Further investigations into post-completion error: the effects of interruption position and duration

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Abstract

Two experiments were carried out to examine the effect of interruption position and interruption duration on post-completion error (PCE) occurrences in a game-like procedural task. Experiment 1 showed a significant main effect of interruption position on PCE rate; significantly more PCEs were obtained when the interruption occurred just before the PC step than interruptions at any other positions in the task. The same effect was also obtained for other non-PCEs suggesting that PCEs are no different to other non-PCEs in terms of the interruption position effect. Experiment 2 replicated the interruption position effect but did not show a reliable difference in PCE rates between a 45-sec and a 15-sec interruption. However, the trend of the differences in PCE rates between the two interruption durations is consistent with our initial prediction. The results of both experiments were explained in terms of the activation-based goal memory model (Altmann & Trafton, 2002).

Introduction

Post-completion error (PCE) is a specific kind of omission error, which occurs after the completion of a main task, for example, forgetting to collect your change after purchasing from a vending machine.

Recent research has identified various factors that affect the error rate in routine procedural tasks such as working memory load (Byrne & Bovair, 1997) and dynamic visual cues (Lee, 1992; Chung & Byrne, 2004). It has also been shown that this robust error phenomenon occurs in non-routine problem-solving situations (Li, Blandford, Cairns & Young, 2005). Although PCE has received more attention recently, there are still many open questions about which factors provoke or mitigate the occurrence of the error.

Given that interruptions are pervasive in most workplace environments and have been shown to lead to increased levels of overall error, their direct consequences in safety critical domains can be serious. Therefore, it seems a logical route to investigate what effect interruptions might have (or not have) on the occurrences of post-completion error. This study set out to investigate the effect of interruption position and duration on the rate of post-completion error and is motivated by the activation-based goal memory model (Altmann & Trafton, 2002).

Background

Several dimensions of interruptions have been investigated and are thought to affect performance on the primary task, e.g. the complexity of the interruption and its similarity to the primary task (Gillie & Broadbent, 1989; Edwards & Gronlund, 1998), the role of retrieval cues after an interruption (e.g. Cutrell, Czerwinski & Horvitz, 2001), control over the interruption (McFarlane & Latorella, 2002), and preparation before engaging the interruption (Trafton, Altmann, Brock & Mintz, 2003). However, there has been no work looking at the effect of interruption on a specific kind of error, namely PCE.

A particularly useful theoretical framework for the current study is Altmann & Trafton's (2002) activation-based goal memory (AGM) model. The AGM model has its origin in explaining goal suspensions and resumptions in problem-solving and has been applied to investigating the disruptiveness of interruption on primary task performance and explaining the occurrence of PCE.

Using the construct of activation, the AGM model suggests that, just like other memory elements in the cognitive system, goals have associated activation levels and cognition is directed by the most active goal retrieved at any given time. The amount of activation associated with a memory item is subject to decay, and this decay process is time-based and gradual.

If the cognitive system needs to refocus attention to (or resume) an old goal then this old goal needs to undergo a priming process to become active again. The priming process is possible through associative links between retrieval cues and the to-be-resumed goal. The retrieval cues can be internal or external to the cognitive system.

The AGM model suggests that task steps in a learned procedural skill can be viewed as a sequence of associative links, an action step acting as a retrieval cue for the next. This procedural cueing mechanism explains how PCE is usually avoided; hence, people usually manage to carry out PC tasks, such as photocopying, without committing the PCE most of the time.

Consideration of the AGM model enables us to predict that different interruption positions during procedural tasks will result in different effects on the rate of PCE. An interruption occurring *just before* the post-completion (PC) step is more likely to lead to a PCE than an interruption occurring at any other point within a task structure. An interruption just before the PC step will have disrupted the associative priming from the preceding step, whereas other interruption points will still allow the pre-PC step to be carried out (after the correct goal is resumed successfully), and once it is carried out, it would cue the PC step.

However, the gradual decay process of the AGM model suggests that the disruptiveness of an interruption also depends on the duration of the interruption. An interruption has to prevent rehearsal of a to-be-resumed goal, and it has to last long enough for the goal activation to undergo substantial decay. Although different interruption durations have not been found to have differential disruptive effect in terms of global task performance (Gillie & Broadbent, 1989), using a more sensitive behavioural measure, resumption lag, recent evidence suggests that interruptions that last a few seconds longer than others may have greater costs in terms of resumption lag (Monk, Boehm-Davis & Trafton, 2004).

Our study examines the effect of interruption position and duration on PCE in a procedural task.

Experiment 1

The objectives of this first experiment are, firstly, to generate a high enough PCE rate for statistical comparisons, and secondly, to test out the effect of interruption positions on PCE occurrences. Based on the activation-based goal memory model, the following hypothesis was proposed: interruptions occurring just before the PC step are more likely to result in PCE occurrences than interruptions occurring at other points in a procedural task.

A reviewer suggested the same hypothesis should be explored in relation to other non-PCEs. therefore, other non-PCEs obtained were also analysed in terms of the interruption position effect.

Method

Tasks The tasks used in the current study are designed within a game-like paradigm. The primary tasks consist of a doughnut-making task and an order collection (Call Centre) task. The doughnut-making task is the main task which requires a participant to follow a set of fixed procedures to operate the machine correctly. The order collection task requires one to collect an order first before making the doughnuts ordered. The rationale for the inclusion of the order collection task is to simulate an environment where one has to physically move away from the main task (doughnut-making) when it is completed. A lot of real-world PCE situations involve moving away physically from the artefact once the task is accomplished. The doughnut-making task and the Call Centre task were implemented on two separate computer terminals.

The secondary interrupting task (doughnut-packing task) is a mental arithmetic task which requires one to pack different numbers of doughnuts following some simple arithmetic rules. The interrupting task is implemented in the same computer terminal as the doughnut-making task; the doughnut-packing task only serves as an interruption to the doughnut-making task, lasting 75 seconds.

<u>The doughnut-making task</u>
The doughnut-making task is a procedural task in which participants are required to carry out a set of predefined procedures to operate the machine correctly in order to produce a required number of doughnuts. The PC step is the "Cleaning" step at the end of the task which requires clicking on a button labelled "Process/Cleaning".

At the beginning of a trial the centre of the doughnut machine indicates the location of the next order. When order collection from the Call Centre has been finished, pressing a button labelled "Next Order" changes the centre of the doughnut task to the current order. The centre of the screen changes back to indicate the location for the next order collection when the participant has finished making the entire order. The presence of this location indicator after the completion of a trial is a false completion signal, which is a distinguishing feature of many PC tasks (Reason, 2002).

<u>The Call Centre task</u>
The Call Centre is a simple search task where one has to find a specified location from the London Underground Map to get an order before the doughnut-making process. This search task is to be carried out at the beginning of each trial. At the beginning of each trial, the centre of the doughnut-making machine indicates a location where an order is to be collected. The participant is then required to physically turn to the Call Centre computer terminal to find the location. Once the location is found and entered, the participant then returns to the doughnut-making machine terminal to begin the doughnut-making process.

Figure 1 shows the screen shots of all three tasks and the hollow arrows depict the transitional sequence of a trial. The black arrow depicts the doughnut-packing interrupting the primary task.

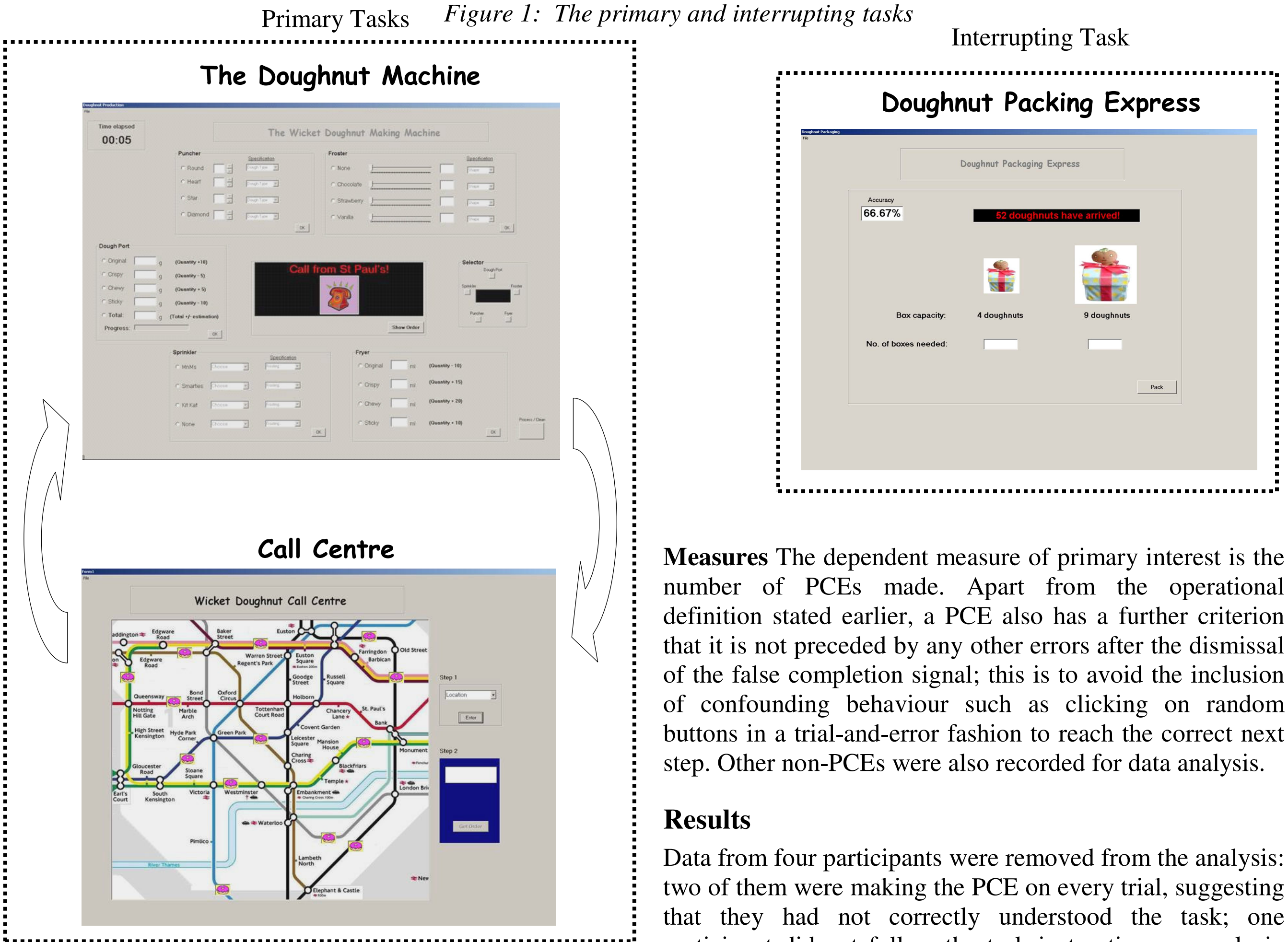
<u>PCE</u>
A PCE is operationalised as the omission of pressing the "Clean" button with the following action sequence: 1) dismissal of a report of performance (no. of doughnuts made), followed by 2) executing the Call Centre task, and followed by pressing the "Next Order" button on the Doughnut task.

Design This is a within-subject design with one independent variable — interruption position — which has three levels: Z (just before the PC step), Other and Nil (no interruptions).

Each session consists of 11 trials in the testing phase; 4 trials with interruption position Z, 4 trials with interruption position Other and 3 trials with Nil interruption. The 4 interruptions at position Other are selected randomly from 5 other positions in the task sequence; no repeating position is selected in a given testing session. The order of trial presentation is randomised.

Procedure Participants read documents describing the experiment then completed a demonstration and a training phase. Participants first observed the experimenter performing both the doughnut-making and the doughnut-packing task separately. When performing the doughnut-making task the experimenter explained the need to respond to the Call Centre when the location signal flashes in the doughnut machine. The experimenter also demonstrated

Figure 1: The primary and interrupting tasks



how to respond to a call using the Call Centre. Participants were then given two training trials on the doughnut-making task; one with and one without the interrupting doughnut-packing task. Any errors occurring in this training phase result in on-screen warning messages and beeps. Participants were required to identify and correct the error in order to continue. The experimenter was present in the room with the participant during training, and the participant was allowed to ask questions about the tasks if necessary.

In the testing phase, participants were required to perform 11 trials in total and the experimenter left the participant to carry on the session alone at this point. The entire experiment took approximately an hour.

Apparatus The programs were written in Visual Basic 6 and run on two different PC terminals. The two computer terminals were arranged at 90° so that the participant had to turn away from either one computer depending which task s/he was carrying out.

Participants 35 participants, undergraduates and postgraduates from London universities, took part in this study. Ages ranged from 19 to 37 with a mean of 24.8.

Measures The dependent measure of primary interest is the number of PCEs made. Apart from the operational definition stated earlier, a PCE also has a further criterion that it is not preceded by any other errors after the dismissal of the false completion signal; this is to avoid the inclusion of confounding behaviour such as clicking on random buttons in a trial-and-error fashion to reach the correct next step. Other non-PCEs were also recorded for data analysis.

Results

Data from four participants were removed from the analysis: two of them were making the PCE on every trial, suggesting that they had not correctly understood the task; one participant did not follow the task instructions properly in that the Call Centre task was not performed; and a data file was lost for one participant due to technical fault.

Overall PCE rate There were a total of 330 procedural errors across the 31 participants. A procedural error is defined as any incorrect actions deviating from the correct sequence. Over half of the participants (20 out of 31) made at least one PCE. A total of 56 PCEs were obtained accounting for about 17% (56 out of 330) of all the procedural errors. Each participant had 11 opportunities to commit PCEs (making a total of 341 opportunities), so there was an overall PCE error rate of 16% (56 out of 341).

Interruption position effect Table 1 shows the distribution of the PCE occurrences according to the different interruption points. The error rate in trials with interruption Z was about three times more than trials with interruption Other and Nil.

Table 1: Number of PCEs and their error rates with respect to different interruption positions

	Interruption position		
	Z	Other	Nil
Total no. of PCE (Total no. of opportunities)	37 (124)	11 (124)	8 (93)
Mean error rate (SD)	29.8% (32.5)	8.9% (19.9)	8.6% (21.0)

SD = Standard deviation

Error rates (%) of PCE occurrences were calculated for the three different interruption trials for each participant. The error rates are calculated using the number of PCEs divided by the number of opportunities for the error. The use of error rates for comparisons eliminates biases imposed by absolute numbers, because there were only three trials with no interruption as opposed to four trials with point Z and Other interruptions each. A one-way repeated ANOVA on the error rates showed a large significant main effect of interruption position. The scores did not conform to the assumption of sphericity, so the Greenhouse-Geisser correction was used ($F_{(1.338,\ 40.149)}$ = 9.921 p = 0.001; Eta squared = 0.249).

Planned contrasts comparing the mean error rates of Z and Other yielded a reliable difference ($t_{(30)}$=3.297, p = .003), and Z versus Nil also yielded a reliable difference ($t_{(30)}$=3.339, p = .002). No significant difference was detected between Other and Nil ($t_{(30)}$=.09, p = .929).

Other non-PCEs Errors at other task steps were categorised into three interruption categories; "immediately after" (IA, error occurring immediately after an interruption), "later after" (LA, error occurring later after an interruption), and "no interruption" (error occurring before an interruption or in trials with no interruption). These categories are equivalent to the PCEs' interruption position Z, Other and Nil respectively.

Table 2 shows the number of non-PCEs and their respective mean error rates according to the three interruption position categories.

A one-way repeated ANOVA on the error rates yielded a large significant main effect of interruption position. The Greenhouse-Geisser correction was used because of violation of sphericity (F(1.015, 30.439) = 25.6, p < .001; Eta squared = .46). Post hoc comparisons with Bonferroni correction showed a reliable difference between IA and LA, difference between IA and NI was also significant. No reliable difference was detected between LA and NI.

Table 2: Number of non-PCEs and their error rates with respect to different interruption positions

	Interruption position		
	IA	LA	NI[1]
Total no. of PCE (Total no. of opportunities)	31 (124)	13 (124)	111 (5264)
Mean error rate (SD)	25% (25)	1.7% (2.6)	2.1% (1.4)

SD = Standard deviation

Discussion

An overall error rate of 16% is obtained for PCEs (56 out of 341 opportunities). The current error rate obtained from trials without interruptions (8.6%; 8 out of 93 opportunities) is comparable to the 9.3% (13 out of 140 opportunities) obtained in Byrne & Bovair's (1997) Experiment 1, which did not have working memory load manipulation. This suggests that the current paradigm has successfully generated PCEs at a level that allows investigation in a laboratory setting.

A significant difference was found in the PCE rate between the different interruption positions. As predicted, the results suggest that more PCEs occur when the task was being interrupted *just-before* (Z) the PC step – almost three times more – than at any other positions in the task.

However, the same interruption position effect was also obtained for non-PCEs at other steps in the task. The result suggests that interruption position had the same disruptive effect on other non-PCEs; an interruption occurring just before a task step was more likely to result in an error than an earlier interruption or no interruption at all.

A difference was observed between PCEs and non-Pces in terms of their qualitative resumption patterns. All the obtained PCEs were not preceded by any other errors; in other words, they were errors omitting the PC step and moving to the Call Centre task immediately. In contrast, for non-PCEs, 45% (14 out of 31) of them involved resuming to the task step just before the interruption, and the remaining lacked a consistent pattern of resumption. We take this as evidence that participants were using the false completion signal in the task environment as a primary cue to the next step in the task sequence after interruptions just-before the PC step.

Experiment 2

This experiment is a continuation of the previous experiment examining the effect of interruption positions of two different interruption durations. Two shorter durations,

[1] About half of the errors in NI (117 out of 228) occurred at a particular step near the very beginning of the task, however, the interruption manipulation does not involve an interruption just before the step. Therefore, errors at that particular step were excluded from the analysis. The occurrence of the particular error suggests a systematic nature, however, it is beyond the scope of this paper to discuss this error.

each 30 seconds apart, 45 seconds and 15 seconds were used. Based on the AGM model, the following hypothesis is made about the interruption positions and durations being tested:

With an interruption duration long enough for a memory item to decay below retrieval threshold, the interruption position effect should persist; on the other hand, the effect should disappear if the interruption duration is too short for substantial decay to take place. More specifically, we should expect an interaction effect between interruption position and duration if the 15-sec interruption is too short for any substantial decay of memory.

Method

Tasks, apparatus and procedure Adjustments were made to the computer program to change the duration of the interruption to 15 seconds for the Short interruption group and 45 seconds for the Long interruption group. In all other ways, the tasks, apparatus and procedure were as described in experiment 1.

Design The experiment is a mixed design. It has two independent variables; the within-subject variable is interruption position with three levels; Z, Other and Nil. The between-subject variable is the duration of the interruption with two levels; Short (15 seconds) or Long (45 seconds).

Participants There were 24 participants (12 in each group). Participants were undergraduate and postgraduate students from London universities, age ranging from 20-24 with a mean age of 21.4 years.

Measures The dependent measure of primary interest is the same as experiment 1's , namely, the number of PCEs.

Results

The data from one participant in the Long group and two participants in the Short interruption group were removed as they made post-completion errors on every trial suggesting that they had not correctly understood the task.

Overall PCE rate A total of 297 procedural errors occurred across the 21 participants. More than half of the participants (16 out of 21) made at least one PCE. A total of 71 PCEs were obtained, accounting for about 24% (71 out of 297) of all procedural errors. Each participant had 11 opportunities to commit PCEs, therefore their obtained number of PCEs yielded an overall error rate of 31% (71 out of 231 opportunities). Table 3 shows the distribution of PCEs according to the different interruption positions, for the two groups.

Table 3: Number of PCEs and their error rates with respect to different interruption positions

		Interruption position		
		Z	Other	Nil
Short interruption (15secs)	No of PCEs (no. of opportunities)	16 (40)	8 (40)	6 (30)
	Mean error rate (SD)	40.0% (39.4)	20.0% (30.7)	20.0% (28.1)
Long interruption (45secs)	No of PCEs (no. of opportunities)	23 (44)	12 (44)	6 (33)
	Mean error rate (SD)	52.2% (48.0)	27.3% (30.5)	18.2% (31.1)

Overall interruption position effect PCE rates were calculated for the three different interruption trials for each participant. The error rates were analysed using a mixed 2 × 3 ANOVA. There was a significant main effect of interruption position ($F_{(2,18)} = 5.092$, $p = .018$) with a large effect size (Eta squared = .361).

Although there was no main effect of interruption length ($F_{(1,19)}=0.215$, $p = 0.648$), the trend of the data clearly demonstrates the predicted direction. In trials where there was no interruption, or where the interruption occurs in any of the Other positions, one would not expect any difference between the groups in terms of the error rate. In trials where the interruption occurs immediately before the post-completion step, there was an increase in the error rate in the Long Interruption group.

The interaction, interruption position × duration, was not statistically significant ($F_{(2,18)} = 0.623$, $p = .548$).

Other non-PCEs errors There were a total of 29 resumption errors, accounting for about 10% of the non-PCEs. Due to time limitation, the analysis of interruption position effect on non-PCEs is under progress. However, we should expect the same pattern of results as in the previous experiment.

Discussion

All errors that occurred after interruption Z were PCEs and all resumption errors were found after interruption Other only. This suggests a systematic bias towards committing a PCE after interruption Z. The systematic bias suggests that cues in the external task environment might prompt participants about the completion of the task.

The results confirm the finding from experiment 1 that the position of the interruption has a critical influence on the number of PCEs. Interruptions occurring just before the PC step are more likely to result in a PCE than interruptions occurring at other positions in the task.

Both the 15-second and 45-second interruptions are of sufficient length to result in an increase in PCEs when interrupted at position Z – almost twice the rate – than at Other and Nil. Although the results suggest a trend in the predicted direction, that the length of the interruption itself can also influence the error rate, the results show that the shorter interruption is not short enough to have no effect on the PCE rate.

The overall PCE rate of participants in experiment 2 is higher than that of experiment 1 (31% compared to 16%). However, statistical comparisons only showed a marginal significance between the difference of the two experiments ($t_{(30.721)}$=.2.011, p = .053). The marginal difference might be due to slight differences in the random samples obtained in the experiments.

General discussion

Results from the current study suggest that the effect of interruption position has a critical influence on the occurrences of PCE: interruptions occurring just before the PC step are more likely to result in PCEs than interruptions occurring at other positions in the task. The effect is robust in that it was replicated in a second experiment in the current study. However, further analysis into other non-PCEs shows that they were also sensitive to the interruption position effect. This suggests that PCEs are no different to other errors in terms of the effect of interruption.

The effect of interruption position is consistent with predictions made from the AGM model. When associative priming between procedural steps is disrupted for long enough that the suspended goal has decayed substantially, then upon task resumption, external cues in the task environment are likely to dominate the priming process cueing the next step in the task sequence. In the case of an interruption intruding just-before the PC step, the combination of the decay of the PC sub-goal and the occurrence of the false completion signal is likely to act as a double-edged sword giving rise to the error. This also highlights a feature distinguishing PCE from other omission errors: that a PCE is almost always preceded by a completion signal. The completion signal can be external in the environment, as in the current study, or internal in one's mental state (Li et al., 2005).

Consideration of the results of the two experiments suggests that longer interruptions can lead to larger increases in PCE rate when interrupted just before the PC step rather than other positions; a threefold increase with a 75sec interruption compared to a twofold increase with a 45-sec and 15-sec interruption. There was no significant difference in error rate between the two groups in experiment 2 is taken as evidence that even relatively short interruptions can result in a significant increase in PCE rate.

All in all, the effect of interruption position on PCE is clear and robust, however, further research is required to confirm the effect of the interruption duration; by including shorter interruption duration than the current ones to examine the predicted interaction effect between interruption position and duration. Further analysis on the non-PCEs from experiment 2 is also in progress to confirm the effect of interruption on these errors.

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