Recovering From Interruptions: Implications for Driver Distraction Research

Christopher A. Monk and **Deborah A. Boehm-Davis,** George Mason University, Fairfax, Virginia, and **J. Gregory Trafton,** Naval Research Laboratory, Washington, D.C.

This research adopted a model of goal activation to study the mechanisms underlying interrupted task performance. The effects of interruption timing, type of interruption, and age on task time and primary task resumption time were explored under conditions in which attention was switched back and forth between two tasks, much as when drivers shift attention between attending to the road and to an in-vehicle task. The timing of interruptions had a significant impact on task resumption times, indicating that the most costly time to interrupt task performance is during the middle of a task. However, this effect was overshadowed by age-related performance decrements for older participants. Interruptions that prevented strategic rehearsal of goals resulted in longer resumption times as compared with interruptions that allowed rehearsal. Actual or potential applications of this research include the design of in-vehicle device user interfaces, the timing of in-vehicle messages, and current metrics for assessing driver distraction.

INTRODUCTION

Crash data from the National Highway Traffic Safety Administration (NHTSA) indicate that approximately 25% of all crashes are the result of inattention or distraction (Wang, Knipling, & Goodman, 1996). It has also been estimated that cell phone use while driving increases crash risk by as much as 38% (Laberge-Nadeau et al., 2003). These numbers are indeed startling, and a great deal of research has demonstrated the deleterious effects of complex cognitive tasks on driving performance. These effects include delayed responses to sudden events in the driving environment (Alm & Nilsson, 1995; Lamble, Kauranen, Laakso, & Summala, 1999; Lee, Caven, Haake, & Brown, 2001), missed signals while driving (McKnight & McKnight, 1993; Strayer & Johnston, 2001), diminished vehicle control (Briem & Hedman, 1995; Dingus, Antin, Hulse, & Wierwille, 1989; Tijerina, Goodman, Johnson, Parmer, & Winterbottom, 2000), narrowed field of view and visual scanning (Harbluk, Noy, & Eizenman, 2002; Recarte & Nunes, 2000), inattention blindness (McCarley et al., 2001; Strayer, Drews, & Johnston, 2003), and changes in braking behavior and headway maintenance (Brookhuis, de Vries, & de Waard, 1991; Hancock, Simmons, Hasemi, Howarth, & Ranney, 1999; Lansdown, Brook-Carter, & Kersloot, 2004).

It is clear that cognitive distraction plays a critical role in the driver distraction problem. However, most of these studies have not delved into the underlying cognitive processes that explain why these performance decrements may occur (however, see Strayer et al., 2003; Strayer & Johnston, 2001). The research reported here was designed to explore a theoretical model that can be used to explain these types of performance decrements and to predict the effect of different types of interruptions on complex task performance.

Specifically, this research explores task performance under conditions in which attention is switched back and forth between two tasks. It has been shown that drivers typically shift attention between attending to the road and to an in-vehicle task (route guidance system destination entry, cell phone dialing, etc.) in consistent bursts of 1 to 3 s (Gellatly & Kleiss, 2000;

Address correspondence to Christopher A. Monk, SAIC, Office of Human-Centered Research, National Highway Traffic Safety Administration, 400 7th St. SW, Washington, DC 20590; christopher.a.monk@saic.com. **HUMAN FACTORS,** Vol. 46, No. 4, Winter 2004, pp. 650–663.

Tijerina et al., 2000; Wierwille, 1993). In this sense, the scenario in which a driver performs an in-vehicle task while driving represents two tasks performed in an interlaced fashion. The tasks can be viewed as mutually interrupting tasks: The driving task is interrupted by the shift of attention to the in-vehicle task and, conversely, the in-vehicle task is interrupted by the driver's need to attend to the driving task. This is important because there is evidence that measures of individual attention-switching ability are an effective predictor of crash involvement (see Ranney, 1994).

By looking at the driver distraction problem as a case of interrupted task performance, there may be lessons to be found in the literature investigating the disruptive effects of interruptions. Although not entirely consistent (e.g., Latorella, 1999), this research has suggested that interruption complexity and similarity are more disruptive than are duration or frequency (Cellier & Eyrolle, 1992; Gillie & Broadbent, 1989; Hess & Detweiler, 1994; Zijlstra, Roe, Leonora, & Krediet, 1999), when *complexity* and *similarity* were defined in terms of task characteristics and processing demands.

A second relevant issue arising from this conceptualization of driver distraction is whether mechanisms exist for minimizing the disruptive effects of interruptions. Some researchers have noted that the ability to resume the primary task after an interruption is a key aspect of interruption management (Adams, Tenney, & Pew, 1995; Zijlstra et al., 1999). The quick and accurate resumption of the suspended, or previous, task goal is arguably the best definition of a minimally disruptive interruption.

The specific theoretical approach that we adopted was taken from Altmann and Trafton's (2002) goal-activation model, which has already been used to make specific predictions about the determinants of successful interruption recovery (Trafton, Altmann, Brock, & Mintz, 2003). The goal-activation model is a formal model of goal encoding and retrieval in memory. In their work, Altmann and Trafton successfully applied this model to simulating reaction time and error data from the Tower of Hanoi task, which depends heavily on the suspension and resumption of goals during problem solving.

Suspended goals are also present in the driver distraction context. When interacting with an in-vehicle device, drivers must suspend their current driving goal (e.g., preparing to change lanes because of a stalled vehicle) while attending to an in-vehicle task. This suspended goal must then be resumed or reinstated upon returning attention to the driving task. Obviously, driving is a continuous task that proceeds in parallel with in-vehicle task performance; however, it can be argued that distinct driving maneuvers such as turns, lane changes, and braking to a stop involve a distinct set of task goals that can be disrupted within the overall driving task. Because the suspension and resumption of goals is a fundamental aspect of interrupted task performance, the model is well suited to predicting the impact of interruptions on primary task resumption.

Specifically, the goal-activation model is based on the activation model of memory items and is instantiated within the ACT-R cognitive architecture (Anderson & Lebiere, 1998). ACT-R has been previously applied to many real-world problems, including cell phone dialing while driving (Salvucci & Macuga, 2002). The fundamental processing assumption in this theory is that when central cognition queries memory, the chunk that is most active at that instant is returned. Simply stated, the goal in mind is the goal with the highest level of activation.

According to the theory, there are two determinants of goal activation. First, activation is determined by the history of a given memory chunk or goal in terms of recent retrievals. In other words, a goal that is retrieved from memory with greater frequency will have a higher level of activation. Conversely, a goal that is not retrieved over time will suffer activation decay. This decay is the principal cause of delayed interruption recovery. Resuming the primary task will take longer because the goal has decayed over time and the operator must spend time attending to environmental cues to reactivate the previous goal. In the lane-change example, this added time increases the driver's reaction time to make appropriate driving inputs, such as braking, steering, or looking to see if the destination lane is clear. As such, the second determinant of goal activation is the relationship between a given goal and the current set of mental or environmental cues. Stronger relationships between the cues and goal help to facilitate that goal's activation; however, weaker connections between the cues and goal will result in little or no boost to that goal's activation. For example, looking back to the road to see that the vehicle is straddling the lane marker would be a powerful reminder that a lane change is in progress.

The goal-activation model proposes that memory for information (i.e., goals) relevant to the interrupted task will decay during an interruption (assuming that the interruption task engages the cognitive processes that would otherwise be used to rehearse such information). The result of this decay is a longer time to resume the primary task, defined by the interval between when the primary task starts again after the conclusion of the interruption and the actual resumption of operations associated with the primary task. This time interval, which is a theory-driven metric for interruption recovery, is called the *resumption lag* (Altmann & Trafton, 2002; Trafton et al., 2003).

The model also proposes that people can strategically rehearse their goals to mitigate this decay, which could be critical in terms of minimizing the disruptive effects of interruptions. There are generally two periods when the information relevant to the interrupted task could be rehearsed. If people can delay the start of the interrupting task, the relevant goals can be rehearsed during this interval, which Altmann and Trafton (2002) and Trafton et al. (2003) called the *interruption lag.* For example, people can choose to complete a lane change or brake to a stop before answering a ringing cell phone.

The second period when the information could be rehearsed is during execution of the interruption task. This would be appropriate when the onset of the interrupting task requires an immediate shift of attention and there is no interruption lag. This is often the case when drivers quickly switch their attention between the driving scene and the in-vehicle task. In these cases, strategic rehearsal of the primary task goals can occur only during the interruption, either during the task or between subtasks. This rehearsal can help to reduce the resumption lag upon returning to the primary task; however, rehearsal may not be possible if the interrupting task consumes all of the available processing resources. Trafton et al. (2003) showed that people do rehearse their suspended goals, even when not instructed to do so, and that this rehearsal mitigates the disruptive effects of the interruptions.

The current set of studies focused on the situation in which the onset of the interruption is immediate, much like switching back and forth between the driving task and an in-vehicle task. In order to explore the best place to resume a task after an interruption, it was important that the task be complex enough to allow us to understand the effects of the timing and point of interruption. To capture this level of complexity in a lab-based study, we elected to use a VCR programming task as the primary task rather than the pursuit-tracking type of task commonly used as a surrogate for the driving task (e.g., Briem & Hedman, 1995). Because pursuit-tracking tasks rely solely on perceptual-motor responses, they are far too simple to adequately capture the complex behaviors associated with driving, whereas the VCR programming task elicited complex goal-directed task performance that shared some important cognitive processes with the driving task.

Like the hierarchical tasks that constitute driving, such as destination planning, navigation, tactical planning, and maneuver execution, the VCR task consisted of multiple layers of goals that directed behavior, ranging from what show to program into the VCR, to the sequence of program entry, to what button to press next on the VCR interface. Because of the similarity in task structure, interruptions in the VCR and driving tasks are likely to have similar consequences for resuming the disrupted goals. Specifically, memory retrieval times for both tasks will be based on goal-retrieval history and the cues in environment. We do not claim that the VCR task captures the essence of the driving task; rather, we argue that that the two tasks share an aspect of goal complexity that enabled us to use the VCR task to investigate a theory of goal resumption that is relevant to the driver distraction problem. In addition, the hierarchical structure of the VCR task also allowed for comparisons with the way drivers handle frequent attention shifts when operating an in-vehicle information task while driving.

An important hypothesis generated from the goal-activation model concerns the point of interruption – that is, where in the primary task the interruptions occur. Interruptions can happen at any point during a task. For example, consider a scenario in which a route guidance system provides instructions for an upcoming turn while the driver is turning right at an intersection. The turn instruction is much less disruptive when it occurs between maneuvers – in this case, when the driver is approaching the turn. Midtask interruptions, however, might lead more often to the driver needing to ask the system to repeat its last instruction.

There may be lower demands associated with encoding some goals as compared with others; specifically, encoding new tasks or subtasks may be less costly than encoding the midtask operation, its position in the task sequence, and the next operation in the sequence. In other words, returning to the primary task in the middle of a subtask may require encoding much more information relevant to the subtask and the sequence of associated operations. Because of the differential encoding costs associated with the various interruption points, the goal-activation model predicts that resumption lags should be shorter for interruptions falling before a new task or subtask is begun, as compared with interruptions occurring in mid-subtask. In addition, the lower encoding demands of a highly repetitive operation, such as scrolling through a list, should result in shorter resumption lags as compared with mid-subtask interruptions.

Monk, Boehm-Davis, and Trafton (2002) found that resumption lags were indeed longest for interruptions falling in the middle of subtasks. There is also empirical evidence that people strategically postpone engaging interruptions until they finish a task (McFarlane, 2002). This finding suggests that people actively avoid midtask interruptions, possibly because of the greater cost of engaging a midtask interruption as compared with waiting to complete some portion of the task before turning attention to the interruption.

The goal-activation model also predicts that preventing or minimizing strategic rehearsal of information related to the primary task during an interruption would result in worse performance, manifested in longer resumption lags. The first experiment compared resumption lags between an interruption that minimized rehearsal and an interruption that allowed plenty of rehearsal (i.e., no-task interruption). As such, we predicted that the no-task interruption would produce shorter resumption lags as compared with those from an interruption consisting of a task. In the paradigm used here, participants could freely rehearse their goals during the no-task interruption but not during the tracking task interruption. Indeed, this manipulation provides an excellent test of the goal-activation model's predictions for interrupted task performance.

To summarize, the current set of studies focused on the point of interruption and the degree to which the interruption affords strategic goal rehearsal (task/no-task interruptions). The first experiment investigated these factors with two levels of interruption task complexity. The second experiment tested an alternative explanation for the differences found in the first experiment. The third experiment expanded the fundamental effects found in the first experiments to include older participants. The results of the three experiments will be discussed regarding their implications for driver distraction, the timing of messages from in-vehicle devices, the current metrics for assessing driver distraction, and the design of in-vehicle device user interfaces.

EXPERIMENT 1

The first experiment was designed to test some basic predictions of the goal-activation model. Specifically, the model predicts that both rehearsal time and point of interruption should affect resumption lag performance. Interruptions containing task demands were predicted to result in longer resumption lags as compared with interruptions that required no cognitive engagement. Interruptions that occurred before a new subtask began or during a repetitive scrolling task operation were predicted to result in shorter resumption lags as compared with interruptions that occurred during a subtask. A computer-based dual-task interruption paradigm was implemented to test these effects.

Method

Participants. Twenty undergraduates from

George Mason University received course credit for participating in this experiment. The participants ranged in age from 17 to 36 years, with an average age of 20 years.

Tasks and equipment. The primary task was to program a VCR using a simulated VCR built in Macintosh Common Lisp. The VCR interface (see Figure 1) was not based on a commercially available VCR; rather, it was designed for experimental use (Gray, 2000; Gray & Fu, 2001). The interruption task was a pursuit-tracking task that required participants to track a moving target. 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.

VCR task. 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 and therefore were considered to be equivalent to the subtask level rather than the task level.

To better understand the steps involved in carrying out these subtasks, consider the subtask of entering the start time (see Figure 1). To enter the start time, the participant first clicked the column button above the hour buttons (the leftmost 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. Table 1 shows the pairing of the start-hour subtask operations

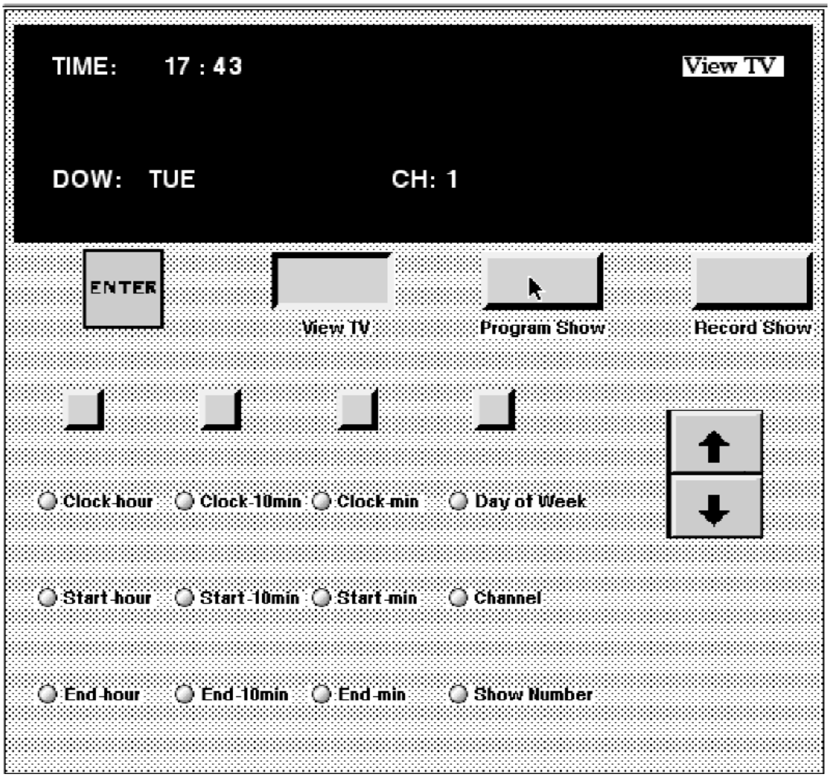

Figure 1. Simulated VCR interface used in primary task.

TABLE 1: Point of Interruption Classification for the Start-Hour Subtask Operations

Subtask Operation	Classification
Click on column button to select column	Start subtask
Click on start-hour button	Mid-subtask
Click on up or down arrow until target is reached	Scrolling
Click on enter to save setting change	Mid-subtask
Click on column button to deselect column	Mid-subtask

with their respective subtask classifications. These subtask stages correspond to the point-of-interruption manipulation.

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.

Interruptions. There were two interruption conditions. The first was a pursuit-tracking task and the second was a no-task interruption. The tracking task interruption required the participant to track an airplane (target) moving around the right half of the screen in a random pattern. In the no-task interruption condition, both sides of the screen went blank and the participant was required to wait until the VCR was displayed again before resuming the programming task.

Design. The experiment was a 2 (type of interruption) × 3 (interruption point) mixed design. The between-subjects factor was interruption type; the interruption interval contained either no task (blank screen) or the tracking task. The within-subjects factor, interruption point, was computed after the data had been collected and represented one of the three points at which the VCR subtasks could be interrupted (at the start of a subtask, in the middle of completing a subtask, or during scrolling). Because there were several interruptions per trial, there were sufficient resumption lag data for each interruption point classification across all participants.

Measures. The primary dependent measure was resumption lag, which was defined as the time that elapsed between the offset of the interruption and the first mouse click on a VCR button. These resumption lags were classified as start-subtask, mid-subtask, or scrolling according to when in the VCR subtasks the interruption occurred. The total time to complete the VCR task, not including interruption times, was also recorded. Each participant completed 10 experimental trials – 5 interrupted and 5 uninterrupted. The uninterrupted trials provided a comparison between the interrupted and uninterrupted task times. The trial order was counterbalanced for each participant using a Latin square.

Procedure. Each participant was tested individually. The sessions, which lasted approximately 1 hr, began with the experimenter explaining the VCR task through a demonstration. The participants were then given two practice trials in which they programmed the VCR without interruption. Participants in the tracking task interruption condition were given two 60-s practice trials with the tracking task. The participants were then introduced to the interruption condition, in which they alternated performing the VCR and interruption tasks. The participants were instructed that the cursor position for each respective task would be saved and reset upon each switch so that dragging the mouse back and forth between the two sides would be unnecessary. Resetting the cursor position with each switch to the VCR task eliminated problems with carry-over cursor movements from the tracking task. The two tasks were essentially paused when not active. After the two practice interruption trials, the participants completed the experimental trials, each with new show information to be programmed. For each trial, participants began programming the VCR. Interruptions occurred every 5 s and lasted for 5 s, creating a back-and-forth sequence between the VCR and interruption task in an interlaced fashion until the VCR program entry was completed. After completing the 10 experimental trials, the participants were debriefed and dismissed.

Results and Discussion

Participants tended to establish a consistent sequence of operations when programming the VCR. Although there were very few programming errors across participants, there were several instances when participants deviated from their set sequence. It was not possible to determine whether these sequence deviations were the result of participants returning to a different goal or subtask, backtracking to confirm previous entries, or verifying what part of the task they were doing when interrupted. Although these sequence deviations were legal entries to the VCR, they indicated that participants had returned to the task at a point different from the expected one. Monk et al. (2002) found no difference in the pattern of results when these path deviations were screened out of the data, so the following analyses include all errors and sequence deviations.

The task time data were analyzed using an analysis of variance (ANOVA) to assess the general disruptive effect of interruptions on the VCR programming task. The task times from the interrupted trials (not including the interruption periods themselves) were just under 1 min ($M = 59.5$ s, $SD = 12.6$ s) and were significantly longer, $F(1, 18) = 19.37$, $p < .0001$, $MSE = 21.85$, than the task times from the uninterrupted trials ($M = 53.0$ s, $SD = 11.3$ s). This effect demonstrates that interrupting the VCR task was detrimental to the overall task time. The interaction between the interrupted/uninterrupted factors and the interruption type factors approached significance, $F(1, 18) = 3.15$, $p = .09$, $MSE = 21.85$. Not surprisingly, the task time difference was greater between the tracking and no-task interruption conditions than between the uninterrupted trials for these two conditions. The main effect for interruption type was not significant.

We then analyzed the resumption lag data to understand how the point at which the task is interrupted plays a role in task performance. Although the participants were instructed to not click the mouse button during the tracking task, accidental clicks did occasionally occur. Accordingly, any resumption lags shorter than 200 ms were assumed to be accidental clicks occurring at the moment of the switch between the tracking task and the VCR task, and these were screened out of the data set. These clicks represented much less than 1% of the data.

The resumption lag data were analyzed using ANOVA. The main effect for interruption point was significant, $F(2, 36) = 16.35$, $p < .0001$, $MSE = 21\ 640$. Post hoc comparisons with the Bonferonni adjustment showed that the resumption lag for the start-subtask interruption point was significantly shorter than that for the mid-subtask point ($p < .05$); the resumption lag for the scrolling interruption point was also significantly shorter than that for the mid-subtask point ($p < .001$). The resumption lags for the start-subtask and scrolling interruption points were not significantly different. This pattern, shown in Figure 2, replicates that found by Monk et al. (2002).

These results clearly show that it is less costly in terms of resumption lags to interrupt a task before a new subtask or during a repetitive operation such as scrolling through a list. More importantly, these results suggest that distractions may be most disruptive during the middle of a driving maneuver or other subtask. This finding supports the prediction of the goal-activation model that task or subtask points that carry a greater encoding demand should result in longer resumption times because of the need to rehearse more information about the goal state and its associated links to next steps. By understanding the cost variability associated with the point at which an interruption occurs, designers can attempt to develop interfaces that have clearly delineated subtasks or that “know” when best to interrupt the driver.

Resumption lag was also affected by whether or not a task filled the interruption period, $F(1, 18) = 29.44$, $p < .0001$, $MSE = 105\ 691$. As is evident in Figure 2, the resumption lags in the tracking task condition ($M = 1605$ ms, $SD = 257$ s) were longer than in the no-task condition ($M = 1149$ ms, $SD = 228$ s) by nearly a half-second. This differential attention switching cost when the interruption consists of a task rather than no task provides strong evidence in

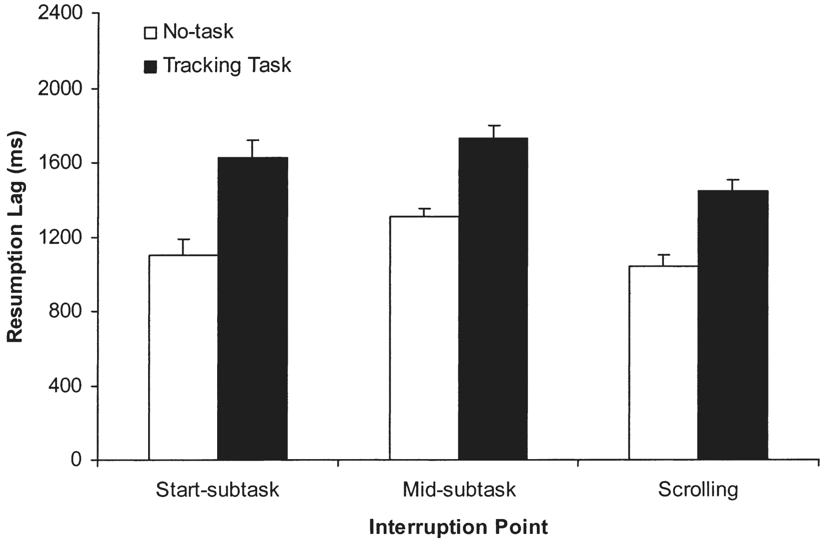

Figure 2. Mean resumption lags (+*SE*) as a function of interruption point and interruption type.

support of the goal-activation model's predictions. Rehearsal of the VCR task goal was much more difficult when participants were required to attend to the tracking task, as compared with the no-task condition, in which they could freely maintain their VCR task goal.

EXPERIMENT 2

To eliminate the predictability of the switch back to the VCR task, it was necessary to vary the interruption timings within each trial. In this experiment, each interruption duration within a trial was randomly set to 3, 5, or 7 s. This randomization of interruption timings made it impossible for participants to plan their resumptions based on predictable switches. If the results of Experiment 1 are attributable to the inhibition of rehearsal during the interruption, as suggested by the goal-activation model, then the same pattern of resumption lag results should emerge even with the randomized interruption durations. Alternatively, if participants were better able to anticipate the return of the VCR task when not loaded during the interruption because of the predictable switch intervals, then the difference between the no-task and tracking task conditions should be nullified.

Method

Participants. Twenty undergraduates from George Mason University received course credit for participating in this experiment. The participants ranged in age from 18 to 27 years, with an average age of 20 years.

Tasks and equipment. The VCR task and interruption conditions were identical to those used in Experiment 1.

Design and measures. Experiment 2 was a 2 (interruption type) × 3 (interruption point) mixed design. Each interruption lasted 3, 5, or 7 s. The times were randomly selected for each interruption within each trial, creating an unpredictable pattern of interruption durations. Aside from the interruption times, the design was identical to that of Experiment 1. The dependent measures were the same as those in Experiment 1.

Procedure. Because the purpose of this experiment was to check the effects of switch predictability on resumption lags, all 10 experimental trials were interrupted trials; we did not include the uninterrupted trials for task-time comparisons. All other aspects of the procedure were identical to those in Experiment 1.

Results and Discussion

The resumption lag data were prepared in the same manner as in Experiment 1. Less than 1% of the data were screened out because of resumption lags shorter than 200 ms. The resumption lag data were analyzed using ANOVA. The main effect for interruption point was significant, *F*(2, 36) = 18.71, *p* < .0001, *MSE* = 17 305. The pattern of results was very similar to that in Experiment 1 (see Figure 3), showing that the mid-subtask interruption point is by far the most disruptive time to interrupt the VCR task. In contrast to the results from Experiment 1, the post hoc comparisons with the Bonferonni adjustment showed that the mean resumption lag for the start-subtask interruption point was not significantly shorter than that for the mid-subtask point (*p* = .25). Also, the resumption lags for the scrolling interruption points were significantly faster than that for the start-subtask point (*p* < .001). However, the resumption lags for the scrolling interruption point were significantly shorter than for the mid-subtask point (*p* < .001), which is consistent with the results from Experiment 1. The interaction between interruption point and interruption type was not significant, *F*(2, 36) = .112, *p* = .895, *MSE* = 17 305.

More importantly, the resumption lag data showed that the tracking task condition resulted in longer resumption lags than did the no-task condition, *F*(1, 18) = 21.33, *p* < .0001, *MSE* = 59 055. As is evident in Figure 3, the resumption lags in the no-task condition (*M* = 1144 ms, *SD* = 166 ms) were shorter than those in the tracking task condition (*M* = 1434 ms, *SD* = 230 ms), much the same as they were in Experiment 1. These data show that the differences between the no-task and tracking task interruption conditions were attributable not to the predictability of the switches but, rather, to strategic rehearsal.

EXPERIMENT 3

Experiment 1 showed that interruptions occurring during tasks are more disruptive than those falling between tasks or during a largely perceptual response. Further, the results confirmed that the effect of an interruption is magnified when the interruption interval is filled with a secondary task. Experiment 2 provided confirmation that the differences between the no-task and tracking task conditions were not attributable to the predictability of the interruption timing in the no-task interruption condition. The current experiment was designed to extend these findings to older participants. Previous research has demonstrated that age plays a role in decreased task-switching performance (Salthouse, Fristoe, McGuthry, & Hambrick, 1998), so there is a concern that the effects seen in the first experiment could be magnified greatly for older participants. Demonstrating

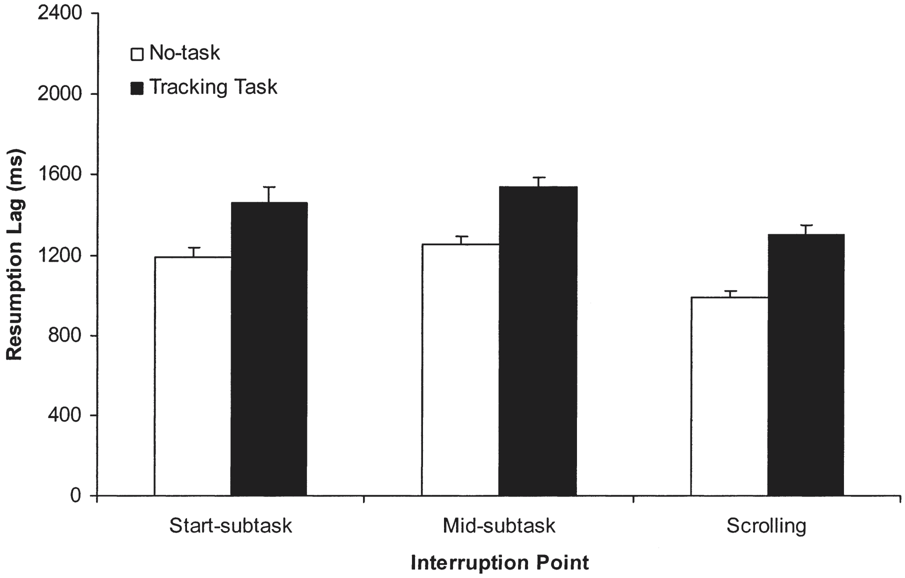

Figure 3. Mean resumption lags (+*SE*) as a function of interruption point and interruption type.

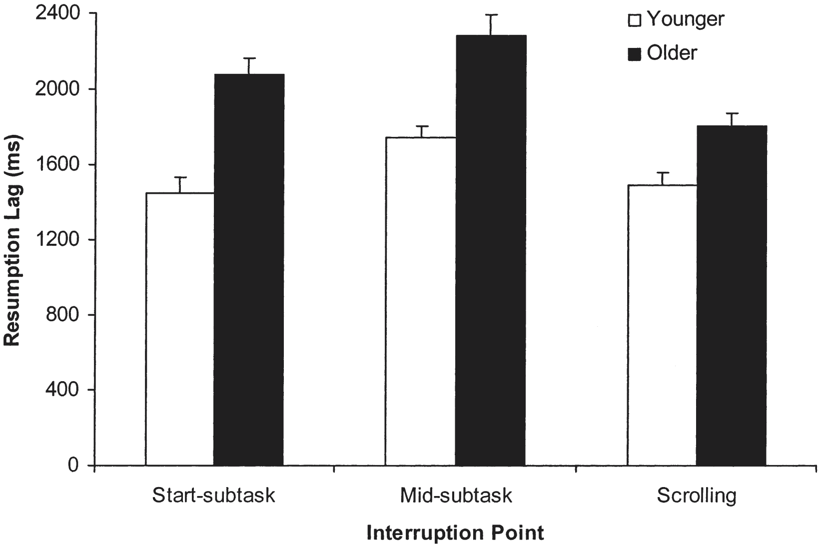

Figure 4. Mean resumption lags (+*SE*) as a function of interruption point and age group.

an additional transition cost for older participants is important because the number of older drivers on the road is expected to increase dramatically over the next several years (Smith, 1998). Because interrupting tasks in a driving environment will require some cognitive resources, this experiment used only the tracking task interruption condition for the age group comparison.

Method

Participants. Twenty individuals participated in this experiment. Half of the participants were younger and half were older. The younger half consisted of undergraduates from George Mason University who received course credit for participating in this study. These participants ranged in age from 17 to 26 years, with an average age of 20 years. The 10 older participants were recruited from a local church and participated on a volunteer basis. They ranged in age from 55 to 69 years, with an average age of 60 years, and reported being in generally good health.

Tasks and equipment. The VCR and tracking tasks were identical to those used in the first experiment.

Design and measures. Experiment 3 was a 2 (age) × 3 (interruption point) mixed design. The within-subjects factor of interruption point was identical to that in Experiments 1 and 2. Because the emphasis was on age effects, this experiment used only the tracking task interruption condition. The timing of the VCR task and the interruptions was fixed at 5 s each, as in Experiment 1. The dependent measures were the same as those in the first experiment.

Procedure. The procedure was identical to that in Experiment 1 except that all participants received the tracking task practice trials because they were all in the tracking task interruption condition.

Results and Discussion

The task time data were analyzed using an ANOVA. As in the first experiment, the task times from the interrupted trials (M = 83.1 s, SD = 28.0 s) were significantly longer, $F(1, 18) = 18.47$, $p < .0001$, $MSE = 111.15$, than those from the uninterrupted trials (M = 68.8 s, SD = 20.7 s). Once again, the total task time measure demonstrated the general disruptive effects of interrupting task performance. In addition, the older participants (M = 94.4 s, SD = 22.9 s) took significantly longer to complete the VCR task, $F(1, 18) = 33.90$, $p < .0001$, $MSE = 401.70$, than did the younger participants (M = 57.5 s, SD = 8.8 s), demonstrating the typical age-related decline in task performance. The interaction between the interruption factor and the age group factor was not significant, $F(1, 18) = 1.52$, $p = .23$, $MSE = 111.15$.

The resumption lag data were prepared in the same manner as in Experiments 1 and 2. Less than 1% of the data were screened out because of resumption lags shorter than 200 ms. The resumption lag data showed a main effect for interruption point, $F(2, 36) = 32.60$, $p < .0001$, $MSE = 21\,316$. Figure 4 shows that the overall pattern of results was very similar to those in the previous experiments; the mid-subtask interruption point was the most disruptive to task resumption.

The main effect for age group was also significant, $F(1, 18) = 22.82$, $p < .0001$, $MSE = 161\,178$, with the older group ($M = 2055$ ms, $SD = 339$ ms) taking significantly longer than the younger group ($M = 1560$ ms, $SD = 261$ ms) by nearly a half-second. There are several possible explanations for this effect, including age-related declines in perceptual speed (Salthouse, 1996) and attention-switching ability (Salthouse et al., 1998).

The interaction between the interruption point factor and age group was also significant, $F(2, 36) = 5.94$, $p < .01$, $MSE = 126\,566$. Figure 4 shows the same general pattern of results as those in the previous experiments for both groups; the mid-subtask interruptions were again the most disruptive. However, post hoc comparisons with the Bonferonni adjustment revealed that for the older participants, resumption lags for the start-subtask point were not reliably different from those for the mid-subtask point ($p = .115$) but were significantly longer than those for the scrolling point ($p = .001$). The longer start-subtask resumption lags indicated that the older participants experienced a greater penalty for interruptions occurring between subtasks. Overall, this pattern of results showed that for older participants, resumption lags may have been influenced more by their age-related performance decrements than by the point of interruption, which indicated that the older drivers were more affected by the interruptions than were younger drivers overall. This finding was consistent with several studies that have demonstrated amplified driver distraction effects for older drivers (Alm & Nilsson, 1995; McKnight & McKnight, 1993; Reed & Green, 1999; Tijerina et al., 2000).

GENERAL DISCUSSION

This set of experiments produced a number of important results. Perhaps least surprising was confirmation of the basic disruptive effects of interruptions on task performance. As in earlier research (Cellier & Eyrolle, 1992; Gillie & Broadbent, 1989; Hess & Detweiler, 1994; Zijlstra et al., 1999), interrupted tasks took longer to complete than did uninterrupted tasks (seen in Experiments 1 and 3). Also unsurprising was the fact that the older group took longer to complete the VCR task, as compared with their younger counterparts. This finding is consistent with general age-related performance declines.

Beyond these basic findings, the experiments produced support for the goal-activation model (Altmann & Trafton, 2002). This model makes specific predictions regarding resumption lag relative to interruption point, interruption type, and age. Working from the assumption that the encoding demands for mid-subtask goals are greater than those for beginning new subtasks or for a repetitive operation such as scrolling, the model predicted longer resumption lags for the mid-subtask interruption points than for the begin subtask and scrolling interruption points. This prediction was indeed confirmed in all three experiments. Participants were always slower to resume the primary task when they were interrupted during the middle of a subtask than when interrupted between subtasks or during the scrolling operation. However, interruptions at the start of a new task had longer resumption times than did the scrolling interruption point, both for older participants (Experiment 3) and when the interruption lengths were unpredictable (Experiment 2).

Intriguingly, an interaction between the interruption point factor and age group showed that whereas interruptions occurring at mid-subtask were the most detrimental to resumption times across age groups, older participants took longer to resume the VCR task in general, so much that interruptions occurring before a new subtask and in the middle of a subtask resulted in nearly equal resumption times. This interaction suggests that age-related task slowing effects may contribute more to the age group main effect than does the interruption point factor.

Because it has previously been shown that cognitive models can produce slowing effects with a single parameter adjustment (Byrne, 1998), it is reasonable that this age effect can be explained using the goal-activation model.

A second important prediction of the goal-activation model was that goal maintenance or rehearsal during the no-task interruption would result in shorter resumption lags because the activation levels of the interrupted goal would be elevated enough to ensure quicker resumptions. In contrast, interruptions that inhibit goal maintenance should lead to longer resumption times, according to the model. Experiments 1 and 2 showed that interrupting the primary task with a tracking task that interferes with strategic goal rehearsal resulted in longer resumption times as compared with interrupting the task with an unfilled interval. According to the model, an unfilled interval allows strategic goal rehearsal during the interruptions. As predicted, when the interruption task minimized rehearsal, the resumption lags were much longer than those for the no-task interruptions. This is an important finding for the goal-activation model, as it confirms a direct test of its claims. These results, along with those of Trafton et al. (2003), offer persuasive empirical evidence for this theory as a framework for studying interruptions.

Beyond supporting the goal-activation model, the results from these three experiments have important implications for driver distraction. The raw resumption times are inextricably tied to the specific tasks and conditions used in this experimental paradigm, but the differences in resumption lags between experimental conditions are indeed relevant to the driving task. The differences between the subtask stages were on the order of 150 to 300 ms for younger participants and 200 to 475 ms for the older participants. Lee et al. (2001) and Brown, Lee, and McGehee (2001) explained how reaction time differences on the order of 300 ms have significant implications for a precrash scenario, especially for braking response times. Therefore, the increase in resumption lags could potentially have dramatic consequences if an in-vehicle device interrupts drivers in the middle of a subtask rather than between subtasks, especially for older drivers. Because these resumption lags occur with each interruption, the increased total task times can be explained in part by the additive effect of resumption lags resulting from each interruption or switch of attention. This cumulative effect of resumption lags is an important factor in predicting task times under dynamic attention-switching conditions.

Experiments 1 and 2 showed that filled interruption tasks result in longer resumption times. In addition to supporting the model, this finding is relevant to the visual occlusion technique, which has gained popularity in driver distraction research in recent years. (See Green & Tsimhoni, 2001, for an overview of the technique and its recent applications to the driver distraction problem.) The present study provides strong evidence that to optimize its usefulness as a predictive tool, the visual occlusion technique should incorporate a task into the occluded periods in much the same way that the tracking task interruption condition did in the present studies. However, tasks that more closely resemble the driving task would be most appropriate to use in future studies. Because there is no task during the occluded periods, such as attending to some driving-related task, the occluded vision condition is essentially the same as our no-task condition. Thus strategic rehearsal of the interrupted goal state is unencumbered, leading to shorter resumption lags and an underestimation of task times. To get better predictions of task time and cognitive loading, it makes sense that the occluded periods should incorporate some other task, much like people attend to the driving task when not looking down at an in-vehicle device interface.

The interruption point results also have two important implications for the design of current and future in-vehicle devices. Future in-vehicle systems may interrupt the driver with various nonsafety-related information, such as route guidance instructions and system status information. It will be important for these systems to “know” when best to interrupt the driver with their messages. Recent research has begun to investigate the effectiveness of in-vehicle workload managers that will handle interruptions appropriately (Piechulla, Mayser, Gehrke, & König, 2003; Verwey, 2000).

Although the driving task is very much a continuous task, it can also be broken down into discrete subtasks. For example, it is reasonable to think of specific driving maneuvers as subtasks, such as changing lanes, making 90° turns, and merging with highway traffic. Each of these maneuvers has a definable beginning, middle, and end. If an intelligent system can detect these maneuvers and the cues that are associated with the beginning, middle, and conclusion of each, then the prudent design would be to have systems delay any noncritical messages to the driver until the completion of a maneuver. The results of the point of interruption manipulation suggest that it would be best to interrupt most drivers with messages before they begin a new maneuver or after they finish a maneuver, although older drivers would probably not benefit as much from this between-task interruption timing.

Another important implication for designers concerns the design of the specific user interfaces for current and future devices. Because the current results show that it is better to interrupt people before new subtasks, designers should seek to design in-vehicle interfaces with clearly defined subtasks that are conducive to the short attention-switching intervals seen in previous research (Gellatly & Kleiss, 2000; Tijerina et al., 2000; Wierwille, 1993).

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Christopher A. Monk is senior human factors psychologist for Science Applications International Corporation at the National Highway Traffic Safety Administration in Washington, D.C. He received his Ph.D. in human factors and applied cognition in 2004 at George Mason University.

Deborah A. Boehm-Davis is a professor of psychology at George Mason University. She received her Ph.D. in psychology from the University of California, Berkeley, in 1980.

J. Gregory Trafton is an engineering research psychologist for the Naval Research Laboratory in Washington, D.C., and an adjunct professor in the Psychology Department at George Mason University. He received his Ph.D. in psychology from Princeton University in 1994.

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