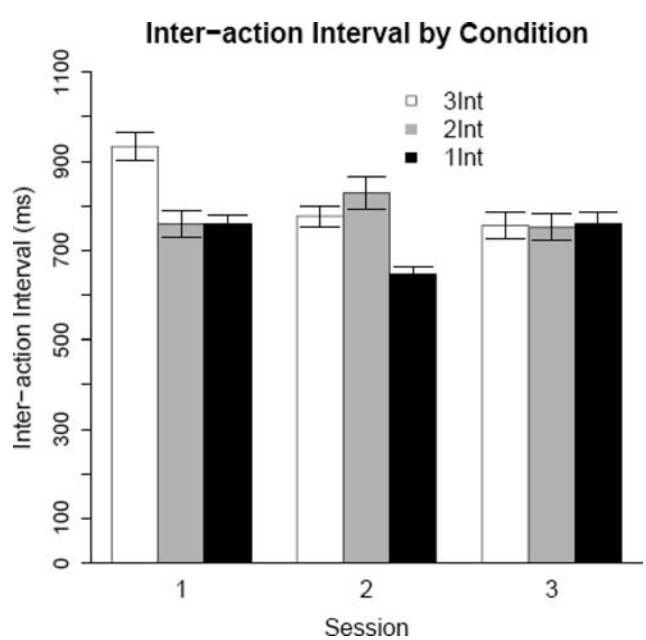

Figure 4. Mean interaction intervals (untransformed) by condition and session for Experiment 2. Error bars are standard error of the mean.

performance of a task under the same conditions (interruptions or no interruptions). This data pattern is unlike the one we found in Experiment 1 with the Tank Task, where participants performed faster across trials, regardless of whether or not the current or previous session contained interruptions. In Experiment 2, participants only showed improvements on the VCR task when they were exposed to the same conditions in two successive sessions (i.e., either with or without interruptions for both sessions). The data across these two experiments continue to support either a task-pair-specific or general-resumption-process mechanism of improvement; faster performance is seen only with exposure to specific primary and interrupting task pairs. However, these data also reveal that some primary tasks may be more or less susceptible to the deleterious effects of interruptions.

Resumption lags. As in Experiment 1, RLs for participants interrupted in all three sessions decreased linearly from Session 1 to Session 3, $F(1, 23) = 23.49$, $MSE = .061$, $p < .001$, $\eta_p^2 = .51$ (see Figure 5). This finding serves as a manipulation check and confirms that people can improve in their ability to resume after an interruption with training at resuming from that interruption.

Consistent with either a task-pair-specific or general-resumption-process view of improvement, a one-way ANOVA comparing the RLs across conditions in Session 3 revealed a linear decrease with increased exposure to interruptions, $F(1, 69) = 4.47$, $MSE = .38$, $p < .05$, $\eta_p^2 = .79$. In other words, the fastest RLs were shown by participants who were performing their third consecutive session with interruptions and the slowest RLs were shown by participants experiencing interruptions for the first time (see Figure 5).

Finally, in line with Experiment 1 and contradicting a primary-task-specific mechanism of improvement (LTWM, Oulasvirta & Saariluoma, 2004, 2006), participants' ability to resume was not affected by prior exposure to the primary task alone, as RLs were similar the first time participants were interrupted, regardless of the session in which the first interruption occurred (i.e., Session 1 for those interrupted in all 3 sessions, Session 2 for those interrupted in Sessions 2 and 3, and Session 3 for those interrupted only in Session 3). A nonsignificant one-way ANOVA on the RLs of each group's first interrupted session, $p = .998$ (see Figure 5), adds support for this interpretation.

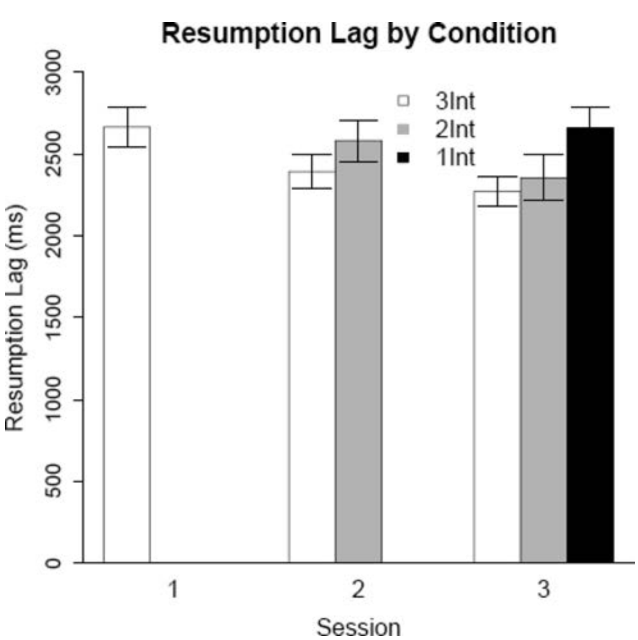

Figure 5. Mean resumption lags (untransformed) by condition and session for Experiment 2. Error bars are standard error of the mean.

Taken as a whole, the results of Experiments 1 and 2 are consistent with either a task-pair-specific or general-resumption-process view of improvement where the pairing of primary and interrupting tasks is important. These results are inconsistent with a primary-task-specific view of improvement. It does not appear that practice on the primary task alone allows people to use the protected encoding and retrieval structures of LTWM to help guard against the disruptive effects of interruptions (Oulasvirta & Saariluoma, 2004, 2006).

Although the ability to resume after an interruption (as measured by RLs) in both Experiments 1 and 2 improved when participants were exposed to interruptions in successive sessions, Experiment 2 also showed that primary task performance (as measured by IAIs) may also be affected by interruptions. Although primary task performance improved over trials in Experiment 1 regardless of whether or not the session contained interruptions, similar improvements in Experiment 2 only occurred over consecutive sessions in the same condition (i.e., interrupted or not interrupted). This suggests that the specific tasks being performed have an effect on how people learn to perform them. Most importantly, however, Experiments 1 and 2 suggest that exposure to a primary task without interruptions is not sufficient to mitigate the disruptive effects of later interruptions.

Experiment 3

Consistent with the idea that the critical components (Goettl & Shute, 1996) necessary for improvement at handling interruptions involve exposure to specific task pairs, Experiments 1 and 2 provide clear support for a task-pair-specific view of improvement through practice. However, neither experiment rules out the possibility that general-resumption-process learning (Altmann & Trafton, 2002, 2007) may also contribute to improved performance. In Experiments 1 and 2, participants were only exposed to one interrupting task (i.e., Radar Task in Experiment 1, Tracking or Shadowing Tasks in Experiment 2). It is therefore possible that people were actually improving at the general process of resuming rather than learning critical components of how to resume for the specific task pairs (e.g., VCR-Tracking or VCR-Shadowing). Thus, Experiment 3 was designed to investigate whether exposure to interruptions in general, regardless of specific tasks, would lead to improved resumption over time.

To address the question of whether the improvements are task-pair-specific or a general-resumption-process, we needed to expose participants to multiple types of interruptions using the same primary task. Therefore, all participants in Experiment 3 were interrupted in all three sessions; however, the interrupting task either changed or remained the same from session to session. If people were improving as a result of learning a resumption process, the actual content of the interrupting tasks should not be important and recovery improvements should be seen in all conditions. Alternatively, if people were improving as a result of learning specific task-interruption pairs, improvement in resumption should only be observed when consecutive sessions feature the same interrupting task.

Method

Participants. Seventy-two undergraduates (51 females and 21 males) with an average age of 20 years from George Mason University participated for class credit. All were randomly assigned to one of six conditions.

Task and materials. The experimental setup, task, and materials were identical to those used in Experiment 2.

Design and procedure. Participants were trained on the primary and secondary tasks (either one or both, depending on the condition to which they were assigned) individually and together before beginning the experiment. All participants performed three sessions of the task. In Experiment 3, participants saw one or both secondary task types (Shadowing and Tracking) depending on which condition they were assigned to. The order of the secondary task presentation, however, was manipulated between subjects. Across the three sessions, there were three possible orders of secondary tasks: A-A-A, A-A-B, A-B-B, where A and B refer to either the Tracking or Shadowing task. For example, A-A-B indicates that the order of sessions was either Shadowing-Shadowing-Tracking or Tracking-Tracking-Shadowing. The remainder of the procedure was identical to Experiment 2.

Measures. The measures were also identical to those used in Experiment 2.

Results and Discussion

All reaction time data were log transformed and then converted to standardized *Z* scores before analysis as in Experiments 1 and 2 (see Table 3 for untransformed means and standard errors for Experiment 3). There were no differences between the IAIs ($F < 1$) or RLs, $F(1, 66) = 2.10$, $MSE = .735$, $p = .15$, $\eta_p^2 = .03$, for participants who performed the Shadowing Task first compared with those who performed the Tracking Task first. There were no significant interactions as a function of which secondary task was performed first or as a function of the order of secondary tasks across sessions for either IAIs ($F < 1$) or RLs, $F(2, 66) = 1.02$, $MSE = .735$, $p = .37$, $\eta_p^2 = .03$. We, therefore, collapsed all data for IAIs and RLs across secondary task type, leaving three patterns of secondary task performance across sessions (A-A-A, A-A-B, and A-B-B).

Interaction intervals. In this experiment, all participants were interrupted in each session. A manipulation check was run to confirm that participants improved on the primary task across sessions. For this analysis, IAIs were collapsed across secondary task, as this variable did not reliably affect performance. Consistent with previous research (Newell & Rosenbloom, 1981), Experiment 1, and the three-session interruption condition from Experiment 2, a linear contrast showed that mean IAIs decreased from Session 1 to Session 3, $F(1, 71) = 11.65$, $MSE = .010$, $p < .01$, $\eta_p^2 = .14$ (Note that all participants in Experiment 3 were interrupted in all three sessions).

Resumption lags. In Experiments 1 and 2, when participants were interrupted in all three sessions, their ability to resume improved across sessions. This is comparable to the A-A-A task order in Experiment 3, where participants were interrupted with the same interrupting task in all three sessions. A linear contrast confirmed that RLs decreased across sessions for the A-A-A condition, $F(1, 23) = 20.96$, $MSE = .091$, $p < .001$, $\eta_p^2 = .48$ (see Figure 6).

The critical question posed in Experiment 3 was whether people were improving as a result of practice with a general-resumption process or practice with specific-task pairs. The A-A-B and A-B-B conditions in Experiment 3 speak directly to this distinction. If improvements were a result of practice with a general-resumption process attributable to strengthening of a general-process goal (Altmann & Trafton, 2002, 2007) then we would expect faster resumption times from Session 1 to 3 for both the A-A-B and A-B-B conditions. However, if improvements were a result of practice with specific-task pairs, consistent with the critical components (Goettl & Shute, 1996) being the relationship between the two tasks attributable to associative priming (Altmann & Trafton, 2007) and/or the formation of episodic traces (Trafton, Altmann, & Ratwani, 2009), then we would expect to only see faster resumption times when successive sessions were performed with the same interrupting task (i.e., the A-A of A-A-B and the B-B of A-B-B). Least Significant Difference post hoc comparisons from the omnibus repeated measures ANOVA for the A-A-B group, $F(2, 46) = 1.33$, $MSE = .147$, $p = .27$, $\eta_p^2 = .06$, revealed, as suspected, that participants' RLs in Session 2 were significantly faster than in Session 1 ($p < .01$, see Figure 6). RLs appeared to increase slightly between Sessions 2 and 3, however the effect was not significant ($p = .88$). The lack of improvement (actually a slight increase) between Sessions 2 and 3 in the A-A-B condition is inconsistent with a general resumption process explanation of improvement. Rather, this finding supports the idea that improvement is attributable to practice at resuming one specific task from another specific task.

Table 3
Means and Standard Error for Inter-Action Intervals and Resumption Lags in Milliseconds in Experiment 3

Condition	Measure	Session 1	Session 2	Session 3
A, A, A	RL	2769 (165.83)	2472 (145.45)	2312 (137.01)
	IAI	873 (45.78)	782 (38.14)	763 (29.99)
A, A, B	RL	2380 (140.84)	2250 (130.80)	2264 (128.30)
	IAI	779 (26.55)	748 (28.16)	713 (22.92)
A, B, B	RL	2454 (106.47)	2417 (116.13)	2105 (79.43)
	IAI	781 (27.84)	758 (27.81)	687 (20.62)

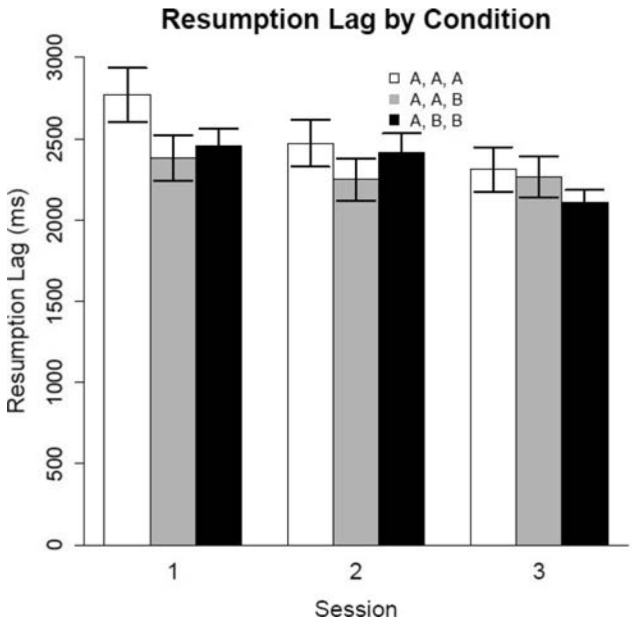

Figure 6. Mean resumption lags (untransformed) by condition and session for Experiment 3. Error bars are standard error of the mean.

Further support for a task-pair-specific view of improvement comes from the analysis of the A-B-B condition. Least Significant Difference post hoc comparisons from the omnibus repeated measures ANOVA for the A-B-B, $F(2, 46) = 6.71$, $MSE = .087$, $p < .01$, $\eta_p^2 = .23$, confirmed a nonsignificant difference between Sessions 1 and 2 ($p = .76$) and a significant decrease between Sessions 2 and 3 ($p < .01$). This is strong evidence that what is actually being learned is a primary and interrupting task-specific interruption/resumption process, not a more general process-specific mechanism.

General Discussion

The goal of this research was to determine whether improvements in interrupted task performance over time are the result of practice with the primary task alone (Oulasvirta & Saariluoma, 2004, 2006), practice with specific task pairs (Goettl & Shute, 1996), or practice with a general resumption process (Altmann & Trafton, 2002, 2007).

Experiment 1 was consistent with both the task-pair-specific view and a general-resumption-process view, showing that although performance on the primary task improves with training, the ability to resume that task after an interruption only improves when people have had previous training at handling that specific task with interruptions. Using different task pairs, Experiment 2 further supported these two views and ruled out the view that practice with the primary task only can help mitigate the disruptive effects of interruptions. Improvement at resuming after an interruption was only seen when participants had previously trained in sessions with interruptions. Finally, Experiment 3 ruled out a more general-resumption-process view, confirming that improvements are task-pair-specific. In this experiment, RLs only decreased when people repeated a specific primary and interrupting task pair. As soon as they performed the same primary task with a different secondary task, they showed a slight performance decrement in the primary task along with no improvement in resumption performance.

These results suggest it is not sufficient to practice either the primary task alone (Oulasvirta & Saariluoma, 2004, 2006) or interruptions in general (Altmann & Trafton, 2002). Thus, our findings were inconsistent with improvement attributable to primary task practice only, as suggested by LTWM (Oulasvirta & Saariluoma, 2004, 2006), a more general resumption mechanism, or the strengthening constraint of Memory for Goals (Altmann & Trafton, 2002). In three experiments, improvement at resuming only occurred when participants performed the same task pairs over time.

Across our three studies, it appears that people improve at resuming when they are exposed to specific primary-interruption task pairs. Anderson (1983) proposed that as people perform tasks over time, they require less and less working memory resources, allowing tasks to be performed more quickly. Given that we only saw improvements when the specific task pair was practiced together, our data suggest that a task performed without interruptions and the same task performed with interruptions may be processed, encoded, and retrieved as completely different tasks. This idea is consistent with the idea that the critical components (Goettl & Shute, 1996) are in the actual process of resuming one specific task from another specific task and not just performance of the task itself. That is, the act of resuming one task from another is what gains strength and requires less mental resources over time. Therefore, training a single task in isolation and then interrupting it would not provide the practice necessary to reduce the mental resources associated with the resumption process. In fact, our data from Experiment 2 showed that exposure to an interruption after practicing a primary task alone can actually lead to *decreased* performance on the primary task, suggesting that the interruption and resumption process of a specific task pair can be novel enough to interfere with a previously learned single task.

Although the results of these experiments clearly support a task-pair-specific view of practice with interruptions, they do not necessarily rule out a process-specific view. In these experiments participants only had one hour of exposure to the tasks. Although this amount of time was sufficient to show changes in performance, it may not have been sufficient to allow process-specific training to take hold. It is possible that both task- and process-specific improvements do occur, but their maturation takes place on different time scales. Future studies should examine how performance improves over longer practice periods (i.e., days, weeks, or even months). It is possible that at longer time intervals, evidence of process-specific improvements may arise.

Additionally, it is possible that alternative approaches to complex task training may help if applied to interrupted task performance. Another type of training that could be investigated in future studies is variable-priority training. Gopher, Weil, and Siegel (1989) showed that providing variable emphasis on different parts of a single complex task led to greater improvements than simply performing the task with no differential emphasis. Further, Metzger, Duley, Abbas, and Parasuraman (2000) showed that a variable-priority approach outperformed both whole- and part-task training approaches in reducing complacency associated with lengthy exposure to automated systems. Although the tasks used in these experiments were single complex tasks, it is possible that applying a variable-priority strategy to interrupted task performance could lead to similar improvements.

Practical Implications

The experiments presented here suggest that the resumption process is not a general process which can be learned outside of a specific context. In order for people to improve at resuming after an interruption, they must train with that interruption. To minimize the disruptive effects of interruptions, it is not sufficient for people to simply become an expert at specific tasks individually; rather, they must also attain expertise at performing tasks with interruptions. Thus, people who work in environments that are subject to many interruptions would be well served to practice specific pairs of primary and interrupting tasks which they often find go together.

Developing interruption-specific training is especially important in safety-critical environments like the flight deck, where not only have interruptions been shown to be both pervasive and disruptive, but where error tolerance is at or near zero percent (Dismukes & Young, 1998). Both task-analytic and observational techniques should be used to first identify what types of interruptions are most common in a given environment. On the flight deck, some examples of the common interruptions are radio contact with air traffic controllers, requests from flight attendants, or alarms and alerts from the aircraft itself. Incorporating these common interruptions into flight simulations on which all pilots are trained would help to reduce disruptions on the flight deck. Obviously, there is no way to know exactly what primary and interruption task pair will manifest during an actual flight, but providing training on the most frequent interruptions paired with common flight deck tasks (e.g., programming flight computer, changing radio frequencies, checking equipment status) increases the probability of giving pilots practice on specific primary and interruption task pairs that they would see during a real flight and would make those interruptions less disruptive.

More importantly, following this approach to training—identifying common interruptions and introducing them into simulations of common tasks—will lead to these interruptions becoming less disruptive in the future. Training programs for both safety-critical and everyday environments should consider implementing common interruptions into the training of common primary task to ensure that operators will be able to resume accurately and quickly when faced with them when performance matter most.

References

Altmann, E. M., & Trafton, J. G. (2002). Memory for goals: An activation-based model. *Cognitive Science, 26,* 39–83.

Altmann, E. M., & Trafton, J. G. (2007). Timecourse of recovery from task interruption: Data and a model. *Psychonomics Bulletin and Review, 14, 1079*–1084.

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. L. (2004). An integrated theory of the mind. *Psychological Review, 111*(4), 1036–1060.

Ballas, J. A., Kieras, D. E., Meyer, D. E., & Brock, D. P. (1999). Cueing of display objects by 3-D audio to reduce automation deficit. In *Fourth Annual Symposium on Situational Awareness in the Tactical Environment.* Patuxent River, MD.

Brock, D. P., & Trafton, J. G. (1999). Cognitive representation of common ground in user interfaces. In J. Kay (Ed.), *User modeling: Proceedings of the seventh international conference.* New York: Springer-Wien.

Cutrell, E., Czerwinski, M., & Horvitz, E. (2001). Notification, disruption, and memory: Effects of messaging interruptions on memory and performance. In M. Hirose (Ed.), *Human-Computer Interaction- INTERACT 2001 Conference Proceedings* (pp. 263–269). Amsterdam: IOS Press.

Detweiler, M. C., Hess, S. M., & Phelps, M. P. (1994). *Interruptions and working memory.* The Pennsylvania State University.

Dismukes, R. K., & Young, G. (1998). Cockpit interruptions and distractions: Effective management requires a careful balancing act. *ASRS Directline, 10,* 4–9.

Edwards, M. B., & Gronlund, S. D. (1998). Task interruption and its effects on memory. *Memory, 6*(6), 665–687.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working-memory. *Psychological Review, 102*(2), 211–245.

Eyrolle, H., & Cellier, J. M. (2000). The effects of interruptions in work activity: Field and laboratory results. *Applied Ergonomics, 31*(5), 537–543.

Gillie, T., & Broadbent, D. (1989). What makes interruptions disruptive? A study of length, similarity, and complexity. *Psychological Research, 50,* 243–250.

Gobet, F., & Simon, H. A. (1996). Recall of rapidly presented random chess positions is a function of skill. *Psychonomic Bulletin and Review, 3,* 159–163.

Goettl, B. P., & Shute, V. J. (1996). Analysis of part-task training using the backward-transfer technique. *Journal of Experimental Psychology: Applied, 2*(3), 227–249.

Gopher, D., Weil, M., & Siegel, D. (1989). Practice under changing priorities: An approach to the training of complex skills. *Acta Psychologica, 71*(1–3):147–177.

Gray, W. D. (2000). The nature and processing of errors in interactive behavior. *Cognitive Science, 24*(2), 205–248.

Hess, S. M., & Detweiler, M. C. (1994). Training to reduce the disruptive effects of interruptions. In *Human Factors and Ergonomics Society 38th Annual Meeting.*

Hodgetts, H. M., & Jones, D. M. (2006). Contextual cues aid recovery from interruption: The role of associative activation. *Journal of Experimental Psychology-Learning Memory & Cognition, 32*(5), 1120–1132.

Johnson, S. L. (1981). Effect of training device on retention and transfer of a procedural task. *Human Factors, 23,* 27–272.

Mané, A. M., Adams, J. A., & Donchin, E. (1989). Adaptive and part-whole training in the acquisition of a complex perceptual-motor skill. *Acta Psychologica, 71*(1–3), 179–196.

Metzger, U., Duley, J. A., Abbas, R., & Parasuraman, R. (2000). Effects of variable-priority training on automation-related complacency: performance and eye movements. *Human Factors and Ergonomics Society Annual Meeting Proceedings, 44,* 346–349.

Monk, C. A., Boehm-Davis, D. A., & Trafton, J. G. (2004). Recovering from interruptions: Implications for driver distraction research. *Human Factors, 46*(4), 650–663.

Monk, C. A., Trafton, J. G., & Boehm-Davis, D. A. (2008). The effect of interruption duration and demand on resuming suspended goals. *Journal of Experimental Psychology: Applied, 14*(4), 299–313.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive Skills and Their Acquisition* (pp. 1–55). Hillsdale, NJ: Erlbaum.

Oulasvirta, A., & Saariluoma, P. (2004). Long-term working memory and interrupting messages in human-computer interaction. *Behaviour & Information Technology, 23*(1), 53–64.

Oulasvirta, A., & Saariluoma, P. (2006). Surviving task interruptions:

Investigating the implications of long-term working memory theory. *International Journal of Human-Computer Studies, 64*(10), 941–961.
Ratcliff, R. (1993). Methods for dealing with reaction-time outliers. *Psychological Bulletin, 114*(3), 510–532.
Ratwani, R. M. (2008). *A spatial memory mechanism for guiding primary task resumption* (Dissertation). George Mason University, Fairfax, VA.
Ratwani, R. M., McCurry, J. M., & Trafton, J. G. (2008). Predicting post completion errors using eye movements. In *Computer Human Interaction 2008 (CHI* 2008). Florence, Italy.
Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist, 24*(2), 113.
Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention, 37*(2), 315–326.
Simon, H. A., & Chase, W. G. (1973). Skill in chess. *American Scientist, 61*(4), 394–403.
Trafton, J. G., Altmann, E. M., Brock, D. P., & Mintz, F. E. (2003). Preparing to resume an interrupted task: Effects of prospective goal encoding and retrospective rehearsal. *International Journal of Human Computer Studies, 58*(5), 583–603.
Trafton, J. G., Altmann, E. M., & Ratwani, R. M. (2009). A memory for goals model of sequence errors. In *Proceedings of the 9th International Conference of Cognitive Modeling.*
Whaley, C. J., & Fisk, A. D. (1993). Effects of part-task training on memory set unitization and retention of memory-dependent skilled search. *Human Factors, 35*(4), 639–652.
Wickens, C. (2008). Executive control: Attention switching, interruptions, and task management. In C. Wickens & J. McCarley (Eds.), *Applied Attention Theory* (pp. 145–160). CRC Press.
Wightman, D. C., & Lintern, F. (1985). Part-task training of tracking and manual control. *Human Factors, 27*(3), 267–283.

Received February 3, 2010
Revision received February 15, 2011
Accepted February 18, 2011 ■