INTERRUPTIONS IN THE TOWER OF LONDON TASK: CAN PREPARATION MINIMISE DISRUPTION?

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Responding to computer-initiated notifications requires a shift in attention and therefore disrupts the flow of work. Two exploratory experiments investigate how this decrement can be minimised when a short preparatory time is available before switching to deal with the interrupting task. The execution phase of a computer-based Tower of London task was interrupted by the requirement to perform simple verbal reasoning problems, incurring a cost relative to continuous plan execution. The goal-activation model (Altmann & Trafton, 2002) proposes a critical time period before engaging in the interruption (the "interruption lag") during which cues pertaining to the primary task can be encoded to facilitate subsequent task resumption. Experiment 1 demonstrated that resumption times were significantly quicker when the interruption was preceded by a three second interruption lag, and that time to complete the interrupting task was also reduced. In Experiment 2, participants chose when to engage in the secondary task. Although this did not benefit task resumption times relative to unexpected interruptions, it significantly reduced completion times on the secondary task. The results are interpreted within the framework of the goal-activation model and suggest that the interruption lag is beneficial in terms of performance on both the primary and interrupting tasks.

Interruptions are a common feature of the modern work environment. Estimates suggest that around ten minutes out of every hour can be spent dealing with unexpected secondary activities (O'Conaill & Frohlich, 1995), with an additional minute required for resumption of the original task to be complete (Jackson, Dawson & Wilson, 2000). Such frequent shifts of attention are costly to primary task performance: Both laboratory-based experiments and studies in real world settings report a decrease in accuracy (e.g., Bainbridge, 1984), productivity (e.g., Paquiot, Eyrolle & Cellier, 1986) and worker well-being (e.g., Kirmeyer, 1998; Zijlstra, Roe, Leonova & Krediet, 1999). Appreciable gains to safety and efficiency could be made if either interruptions were minimised or the cost to performance in the resumption phase could be reduced.

Factors thought to affect primary task performance include interruption complexity (Gillie & Broadbent, 1989), similarity of the interrupting task to the primary task (Perry, 1998; Edwards & Gronlund, 1998; Czerwinski, Chrisman & Rudisill, 1991), the availability of retrieval aids (Cutrell, Czerwinski & Horvitz, 2000; Czerwinski, Cutrell & Horvitz, 2000; Lahlou, Kirsh, Rebotier, Reeves & Remy, 2002) and control over the interruption (McFarlane, 1999). Some computer-initiated interruptions require immediate attention before work on the primary task can continue: For example, "save" reminders in spreadsheet programs that freeze the current screen, or pop-up advertisements during a web search that need to be closed before the desired page is displayed. Other computer-initiated interruptions allow the worker to choose when to deal with the intruding task, such as instant messenger services that use a flashing icon at the bottom of the screen to alert the user to the communication. In the current paper, we investigate how the disruptive effects of interruption can be minimised when the switch between tasks allows for a brief preparatory period, in comparison to those interrupting tasks that demand immediate attention. The theoretical motivation for the study comes from the goal-activation model (Altmann & Trafton, 2002), one of the few available frameworks to have been specifically applied to the study of interruption.

The goal-activation model (Altmann and Trafton, 2002) is a computational model derived from the principles of ACT-R (Anderson, 1993) to model the suspension and resumption of goals. It challenges the assumption that goals are held in a goal stack (e.g. Anderson, 1993), and suggests that whichever goal is most active at a given moment is the one that governs behaviour. Two factors determine the activation of goals: strengthening of new goals above an interference threshold to govern behaviour, and priming to resume old goals through associative cues.

The current paper examines a feature proposed by the goal-activation model: the "interruption lag". This is the time between the alert of an interruption (e.g., telephone ringing) and actually engaging in the interrupting activity (e.g. the telephone conversation). It is proposed that this is a critical time during which retrieval cues can be encoded to facilitate subsequent task resumption. The current experiments examine the effect of an interruption lag using interruptions in a well established cognitive task, the five-disc Tower of London problem (Ward & Allport, 1997). Based on the well known Tower of Hanoi problem, this task is useful for the study of interruptions as it provides a controlled task environment in which to establish key phenomena. Discs are to be moved one at a time from an initial configuration, until the display matches a given goal state. Unlike the Tower of Hanoi, there are no constraints on disc size so any disc can be moved to any peg. It allows for a fine-grained analysis of performance, uncontaminated by compensatory strategies. Performance is measured at the level of individual moves that can be timed precisely and interrupted and resumed at any point.

The interrupting task in our experiments was to complete verbal reasoning problems of the type "A follows B - - AB" [false] (Baddeley, 1968). This enables assessment of performance on the interrupting task as well as the primary task: In some situations an ability to respond quickly and accurately to the interrupting task may be just as critical as primary task resumption.

EXPERIMENT 1

Experiment 1 tested whether task resumption times following interruption of six-move Tower of London problems could be reduced if preceded by a brief interruption lag. Furthermore, the experiment examined whether the interruption lag may also benefit performance on the secondary task, in terms of task performance times and accuracy. The expectation was that, relative to immediate interruptions, a preceding three second pause would facilitate subsequent task resumption by allowing time to encode retrieval cues, and to build up activation of the next goal.

Method

Participants. Nineteen undergraduate psychology students at Cardiff University (age range 18 to 22) received course credit for their participation.

Apparatus and materials. The task was conducted on a PC using a Tower of London (TOL) computer program written in *Visual Basic 6.0*. The main display panel (33 x 25 cm) showed a starting configuration of five different coloured, same-sized, moveable discs arranged on three pegs with a goal state box (9 x 5 cm) positioned in the top right hand corner of the screen. Discs on the main display could be moved by first clicking with the mouse on the peg holding the chosen disc, and then on the peg to which the disc was to be moved. A pop-up box notified the participant upon completion of each problem, and a mouse click initiated the next trial. Number of moves, and time taken to make each move were recorded.

Following the third move on interruption trials, the TOL display was replaced by a blank screen displaying a verbal reasoning statement of the type described earlier, positioned in a box in the centre. Below this were listed the words 'True' and 'False', one of which the participant was to highlight by clicking with the mouse to input their answer. They then pressed a button labelled 'Continue' in order to return to the primary task. The interrupting task would either appear immediately on completion of the third move, or following a three second pause, during which time the main display was frozen and no actions could be performed on the primary task.

Design. A within-participants design was used. There were 25 trials in total, which included six interruption trials and six matched no-interruption control trials. On interrupted problems, the reasoning task was either displayed immediately (trials 4, 12 & 19) or followed a three second pause (trials 7, 15 & 25); half the participants received this arrangement, whilst for the other half, trials 4, 12 and 19 were "delayed" trials, and 7, 15 and 25 were "immediate". The six control trials were matched to the six experimental trials, requiring the same solution path but with the disc colours changed around (trials 6, 9, 13, 16, 20 & 23).

Procedure. Participants read through a standardised instruction sheet. The need for preplanning was emphasised so that solution execution could be continuous once the first disc was moved. In order to provide face validity, the task was introduced as one studying the relationship between spatial problem solving and verbal problem solving. Participants were told that at certain points they would be asked to complete verbal reasoning problems, which they should do as quickly and accurately as possible, before continuing promptly with the Tower of London task as normal.

Participants were given two non-interrupted practice trials. They began each trial by planning the best way to achieve the goal state in the minimum number of moves. The participant then moved the coloured discs one at a time, the aim being that those in the main display should match those in the goal state box. The experiment typically lasted about 30 minutes.

Results and discussion

The number of additional moves taken on the Tower of London task above the minimum of six were recorded and subjected to a repeated measures ANOVA. There was no difference between immediate, delayed, or control conditions, $F(2, 36) = 2.694, p > .05$. However, a repeated measures ANOVA on the times taken to make the fourth move revealed a significant difference between conditions, $F(2, 36) = 24.01, p < .0001$. Fisher's post hoc tests showed that participants were significantly quicker to make the fourth move in control trials (mean of 2.31 sec) than when the fourth move was preceded by an interruption. Participants were also significantly quicker to make this move when the interruption was preceded by a three second interruption lag (mean resumption time of 3.77 sec) than when it occurred immediately (mean resumption time of 6.05 sec). This supports the idea that a brief interruption lag can facilitate subsequent task resumption: During the three seconds when participants are unable to move any of the discs, the current state is being repeatedly sampled, building up activation of the current goal and enabling the encoding of retrieval cues. Following interruption, the old goal can be more easily reinstated through associative priming.

A further finding was that participants were significantly quicker to complete the interrupting reasoning task in the condition when the interruption was preceded by a pause, $t(18) = 2.07, p < .05$. It is possible that the interruption lag not only serves the function of enabling the encoding of retrieval cues, but also helps transition between tasks so that the participant is more "prepared" to begin the secondary task. This, however, is contrary to previous findings reported by Trafton, Altmann, Brock and Mintz (2003) in which the interruption lag did not facilitate performance on the secondary task.

One problem with these results is that the resumption time data are potentially confounded with the finding that participants also completed the interrupting task quicker in the three-second pause condition. A number of studies suggest that the duration of the interruption has little effect on performance of the primary task (e.g. Bailey, Konstan & Carlis, 2000; Gillie & Broadbent, 1989), but this is nevertheless a factor that requires further investigation. As a preliminary experiment however, Experiment 1 demonstrates a clear benefit of an interruption lag for both primary and secondary task performance, relative to the immediate interruption condition.

In terms of the number of errors made on the reasoning tasks, there was no significant difference between the two interruption conditions, $t(18) = .62, p > .05$, as participants' performance was generally at ceiling.

EXPERIMENT 2

Research suggests that "negotiated" switches between tasks – that is, those that are under the control of the participant – result in better overall performance than those that demand immediate attention (McFarlane, 1999). Experiment 2 examined whether making the interruption point, and subsequently the interruption lag, controllable would be of benefit to participants in terms of performance on the primary and interrupting tasks.

Method

Participants. Twenty-seven undergraduate psychology students at Cardiff University (age range 18 to 23) received course credit for their participation.

Apparatus and materials. The same Tower of London program was used as in Experiment 1, but with one alteration. Half of the interruptions occurred immediately, displaying the verbal reasoning task as in Experiment 1, following the third move. For the remaining interruption trials, the participant could decide themselves at what point during the primary task to engage in the verbal reasoning problem (from the point prior to making the second move to the point prior to the sixth move). After completion of the first move, a grey button labelled *verbal task* appeared on the screen, centrally and above the main TOL display. Clicking on this button at any point during the rest of the trial would take the participant to the reasoning task. If, after making the fifth move, the participant still had not completed the secondary task, the main display would be frozen so that no more discs could be moved. This then forced the participant to switch to the verbal task before completion of the Tower of London problem, so that every trial would suffer an interruption for which resumption data could be recorded.

Design. There were 8 interruption trials in total. For half the participants, "immediate" interruptions occurred on trials 4, 7, 12, and 19, and "negotiated" interruptions on trials 10, 15, 21 and 25. This arrangement was reversed for the other half of participants.

Procedure. The same as Experiment 1 except that for the two practice trials, one was from the negotiated interruption condition including an example of the reasoning problem. There were 25 trials in total.

Results and discussion

Task resumption times were recorded and a paired t-test was conducted. Interestingly, there was no difference between the immediate and negotiated conditions, $t(26) = .81, p > .05$: The opportunity to choose when to engage in the secondary task did not reduce subsequent task resumption times. Even though participants could effectively control the interruption lag themselves in this condition, they were not able to take advantage of this for the encoding of retrieval cues. Perhaps the brief time prior to the interrupting task was not spent encoding cues relating to the current state of the display, but spent rather on concentrating more on the button and the process of when to switch, a factor that may therefore have served as an additional load. Previous research has also suggested that there are more overhead costs associated with negotiated interruptions (Katz, 1995).

Participants did not seem to take full advantage of the negotiated condition, as the largest proportion of switches (49%) were actually made immediately regardless of the opportunity to "negotiate". In these cases, the mean time between the button appearing and switching was 1.49 seconds. This is half the time of the three-second pause given in Experiment 1, so it is perhaps not surprising that the same advantage was not observed especially given the overhead costs of the negotiated condition.

Task switches were left until the final move 32% of the time. Although participants were aware that they would eventually be required to complete the verbal reasoning problem before they reached the end of the trial, this strategy probably reflects their tendency to try to finish off as much of the task as possible before the switch is enforced. Had there been the option to engage in the secondary task after completion of that particular Tower of London trial, it is likely that many participants would have chosen to switch then, after they had achieved their primary goal. Participants would occasionally change tasks at other points, but dealing with the interruption immediately to "get it out of the way", or trying to finish off as much of the problem as possible, were by far the most popular strategies.

In Experiment 2, task times were also recorded for time spent completing the verbal reasoning problem in each condition. A paired samples t-test showed that participants were able to complete the secondary task significantly quicker in the negotiated condition, compared to when it occurred immediately, $t(26) = 2.43, p < .02$. It is possible that this benefit is related to a "preparedness" to switch tasks, as there is a clear benefit when the interruption is anticipated. This is in line with findings from the task switching literature which reports a reduced time cost if the switch is predictable (Garcia-Ogueta, 1993) or if participants are given time to prepare through longer response-stimulus intervals (e.g., Rogers & Monsell, 1995). There was, however, no difference between conditions in the number of errors made on the verbal reasoning task as performance was generally at ceiling, $t(26) = .28, p > .05$.

Unlike in Experiment 1, time taken to complete the interrupting task and time taken to resume the primary task did not covary. It would seem then that these factors are not interdependent and that the duration of the interruption alone is not sufficient to explain the difference in task resumption times observed in the first experiment. More critical to prompt goal retrieval is an adequate opportunity to boost activation of the to-be-suspended goal before engaging in the interruption.

GENERAL DISCUSSION

Experiment 1 demonstrated that a pause before the interruption reduced both primary task resumption times as well as the time needed to complete the secondary task. Experiment 2 showed that although completion times on the reasoning task were reduced by a negotiated switch, resumption times were not. Perhaps a negotiated switch would be more beneficial if participants were able to choose to change tasks after a goal had been completed (e.g., between trials).

Other interruption studies have used secondary tasks of 30 seconds to several minutes in duration, but the present experiments demonstrate that even very brief interruptions can be disruptive to performance. Computer initiated notifications such as e-mail alerts, "save" reminders on spreadsheets programs and office assistants, for example, may only distract the worker for a matter of seconds but still incur a cost in resuming the ongoing activity. Their frequency in an office environment is often unnecessary, and efficiency could be improved for example by having the system check for e-mail less regularly rather than displaying notifications each time e-mail is received.

These experiments show the importance of the interruption lag as a time for "preparing to resume"; a time when workers can either hurriedly finish what they are working on before attending to the interruption, or by encoding retrieval cues to aid later task resumption. The user interface could support these activities for example by allowing workers to continue typing when such an alert appears on the screen, rather than the alert receiving focus and requiring action immediately. If the interface allows writing to continue before switching to deal with the notification (for example, making a clear/ delete/ read decision on an e-mail alert), it may allow the user to consolidate their place in the task and also to reach a convenient break point before suspending the activity in hand.

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