The Effect of Interruptions and Global Placekeeping on Postcompletion Error Rates

Jennifer M. Chen, Raj M. Ratwani and J. Gregory Trafton

Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2010 54: 463
DOI: 10.1177/154193121005400440

The Effect of Interruptions and Global Placekeeping on Postcompletion Error Rates

Jennifer M. Chen, George Mason University
Raj M. Ratwani, George Mason University
J. Gregory Trafton, Naval Research Laboratory

A postcompletion error occurs when the final step of a task is omitted because the main goal of the task is thought to be completed (Byrne & Bovair, 1997). Postcompletion errors are more likely to occur after interruptions (Ratwani, McCurry & Trafton, 2008). Global placekeeping cues (Gray, 2000) allow a user to track their progress in a task and may be a method for reducing the rate of postcompletion errors. A computer-based procedural task with a postcompletion step was used in this experiment to determine how the interaction of global placekeeping cues with interruptions would affect postcompletion errors. These results suggest that global placekeeping cues reduce the postcompletion error rate after interruptions, but that global placekeeping does not completely eliminate postcompletion errors.

SUMMARY

A postcompletion error is an instance where a person does not perform the last step in a task which occurs after the main goal of the task has been completed (Byrne & Bovair, 1997). Past research in aviation (National Transportation Safety Board [NTSB], 1988) and driving (Monk, Boehm-Davis & Trafton, 2004) have shown that interruptions increase error rates. Two theoretical models (Byrne & Bovair, 1997; Altmann & Trafton, 2002) suggest that high working memory load is associated with making postcompletion errors. The use of global placekeeping to provide a way to track what parts of a task have been achieved and what parts remain to be completed could reduce postcompletion errors. The issue we address in this paper is how we can reduce or eliminate postcompletion errors in error-prone, complex environments. A computer-based procedural task with a postcompletion step was used in this experiment to determine how the interaction of global placekeeping with interruptions would affect postcompletion errors. Results show that global placekeeping reduces but does not eliminate postcompletion errors in environments with interruptions and has no effect on performance when no interruptions are present. The postcompletion error rate after interruptions was greater than 9%, even with global placekeeping; and global placekeeping did not reduce the postcompletion rate to the level found in trials without interruptions (below 1%).

INTRODUCTION

Even in well-known and well practiced tasks, operators still occasionally make errors (Reason, 1990). Though errors in non-critical environments can typically be corrected with no ill effect, in critical systems, the effect of errors can be far-reaching and life-threatening. A postcompletion error (PCE) is a type of slip error (Norman, 1981), an instance where a person does not perform the last step in a task which occurs after the main goal of the task has been completed. A PCE is a type of omission error, meaning that the mistake consists of forgetting to do a particular procedure in a task (Byrne & Bovair, 1997). Omission errors are distinguished from anticipation and perseveration errors. Anticipation errors occur when a step in a task is unintentionally completed earlier than usual, such as trying to back the car out of a parking spot without first putting the gear into reverse. A perseveration error is when a step in a task is accidentally repeated such as re-starting the car engine although it is already running (Cooper & Shallice, 2000).

A key characteristic of the PCE is that an "extra" step needs to be completed after the main goal of the task has been satisfied. One example of a PCE is leaving the original on the glass platen after making duplicates at the copy machine. Another is leaving one's ATM card in the machine after withdrawing money. Because these tasks are well-known and practiced hundreds of times, the reason for the error is not typically due to a lack of knowledge (Byrne & Bovair, 1997).

There are two theoretical accounts for postcompletion errors; both accounts are activation-based. Byrne and Bovair (1997) suggest that working memory load is associated with PCEs. They posit that postcompletion omissions happen because of goal loss from working memory. Subgoals are maintained in working memory by activation from the main goal. When the main goal is achieved and removed from working memory, activation to subgoals is also removed. The decay rate of the main goal from working memory varies by memory load where high working memory load is associated with faster decay (Byrne & Bovair, 1997).

A different model, called the memory for goals theory (Altmann & Trafton, 2002), explains goal-directed behavior as driven by three components: the interference level (residual memory for old goals), the strengthening constraint (recency and frequency) and the priming constraint (associated cues in the mental or physical context). Goal activation is primarily determined by strengthening and priming. A postcompletion error is made when the level of activation is too low or interference causes the wrong goal to be recalled (Altmann & Trafton, 2002).

Like other error types, people are more susceptible to making a postcompletion error in complex, interruption-prone environments (Li, Blandford, Cairns & Young, 2008; Ratwani, McCurry & Trafton, 2008). Interruptions have been shown to increase error rates in aviation (National Transportation Safety Board [NTSB], 1988) and driving (Monk, Boehm-Davis & Trafton, 2004). The issue we address in this paper is how we can reduce or eliminate postcompletion errors in error-prone, complex environments.

One method is to provide global placekeeping cues to give users a way to track their progress through a task. Gray (2000) coined the term "global placekeeping" to describe "knowing what parts of the task have been completed and what parts remain to be accomplished" at the task-level. For example, a car dashboard provides informative cues on what actions have or have not taken place. If the car has not been started, the display stays dim indicating that it has not been turned "on," and when a driver puts the car into drive, an indicator light shows that the action has taken place. Although global placekeeping does not reduce the interference level of interruptions, based on the priming constraint, it should increase priming by providing explicit links from the environment (e.g. Trafton, Altmann, Brock & Mintz, 2003) to the postcompletion step.

In the experiment presented here, a computer-based procedural task with a postcompletion step was used to assess how the presence of global placekeeping cues would affect PCE rates in environments with and without interruptions. Because of the additional priming provided by the global placekeeping cues, we hypothesize that the presence of global placekeeping cues will reduce the likelihood of making PCEs.

MATERIALS AND METHOD

Participants

Seventy-three George Mason University undergraduate students participated for course credit. All participants were English-speaking. None of the participants had any prior experience with the experiment. Thirty-eight of the seventy-three participants were randomly assigned to the condition that provided global placekeeping cues and thirty-five participants were assigned to the condition without global placekeeping cues.

Materials

Primary task. The primary task was a complex financial management task (see Figure 1). Participants bought and sold stocks according to client orders. Four client orders were present on the screen at any time. Information for three different stocks was presented in the middle of the interface and the stock prices fluctuated every 45 seconds. As with most procedural tasks, there were strict order constraints for most aspects of the task. There were, however, no time regulations imposed on the participant to complete orders in a given time frame. Instead, participants were instructed to complete the task at their own pace.

To complete an order, participants first had to correctly select a stock order that could be successfully completed according to the client's desired stock price and the current stock price. To begin an order, the participant clicked the *Start Order* button for the respective client order. The participant would then complete each of the separate components of the order form by filling in details from the client order. In total, there were eight components to the order and the specific sequence for completing them was: Quantity, Cost, Order Info, Margin, Stock Exchanges, Transaction, Stock Info, and Review.

After filling out all of the information in each component, the participant clicked the *Confirm* button to move on to the next component. After completing the last component (Review) and clicking *Confirm*, a pop-up window would appear to confirm the details of the order. The participant then had to acknowledge the window by clicking *OK*. Finally, to complete the order, the participant clicked the *Complete Order* button located in the upper-right corner of the interface. This final action is the postcompletion step and the pop-up window is a false completion signal that is generally associated with postcompletion errors (Reason, 1990).

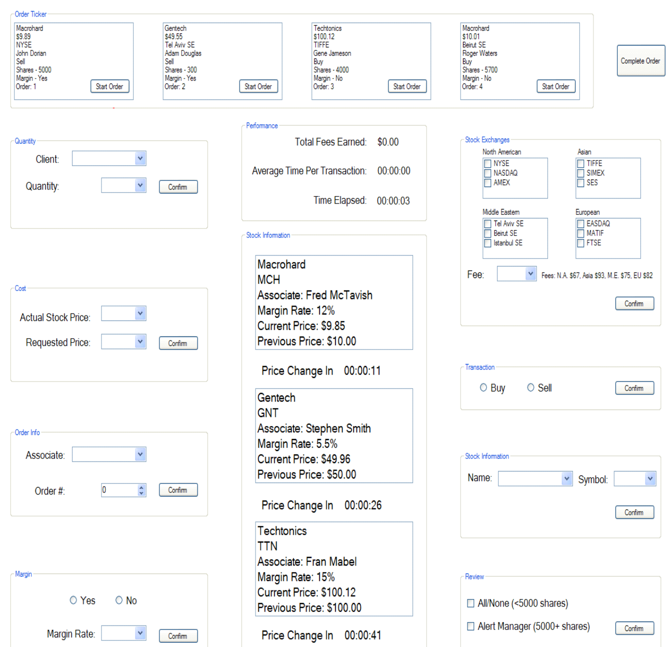

Figure 1. Screenshot of the financial management task.

All of the information required to complete the task was directly available on the task interface. All inputs to the interface were made through the mouse so that participants never had to direct their gaze away from the order form. When a participant made an error such as attempting to work on a component or clicking a button that deviated from the strict procedure, the computer emitted a beep signifying that an error had been made. The participant must then continue working on the task until the correct action is completed.

Interruptions. Interruptions were introduced to replicate findings from earlier work using the financial management task, as well as other procedural tasks (Ratwani et al., 2008; Li et al., 2008) and to increase the probability of errors. In addition, trials with interruptions were compared to trials without interruptions to assess if the interruptions did, in fact, increase errors.

The interrupting task consisted of multiple-choice addition problems. Each problem contained five single-digit addends and five possible solutions (four incorrect, one correct). A single addition problem and solution set were presented one at a time for a duration of fifteen seconds. Participants were told to complete as many problems as possible during the interruption. Although we used an interruption unrelated to the financial management task, we do not feel this is a concern because the interrupting task is engaging. It is still unknown how features of the interruption such as modality, similarity and difficulty affect the disruptiveness of the interruption (Cades, Trafton, Boehm-Davis & Monk, 2007). Here, we have focused on the length and timing of the interruption as opposed to the content of the interruption. This interruption was also used in prior iterations of this experiment which will allow us to compare results across studies.

Global placekeeping. In the condition with global placekeeping cues, the information entered in each component or module by the participant remained on the screen after the *Confirm* button was pressed. After an interruption, the participant could see where work was last completed. As shown in the top of Figure 2, the information entered in the Cost component would remain even as the participant continues to work on other components. Thus, unlike previous studies (Li et al., 2008; Ratwani et al., 2008), participants in this condition could use the information that remained in the components to track their progress in the task. Conversely, in the condition without global placekeeping cues (bottom of Figure 2), the information in the components would disappear after the *Confirm* button was pressed. Participants had to mentally keep track of their progress during the task. The condition without global placekeeping, while not very realistic, did stress memory and was expected to increase error rates overall. The global placekeeping condition is the way that most designers would build this type of task (and, in fact, this task was based on actual stock buying interfaces).

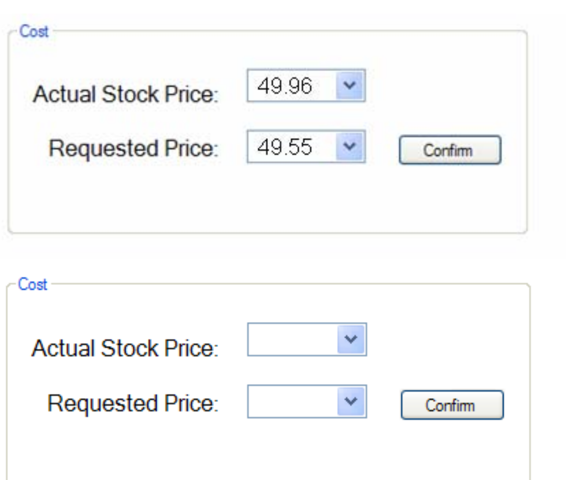

Figure 2. Example of global placekeeping (top) and no global placekeeping (bottom) for the Cost component.

Design

Control and interruption trials were manipulated in a within-participants design. Global placekeeping and no global placekeeping were manipulated between-participants. The completion of one order on the financial management task constituted a trial. Participants completed twelve trials; six were control and six were interruption trials. The order of control and interruption trials was randomized. The interruption point occurred after acknowledging the false completion signal and just prior to the postcompletion action. The presence of the interruption just prior to the postcompletion step was randomized with the constraint that two interruptions occurred throughout the twelve trials (and only during interruption trials). The interruption itself lasted for fifteen seconds. Interruptions were also introduced at other points in the order process during the interruption trials but the results from this manipulation will not be discussed in this paper.

Procedure

Participants were seated approximately 47cm from the computer monitor. After the experimenter explained the financial management and the interrupting task to the participant, the participant completed three training trials (two without and one with interruptions). In order to begin the experiment, participants had to complete three consecutive, error-free trials to ensure the financial management task was well-learned. Each participant was instructed to work at his/her own pace. When performing the interrupting task, participants were instructed to answer the addition problems as soon as the solution was known. Upon resumption of the financial management task, the information that was entered in the component prior to the interruption remained on the screen in the condition with global placekeeping cues but disappeared in the condition without global placekeeping cues.

Measures

Mouse data were collected for every participant. A postcompletion error was defined as skipping the step of clicking the *Complete Contract* button and making an action that is related to a new order on the financial management task (e.g. erroneously attempting to click the *Start Order* button or attempting to work on the first component). If the participant repeated a step by pressing the *Confirm* button after an interruption immediately following the false completion signal, this error was not coded as a postcompletion error. Although these errors happened at the postcompletion step, they are perseveration and not omission errors.

The raw counts of postcompletion errors in each condition X trial-type were converted to percentages by taking the ratio of the actual number of errors made to the opportunity for making that type of error. For this report, we only focused on PCEs; sequence errors and device initialization errors will not be discussed.

RESULTS

A 2x2 mixed ANOVA was used for data analysis. Figure 3 shows the mean PCE rates in each of the four conditions: global placekeeping (with/without) X interruption (with/without).

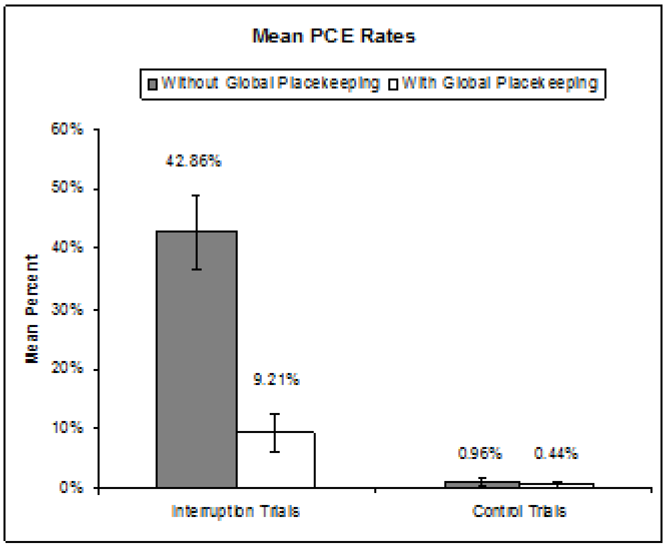

Figure 3. A comparison of the percentage of postcompletion errors (PCEs) made within the different manipulations. Error bars represent standard error.

Interruptions

As expected, there was a main effect of interruption present/not present. Participants made significantly more postcompletion errors immediately following an interruption (M = 26.03%) than in control trials (M = 0.70%) where no interruptions were present, $F(1, 71) = 58.0$, $p < .001$. Interruptions significantly impacted the number of PCEs made by participants which replicates previous results (Li et al. 2008; Ratwani et al., 2008).

Global Placekeeping

There was also a significant main effect of global placekeeping cues on PCE rate, $F(1, 71) = 23.5$, $p < .001$. On average, participants in the no global placekeeping condition made significantly more errors (M = 21.91%) compared with participants that had global placekeeping cues available to them (M = 4.83%). Note that global placekeeping did not eliminate errors: participants still made almost 5% errors even with global placekeeping.

Global Placekeeping x Interruptions Interaction

There was a significant interaction between global placekeeping cues and interruptions, $F(1, 71) = 24.8$, $p < .001$. *T*-tests corrected with the Bonferroni procedure were run on all possible pair-wise comparisons to further explore the interaction between global placekeeping and interruptions. All comparisons were significant, $p < .001$, except for the comparison between control trials with global placekeeping and control trials without global placekeeping. Thus, the PCE rate during control trials without interruptions was low, regardless of whether there was global placekeeping or not.

The significant interaction is driven by the difference in PCE rates between the global (M = 9.21%) and no global placekeeping (M = 42.9%) conditions when interruptions were present. Interruptions had a stronger effect on PCE rates than global placekeeping. Interruption trials regardless of condition yielded higher PCE rates when matched to either control trial condition.

During interruption trials global placekeeping reduced the postcompletion error rate, but did not completely eliminate them. The postcompletion error rate during interruption trials with global placekeeping was significantly higher than either of the control trials. Therefore, the presence of global placekeeping during interruption trials did not reduce PCEs to the rate found in control trials in either condition (below 1%).

DISCUSSION

Results from this experiment replicate other work suggesting that interruptions significantly impact the rate of postcompletion errors made on multi-step, procedural tasks, even if well-known and well-practiced. The low PCE rate during control trials indicates that participants understood and could proficiently complete the financial management task, but at the same time, occasionally made PCEs on a well-practiced task. Interruptions increased the PCE rate regardless of whether or not the participant received global placekeeping cues. On average, participants made 25% more PCEs when interrupted compared to control.

The results of this research support the use of perceptual cues in interface design. Given the significant and substantial difference in postcompletion error rates between the global placekeeping condition and the no global placekeeping condition, the priming provided by global placekeeping clearly reduces the error rate. Thus, when designing interfaces, environmental cues should be available such that users can easily tell what parts of a task have already been accomplished and what parts still need to be achieved. This suggestion is “business as usual” and is not surprising.

However, it is important to note that when participants were interrupted, the postcompletion error rate is still quite high (greater than 9%), even with global placekeeping. Global placekeeping did not reduce PCE rates to the level of control trials (below 1%), and had no significant effect on PCE rates during control trials (probably because the error rates during control trials were so low). Interruptions had a stronger effect on PCE rates than global placekeeping with error rates higher during interruption trials when compared to control trials (without interruptions). Thus, while global placekeeping reduces the likelihood of an error, it is not a complete solution in error-prone environments. In sensitive environments with interruptions, other ways of reducing errors must be considered besides supplying global placekeeping cues as designed in this study.

Ratwani, McCurry, and Trafton (2008) have developed a technique that uses eye-movement data to predict when users of an interface are likely to make errors. Ultimately, this model could be applied in a real-time system to alert users when they are likely to make errors. In addition, there are multiple ways to provide global placekeeping cues. For example progress bars or indicators of completion percentage have been used in sequential tasks such as questionnaires and e-learning. Future work includes exploring other methods of providing visual cues for participants to track their progress through the financial management task.

ACKNOWLEDGMENTS

This work was supported by ONR under funding document N0001410WX20426 and N0001410WX30037 to JGT. The views and conclusions contained in this document should not be interpreted as necessarily representing the official policies of the U.S. Navy. In addition, the authors would like to thank Malcolm McCurry for his help with programming the experiment.

REFERENCES

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

Blandford, A., Cairns, P., & Young, R. (2008). The effect of interruptions on postcompletion and other procedural errors: An account based on the activation-based goal memory model. Journal of Experimental Psychology: Applied, 14(4), 314-328.

Byrne, M., & Bovair, S. (1997). A working memory model of a common procedural error. Cognitive Science: A Multidisciplinary Journal, 21(1), 31-61.

Cades, D.M., Trafton, J.G., Boehm-Davis, D.A., & Monk, C.M. (2007). Does the Difficulty of an Interruption Affect our Ability to Resume? Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting.

Cooper, R. & Shallice, T. (2000). Contention Scheduling and the Control of Routine Activities. Cognitive Neuropsychology, 17(4), 297-338.

Gray, W. (2000). The nature and processing of errors in interactive behavior. Cognitive Science: A Multidisciplinary Journal, 24(2), 205-248.

Li, S. Y. W., Blandford, A., Cairns, P., & Young, R. M., (2008) The effect of interruptions on postcompletion and other procedural errors: An account based on the activation-based goal memory model. Journal of Experimental Psychology: Applied, 14 (4), 314-328.

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

National Transportation Safety Board. (1988). Aircraft accident report: Northwest Airlines, Inc., McDonnell Douglas DC-9–82, N312RC, Detroit Metropolitan Wayne County Airport, Romulus, MI, August 16, 1987(NTSB/AAR–88/05). Washington, DC: Author.

Norman, D.A. (1981). Categorization of action slips. Psychological Review, 88(1): 1-15

Ratwani, R. M., McCurry, J.M., & Trafton, J.G. (2008). Predicting postcompletion errors using eye movements. In M. Czerwinski, A.M. Lund & D.S. Tan (Eds.), Proceedings of the 2008 Conference on Human Factors in Computing Systems, CHI 2008, 539-542: ACM.

Reason, J. (1990). Human Error. New York: Cambridge University Press.

Trafton, J.G., Altmann, E.M., Brock, D.P., & Minz, 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.

Young, R.M., Barnard, P., Simon, T., & Whittington, J. (1989). How would your favorite user model cope with these scenarios? ACM SIGCH Bulletin, 20, 51-55.