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Interruptions, visual cues, and the microstructure of interaction: Four laboratory studies

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Abstract

Visual cues relating to an interrupted task can help people recover from workplace interruptions. However, it is unclear whether visual cues relating to their next steps in a primary task may help people manage interruptions. In a previous intensive care unit simulation study, Grundgeiger et al. (2013) found that nurses performing equipment checks were more likely to defer an interruption from a colleague if they could see the next steps of their task on the equipment screen. We abstracted some elements of the simulation study into a controlled laboratory study to test whether visual cues support interruption management. Participants' primary task was to verify a set of linked arithmetic equations presented on a computer page. From time to time, an animated virtual character interrupted the participant to mimic a social interruption, and the participant chose whether or not to defer a response to the

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interruptions until they finished their page of equations. In four experiments, the independent variable was visual cue (cue versus no cue) and the primary outcome was the proportion of interruptions from the character that the participant deferred so that she or he could complete the page of equations. Experiment 1 suggested that the visual cue made participants more likely to defer the interruption. However, a potential confound noted in Experiment 1 was eliminated in Experiment 2 and the effect of the visual cue disappeared. Experiments 3 and 4 repeated Experiments 1 and 2 with another population of participants, and replicated their findings. Participants' decisions to defer interruptions can depend on apparently minor properties of their primary task.

Keywords: Interruptions; interruption management; distraction; visual cues; soft constraints

1 Introduction

Interruptions are ubiquitous in modern society. Office workers are interrupted more than four times an hour (O'Conaill and Frohlich, 1995) and managers use a PC barely two minutes before they switch their task or get interrupted (Gonzalez and Mark, 2004). Intensive care unit nurses are distracted about every three minutes and interrupt their task at hand almost seven times an hour (Grundgeiger et al., 2010). Interruptions have been associated with errors or degraded performance in healthcare (Westbrook et al., 2010), aviation (Loukopoulos et al., 2003), and human-computer interaction (Bailey and Konstan, 2006). In the literature, definitions of interruptions typically note the unexpected nature of the interruption and the prompt cessation of the task at hand due to the interrupting task (Brixey et al., 2007; Trafton et al., 2003). However, further studies report that participants use discretionary interruption management strategies; such strategies include immediately engaging with the interrupting task, as described above, but also include deferring or blocking the interrupting task (Bogunovich and Salvucci, 2011; Colligan and Bass, 2012; Grundgeiger et al., 2010; Liu et al., 2009; Salvucci and Bogunovich, 2010). In the present paper, we investigated whether the presentation of subtle visual cues, emphasizing the remaining steps of a procedural task, can influence how humans manage interruptions.

1.1 Discretionary behavior in handling interruptions

In their model of the time sequence of an interruption, Trafton et al. (2003) suggest that an initial distraction alerts a person that an interruption may be imminent. The time between the initial distraction and the person attending to the interruption is the *interruption lag*. After the interruption lag, the person deals with the interrupting task. The time from the end of the interruption until the person resumes the primary task is the *resumption lag*. The duration of the resumption lag is used as an index of how cognitively demanding the task resumption process was. This framework has supported many empirical findings and has advanced our theoretical understanding of the effects of interruptions on cognition (Trafton and Monk, 2007).

Using the Trafton et al. (2003) framework, several studies have investigated the effect on task resumption of visual cues during different stages of the interruption sequence. For example, Hodgetts and Jones (2006) introduced interruptions to the execution phase of Tower of London problems. They found that contextual cues provided during the interruption lag gave participants the opportunity to prepare before the break-in-task, which reduced the time cost when participants resumed the primary task. Further studies found evidence that cues provided during an interruption can also help participants when they resume the primary task. Usually such cues contain contextual information about the interleaved primary task (e.g. Altmann and Trafton, 2004). For example, in an eye tracking study in an intensive care unit, Grundgeiger et al. (2010) observed that nurses used external cues to facilitate the task resumption, such as leaving work objects of the primary task in their hands when being interrupted. Finally, visual cues provided at the task resumption stage of an interruption can improve task resumption as well. In a laboratory study, Trafton et al. (2005) found that participants who received a blatant environmental cue (a red arrow) near their previous action after an interruption were able to resume their primary task faster than participants who received only subtle or no environmental cues. Taken together, the above findings underscore the effectiveness of providing visual cues before, during, and after an interruption. However most of the research about visual cues in the context of interruptions focuses on the task resumption stage. Less is known about how visual cues can influence interruption management strategies, such as during the interruption lag.

Many laboratory studies of interruptions do not explore interruption management strategies, which is a shortcoming. Participants are frequently forced to interrupt their primary task almost immediately; no other means are given them to manage the interruption as might be the case in everyday life. However, more natural interruption management strategies can be observed in the laboratory if participants are free to engage in discretionary behavior. For example, in a study on informative cues for interruption management, Hameed et al. (2009) observed that participants preferred to engage with important interruptions and blocked unimportant interruptions (see also Ho et al., 2004). In a further study by Salvucci and Bogunovich (2010), participants were required to work on a task which alternated between high and low mental workload. When faced with an interruption, in 94% of all cases participants switched to the interrupting task during a phase of low mental workload (see also Lenox et al., 2012).

Field studies in different domains report that humans manage interruptions in different ways. In an early study, Zeigarnik (1927) reported that participants refused to accept interruptions from an experimenter so that they could first finish their task. In a field study of office work, Zijlstra et al. (1999) observed that office workers who were interrupted by a phone call while working on a text editing task let their phone ring for some time until they had completed a sub-step of their primary task. Finally, in a critical care context, Grundgeiger et al. (2010) observed that in about 19% of cases, intensive care unit nurses finished their primary task before turning to the interrupting task. However, the latter study was observational and it remained unclear why nurses sometimes finished the primary task and sometimes not.

In a further study, Grundgeiger et al. (2013) provided a possible reason that nurses sometimes finished their primary task. The Grundgeiger et al. study is described in some detail here, because certain aspects of it guided the studies reported herein. Grundgeiger et al. examined whether visual cues would improve nurses' memory for future tasks (prospective memory). The study was conducted in an intensive care unit (ICU) in an isolation room with a patient manikin, real ICU equipment, and ICU nurses as participants. The prospective memory events and visual cues were carefully controlled; however, the scenario was openended in terms of how nurses could behave, meaning that naturalistic, discretionary behavior was captured.

In one part of the Grundgeiger et al. (2013) study, the participating nurse was conducting a bedside safety check, which is a routine task at the beginning of a shift that includes, for example, checking running medications, checking alarm limit settings on the vital sign monitor, and checking alarm limits on the mechanical ventilator. A colleague (actor) at the other side of the room interrupted the nurse just as the nurse was about to start checking the alarm limits on the mechanical ventilator. In the 'visual cue' condition, the ventilator's display screen was open at the page showing the alarm limits, very clearly displaying the upcoming task. In the 'no visual cue' condition, however, the ventilator's display screen did not show the alarm limit page – the participant had to click on a tab to open it. The original hypothesis was that nurses in the visual cue condition would more frequently resume the unfinished primary task at the end of the interruption than would nurses in the no visual cue condition. However, some nurses deferred attending to the colleague's interruption and finished the alarm limit check (primary task) before attending to the interruption. This behavior occurred significantly more often in the visual cue condition than in the no visual cue condition. Grundgeiger et al. suggested that "for the interrupted alarm limits task, nurses frequently avoided the anticipated memory demand of resuming the interrupted task by asking the interrupting nurse to wait until they had finished the alarm limits check," (p. 586).

The above finding from Grundgeiger et al. (2013) is interesting from both a practical and theoretical perspective. From a practical perspective, it suggests that visual support provided as part of a primary task display, highlighting the next steps of a task, may actually encourage people to use a deferral interruption management strategy and thereby avoid the prospective memory demand of needing to return to the primary task. Such a principle could be of interest for the design of any graphical user interface. From a theoretical perspective, the finding contributes empirical evidence to the under-studied area of discretionary interruption management. Furthermore, the findings may also contribute to the development of theoretical models of multitasking (Wickens and Gutzwiller, 2015).

However, the Grundgeiger et al. (2013) study has several shortcomings. First, the results regarding interruption deferral were observed post-hoc. Second, the analysis regarding this result included only 18 participants. Third, the behavior observed may be specific to an interruption-driven critical care environment. Healthcare staff may be aware that they are less likely to resume the task after an interruption and therefore tried to avoid any prospective memory demands. In sum, it is premature to conclude that visual cues of task steps encourage people to complete their primary task before they attend to an interruption. In the present study our goal was to provide an initial further test of the conjecture arising from the Grundgeiger et al. study—that visual cues encourage participants to defer an interruption.

1.2 The present study

A key motivation for the present study was the findings of Grundgeiger et al. (2013). We investigated whether the use of subtle visual cues emphasizing the task structure can influence how humans manage interruptions. To this end, we extracted some characteristics of the interruption event in Grundgeiger et al.'s simulation study and constructed a laboratory study that could be used to investigate interruption management in a controlled setting.

We preserved certain aspects of the Grundgeiger et al. (2013) simulator study when designing the interruptions for the laboratory study. The purpose of doing so was to capture some of the conditions underlying the nurses' interruption management strategies. First, we used an animated virtual character to interrupt the participant in order to capture the social aspect of many workplace interruptions. Second, the monitor with the virtual character was located behind the participant, so that the participant had to reorient physically to attend to the interruption, as the nurses had been required to do. Third, the participants had to pay attention to the interruption not immediately, but as soon as possible. If the participant did not engage with the virtual character, the audio comments of the character became more obtrusive and eventually the monitor showing the arithmetic equations would freeze and the participant would be forced to attend to the interruption. All these properties reflected aspects of the incoming nurse's interruption, including the requirement to eventually attend to the incoming nurse.

We also preserved key aspects of the 'ongoing task' in the Grundgeiger et al. (2013) ICU study in which the ventilator alarm limits display either did or did not cue the ICU nurses for their next task. In the laboratory study, participants' primary task was to verify arithmetic equations presented on a computer screen in a series of pages (Meys and Sanderson, 2013) - see Fig. 1. Each page included four equations that were presented consecutively, but that were interrelated because participants had to remember a certain digit from the previous equation in order to solve the next equation. For the first equation of each page, however, the digit was provided. Therefore, if a participant solved all four equations on a page – a so-called "page finish" – and moved to a new page, the digit for the first equation on the new page would be provided by the computer, removing the memory demand. The latter aspect reflects the fact that until nurses had completed checks on a piece of equipment, they carried the prospective memory load of completing it later if they were interrupted.

Finally, and most importantly, we implemented two different layouts for the primary task, reflecting (a) the alarm limits tab being closed with the alarm limit values invisible vs. (b) the alarm limits tab being open with the alarm limit values visible, for the nurses in the Grundgeiger et al. (2013) study (see Fig. 2 for examples). In both layouts, the location of the equations on the screen indicated which equation was currently being worked on. One layout provided only a minimal amount of context information (the 'no cue' condition). In this condition, participants could use only the location of the current equation and the previously-solved equations on the page to determine their current position in the task and there was no visual information about the remaining tasks. The other layout provided additional visual support for the task (the 'cue' condition), revealing the remaining sub-steps of the task.

Note that by the term "cue" we refer specifically to the extra visual support provided when the remaining task steps on the page are visible, which may or may not affect interruption management during the interruption lag. This differs from the way cues might be manipulated in investigations on the effect of cues on task resumption, where the ongoing task context might be wholly removed during the interruption and blatant or subtle cues given at resumption (e.g. Trafton et al., 2005). Even though the displays in both our cue and no cue conditions have properties that might also cue participants—colors, consistent locations of equations on the screen, and so on—by the terms 'cue' and 'no cue' we refer to the presence or absence of the additional visual support that we manipulated in the experiments.

Of course, our laboratory tasks do not capture many aspects of the nurses' work domain and work tasks. However, our goal was to create an interaction in which visual cues of a still-uncompleted task might motivate participants to defer a social interruption until the task is completed.

In all four experiments, the independent variable was the task layout (cue versus no cue) and the primary outcome was the proportion of interruptions that the participant deferred until he or she had completed the page of equations. If visual cues emphasizing the task structure and next steps influence interruption management, we expected that participants in the cue condition would defer the interruptions more frequently compared to participants in the no cues condition.

Two experiments performed in English in Australia are reported first, and then two experiments performed in German in Germany. A potential confound noted in Experiment 1 (English) was eliminated in Experiment 2 (English) and in Experiment 3 (German), and it was restored in Experiment 4 (German) to check the generality of our findings.

2 Experiment 1

2.1 Introduction

The purpose of Experiment 1 was to test whether visual cues indicating the location of the next steps of a primary task might make participants more likely to defer an interruption, continuing their primary task until they finish all equations on the page. In contrast, participants without access to visual cues might be less likely to defer the interruption, instead breaking off their primary task to attend to the interruption.

A further possibility is that visual cues may help participants perform the arithmetic task faster, with the result that they are more likely to defer the interruption because they estimate they can finish the page of equations before they are forced to turn to the interruption. We therefore tested whether participants working with the visual cues were generally faster at performing the arithmetic tasks.

2.2 Method

The method was very similar across the four experiments. Here we provide a detailed description of the general method, and we highlight the aspects that are unique to Experiment 1. The method sections for Experiment 2, 3, and 4 will simply highlight the aspects that are different from Experiment 1.

2.2.1 Power analysis

A power analysis was performed on a pilot sample of 10 participants in a between-subjects design, with $1\text{-}\beta = .80$ and $\alpha = 0.05$, using G*Power (Faul et al., 2007). The primary outcome measure was the probability that a participant would defer an interruption until the page of arithmetic equations was finished. The analysis indicated a required sample size of 2 x 37 participants, or 74 in all.

2.2.2 Participants

Ethics approval for Experiment 1 and all subsequent studies was granted through either the School of Psychology or the Behavioural and Social Sciences Ethics Review Committee at The University of Queensland. Seventy-nine students from The University of Queensland participated in Experiment 1. Participants were recruited through an online sign-up system and participated in exchange for either course credit or a $10 gift voucher.

All participants provided written informed consent. Participants were randomly assigned to a condition (cue or no cue) after they had received instructions. Prior to data analysis, a participant's data were excluded if there was evidence from their questionnaire data that they did not understand the instructions, or if a preliminary examination of their data log revealed exceptionally long times to complete the arithmetic tasks. Table 1 indicates the number of participants run, number of participants whose data were used, and a breakdown of participants by condition and gender for each experiment.

2.2.3 Tasks

Each participant worked on two different computer-based tasks. The primary task was a continuous sequence of arithmetic problems, where the participant judged whether an equation was correct or incorrect. From time to time, the participant was interrupted by a virtual character wanting to play Tic-Tac-Toe (TTT). Participants were required eventually to perform the interrupting TTT task, but for a certain time they could defer switching to it so as to complete what they were doing on the arithmetic task. More detail is provided below about each task and the costs and benefits of continuing with the arithmetic task versus turning to the TTT game. Both the arithmetic task and the TTT game were written in LiveCode 6.1 (RunRev Ltd., Edinburgh, UK).

2.2.3.1 The Arithmetic Task (primary task)

The arithmetic task was a variant of the task in Meys and Sanderson (2013). The participants worked sequentially through a screen, or “page”, of four simple arithmetic problems, each represented by an equation (see Fig. 1). Participants were required to carry forward a number from one equation to the next and decide whether the next equation was a correct or incorrect arithmetic expression. After participants finished the last equation on a page they started afresh at the top of the next page, where a new number was provided to carry forward to the first equation. Specifically, to complete one arithmetic equation the following steps were performed (see Fig. 1 for details):

1. Click on the grey box with the “X” (“placeholder”) for the next equation. If the wrong grey box is clicked, nothing happens. If the correct grey box is clicked, a virtual number pad pops up.
2. Select correct number (“carryover number”) from the number pad. If the wrong number is selected, the participant tries again. Once the correct number is selected, the whole equation is displayed.
3. Decide whether the equation is correct or wrong. Click on the green tick if it is correct, and on the red cross if it is wrong. The correct result appears at the right, together with either a green thumbs up (participant’s decision was correct) or a red thumbs down (participant’s decision was incorrect). The correct result and thumbs up or down are displayed for 1.5 seconds and then disappear. The absolute value of the correct result becomes the carryover number for the next equation on the page.
4. When the placeholder for the next equation appears, the participant can proceed from step 1 again.
5. At the top of every new page, a fresh carryover number for the first equation is displayed.

The layout of the arithmetic task differed between the cue and no cue conditions. In the cue condition there were many visual cues to provide context (see Fig. 2, upper part) whereas in the no cue condition there were minimal visual cues to provide context (see Fig. 2, lower part). The participants in the cue condition could always see the equations they had already solved as well as the grey boxes indicating the location of the equation(s) remaining to be solved.

2.2.3.2 The TTT task (interrupting task)

While the participants were working on the arithmetic task, from time to time they were interrupted by the voice of an animated virtual character ("Mr Tic Tac", abbreviated as "Mr TT"). Mr TT appeared on a workstation located behind the participant as they performed the arithmetic task, so that participants would have to turn 180^{o} to start playing TTT (see Fig. 3). Mr TT would ask the participant to play TTT with him, in tones of increasing insistence across three separate interactions, until the participant chose to comply. Eventually the participant was forced to play TTT. Details of the interactions are below.

1. Mr TT asked participants to come to the TTT station and play TTT against him. A participant could accept the challenge immediately or they could switch to the task slightly later so that they could first solve some more arithmetic equations or even complete the current page of arithmetic equations before switching (a so-called "page finish").
2. If the participant continued performing the arithmetic task and let Mr TT wait for too long, then after a randomly chosen delay between 6 and 9 seconds after the initial invitation, Mr TT would call them a second time, with a more determined intonation. If the participant still kept performing the arithmetic task, then after 2 to 4 more seconds Mr TT would start the TTT game without the participant, and put the participant's tokens at random locations on the game board.

3. If the participants did not switch to the TTT task within 1 to 5 seconds after Mr TT started the game, the program would block the arithmetic task and force the participant to switch to the TTT game.

The timing for each interaction was varied slightly across interruptions so that participants did not know exactly when Mr TT would escalate the interaction. Overall, Mr TT started the game between 9 and 12 seconds after the first invitation and Mr TT blocked the primary task between 11 and 17 seconds after the first invitation.

The board of the TTT game consisted of nine fields (see Fig. 4). The participant and Mr TT took turns putting a token on one of these fields. The participant's aim was to beat Mr TT by getting three of their "X" tokens in a row. Above the TTT board a countdown indicated how much time remained for the participant's current turn before the program would place the participant's token on a randomly-chosen vacant field.

The Mr TT character was located on the top of the screen (see Fig. 4). He regularly talked to the participants during the game and reacted to their moves and the outcomes of the game. The number of games played, the pace of Mr TT's moves, the sophistication of Mr TT's play, and the comments Mr TT made during the games were varied moderately across interruptions to lessen predictability.

On the bottom of the screen the participants could see the outcomes of the current TTT games and their overall score of both tasks (see section "Award of points for performance").

2.2.3.3 Resumption of the arithmetic task

After the participants played either three or four games of TTT with Mr TT, the program summoned them to return to the arithmetic task and Mr TT became silent. Depending on where the participant had left the arithmetic task, there were two possible ways of resuming the arithmetic task.

First, if the participant had not completed the page of equations they were working on before they started the TTT task, then when they resumed the arithmetic task they had to remember which equation they had been working on, and what the last carryover number had been. They would see a page with four empty placeholders on it (see Fig. 5) with no indication of which equation they had been working on, or what the carryover number was. They had to click on the appropriate placeholder and select the proper carryover number on the number pad. Therefore, if the participant did not finish the page of equations before turning to the TTT game, then while playing TTT they had to remember which equation they were up to and what the carryover number was.

Second, in contrast, if the participant had previously completed a full page of equations before turning to the TTT task, they did not have to memorize either the placeholder or the carryover number. Upon resuming the arithmetic task they started on a new page of arithmetic equations, with the starting number displayed for them to enter into the first placeholder, as normally done at the start of each new page of equations. Therefore, if the participant finished the page of equations before turning to the TTT game, then they did not have to remember anything about the arithmetic task while playing TTT.

2.2.3.4 Award of points for performance

Participants were asked to earn as many points as possible in both tasks. Rewards for performance were derived from extensive pilot work in the no cue condition, where our goal was for about 30% of interruptions to lead to page finishes. In that case, any increase in percentage of page finishes in the cue condition would be clearly evident. The points were allocated as follows:

- +2 points for solving each equation correctly.
- +2 points for drawing against Mr TT in an individual TTT game.
- +5 points for winning against Mr TT in an individual TTT game.
- +5 points for remembering the correct placeholder on the first try when resuming the arithmetic task.

- +5 points for remembering the correct placeholder on the first try when resuming the arithmetic task.
- +10 points for finishing the page of equations prior to changing to the TTT game. The 10 points were given to equalize the maximum reward that participants could receive when resuming the arithmetic task, regardless of their strategy for responding to Mr TT.

Participants could see their current score at all times, because it was displayed on both the arithmetic screen and the TTT screen. On the arithmetic task screen there was also a display of the maximum score possible so far, so participants could judge the absolute quality of their performance.

2.2.4 Questionnaires

During the experiment the participants completed two questionnaires.

- Block-End Questionnaire. There were three blocks of trials in the experiment. After each block, participants answered two questions using 9-point Likert scales about (1) the difficulty of performing the arithmetic task and (2) the difficulty of performing the TTT game on the immediately preceding experimental block. After the final block of the experiment, a further four questions were added to probe participants' overall impressions about (3) the helpfulness of the screen layout for performing the task, (4) how strongly they felt compelled by Mr TT to play the TTT game, (5) how demanding Mr TT was, and (6) how annoying Mr TT was.
- Experiment-End Questionnaire. At the end of the experiment participants gave written open-form answers to a series of questions that inquired about their understanding of the tasks, the strategies they used to accomplish the two tasks, the strategies they used to remember the equation to return to and the carryover number, and how they decided when to switch between tasks.

Results of the Block-End Questionnaire are in the online Appendix (Table A1) and conclusions only reported herein. Results of the Experiment-End Questionnaire are not reported in this paper.

2.2.5 Design

In Experiment 1, condition (cue, no cue) was the independent variable and it was manipulated on a between-subjects basis. Controlled variables were (1) the interruption position (after the 1st, 2nd, or 3rd equation on a page) and (2) block configuration (A, B or C).

For each block configuration, the order, timing and nature of each interruption were specified slightly differently. The order in which interruptions occurred, the page on which they occurred, and the timing of the escalation of Mr TT's interruptions was varied across the blocks. However, in each block, there was always 1 interruption after a 1st equation on a page, 3 interruptions after a 2nd equation on a page, and 3 interruptions after a 3rd equation on a page, making 7 interruptions per block. Within each block, the 7 interruptions were distributed amongst 11 pages of 4 equations each so that only 0 or 1 interruption occurred per page.

Each participant experienced all three block configurations, A, B, and C, but the order of block configurations was counterbalanced across participants[2]. Given that there were 7 interruptions per block, and 3 blocks of trials, there were 21 interruptions overall for a participant across the whole experiment.

All combinations of cue conditions and block configuration orders were identified in advance of the experiment. After a participant had completed training, they were assigned at random to a specific combination of cue and order.

The primary outcome was the proportion of Mr TT's interruptions that the participant deferred until he or she had completed the page of equations ("deferral rate"). Deferral rate was computed from the number of page finishes performed divided by the total number of

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[2] Inadvertently, in Experiment 1 participants in the cue condition were assigned to either block sequence ABC, BAC, or CAB, whereas participants in the no cue condition were assigned to either block sequence ACB, BCA, or CBA. However, the blocks were very similar and further analysis suggested no bias had resulted. In later experiments, participants within a condition could be assigned to any of the six possible block orders.

possibilities (interruptions) to perform a page finish, reflecting the proportion of interruptions accompanied by a page finish. Our initial power analysis was performed on the primary outcome.

Secondary outcomes were the participants' speed at performing the arithmetic task and their responses to the questionnaires, as well as further analyses performed to investigate more detailed aspects of participants' behavior.

2.2.6 Procedure

Experiment 1 was run by authors SH and MW. Each participant took part in a testing session lasting around 60 minutes that contained the following steps:

1. The participant was greeted. They read an information sheet about the experiment and completed the informed written consent process.
2. The participant worked with an interactive Microsoft PowerPoint™ presentation that explained the two tasks of the experiment. The presentation required the participant to work through some part tasks similar to the tasks they would experience in the full experiment.
3. Any misunderstandings were corrected in a short training session with the experimenter, using screenshots of the arithmetic and TTT tasks.
4. The participant moved to the experiment workstation and completed three short practice sessions: (1) the arithmetic task, (2) the TTT task and (3) both tasks together, including the switch between the tasks.
5. The participant then started to work on the full experiment. The experiment had three experimental blocks in which the participant solved arithmetic equations and was interrupted several times. After each block they filled in the Block-End Questionnaire on the screen and had the opportunity to take a short break.
6. After the participant finished the third block they completed the longer version of the Block-End questionnaire as well as the Experiment-End Questionnaire.

2.2.7 Data extraction

The experiment software generated a log file of time-stamped program actions and participant actions. A program in LiveCode 6.1 (RunRev Ltd., Edinburgh, UK) extracted all relevant data for analysis.

2.2.8 Statistical analysis

All statistical analyses reported in this paper were processed in IBM SPSS version 22. Deferral rate was calculated as the number of interruptions during which a participant deferred responding to Mr TT until they had completed the whole page of equations, divided by 21 (the total number of interruptions experienced by each participant). Results for deferral rate were examined for homogeneity of variance, normality of residuals, and independence of observations; parametric tests were used when the assumptions were met. Deferral rate was tested in one-way factorial ANOVAs, with condition (cue, no cue) as the factor.

The potential impact on deferral rate of participants' speed at performing the arithmetic tasks was also examined. Participants' arithmetic speed was compared across conditions and across situations where Mr TT had called the participant to the TTT game and was waiting (interruption "active") versus situations where Mr TT had not called the participant to a TTT game (interruption "inactive"). Arithmetic speed was tested in a two-way ANOVA with condition as a between-subjects factor, and interruption (present, absent) as a within-subjects factor. To ensure more reliable estimates of arithmetic speed to compare the interruption active and interruption inactive conditions, participants were included in the analysis only if they had deferred responding to Mr TT until they had finished the page of equations on four or more occasions over the whole experiment—we would therefore have at least four data points for that participant where the interruption was active. In that way we ensured a more stable estimate of arithmetic speed when the interruption was active than if we had included participants who had deferred on only one, two or three occasions.

Finally, the results for the six questions in the Block-End Questionnaires were analysed with Mann-Whitney U Tests that compared responses from participants in the cue versus no cue conditions.

2.3 Results

A one-way ANOVA revealed that deferral rate was significantly higher in the cue condition (M=.47, SD=.26) than in the no cue condition (M=.25, SD=.29), $F(1,70)=11.192$, $p=.002$, $\eta_p^2=.138$ (see Table 2).

Thirty-one (86%) participants in the cue condition and 19 (53%) participants in the no cue condition made four or more deferrals of the interruption. Using the data from these participants, a two-way mixed ANOVA revealed no difference in arithmetic speed across the cue and no cue conditions, $F(1,48)=1.492$, $p=.228$, $\eta_p^2=.030$ (see Table 3). However, combining cue conditions, arithmetic speed was significantly faster when an interruption was active than inactive, $F(1,48)=38.891$, $p<.001$, $\eta_p^2=.448$. There was no interaction between cue conditions and whether an interruption was active or inactive on arithmetic speed, $F(1,48)=1.748$, $p=.193$, $\eta_p^2=.035$.

Median values of responses by participants in the cue and no cue conditions to the six questions in the Block-End Questionnaires are provided in the online appendix (Table A1). The Mann-Whitney U test revealed no significant differences across the two conditions for any of the questions (all p values greater than .2)

2.4 Discussion

The results of Experiment 1 appear to support the hypothesis that visual cues indicating the location of a person's next task steps can make that person more likely to defer an interruption and to complete their next task steps. Once participants had been interrupted, but before they responded to the interruption, they worked faster through the arithmetic tasks.

However, we noted a potential confound associated with the presence and absence of the visual cue. After the participant had completed each arithmetic task, they were given 'thumbs up' or 'thumbs down' feedback about the correctness of their answer. This feedback was displayed together with the correct answer to the equation (the 'carryover number') for 1.5 seconds. Participants were required to remember the carryover number and could not begin the next arithmetic problem until these 1.5 seconds were over.

During the 1.5 second delay, the placeholder to click to begin the next equation was visible but disabled in the cue condition, whereas there was no visible placeholder at all in the no cue condition. Participants in the cue condition could therefore use the mouse to move their cursor to the next placeholder during the 1.5 second delay, whereas participants in the no cue condition had no visible placeholder to which to move their cursor, and so could not start their movement to the next placeholder with any certainty during the 1.5 second delay. Table 4 specifies the difference between the cue and no cue conditions during the 1.5 second delay before participants could continue with the next placeholder.

For the reason given above, participants in the no cue condition were not able to advance in the task during the 1.5 second delay as much as participants in the cue condition could. As a result, participants in the no cue condition were one task step further away from the end of the page if interrupted at this point, and so may have been less likely to judge that they could finish the page before responding to Mr TT.

In Experiments 2 and 3, we explored two different ways of removing this possible confound—the "task advancement" asymmetry—to see if participants in the cue condition are still more likely to defer the interruption. If participants in the cue condition are still more likely to defer the interruption, then the results of Experiment 1 are probably due to the presence of visual cues and not to the effect of the task advancement asymmetry. However, if participants in the cue condition are no more likely to defer the interruption than are participants in the no cue condition, then the results of Experiment 1 are probably due to the task advancement asymmetry. In Experiment 2, reported below, participants in both the cue and the no cue condition had the opportunity to move their cursor to the next placeholder to begin the next equation as soon as they clicked the tick or cross of the previous equation.

3 Experiment 2

3.1 Introduction

The purpose of Experiment 2 was to determine whether the task advancement asymmetry between the cue and no cue conditions, as described above, would provide an alternative explanation for the findings. If the task advancement asymmetry is removed by making the next placeholder visible in the no cue condition, but a statistically significant difference remains across the cue and no cue conditions, then the results of Experiment 1 are more likely to have been caused by the visual cues. If there is no statistically significant difference between the cue and no cue conditions when the task advancement asymmetry is removed, however, then the results of Experiment 1 are more likely to have been caused by the task advancement asymmetry rather than by the visual cues, and we would conclude that the task advancement asymmetry was a confound that caused the results of Experiment 1.

3.2 Method

3.2.1 Statistical power

Power was held at the same level as in Experiment 1, on the basis that if the effect of visual cue was not diminished, Experiment 1 had demonstrated that we still had adequate statistical power to see its effect.

3.2.2 Participants

Seventy-nine students from The University of Queensland participated in the study. Ethics approval was granted through the School of Psychology's ethics committee. Recruitment, assignment to conditions, and exclusion criteria were as for Experiment 1. Table 1 provides a breakdown of participants by condition and gender for Experiment 2.

3.2.3 Design

The experimental design for Experiment 2 was the same as for Experiment 1: a between-subjects comparison of the cue and no cue conditions. Block configurations and assignment to conditions were the same as in Experiment 1, with participants within a condition being assigned to one of the six possible sequences of block configurations.

3.2.4 Tasks

In Experiment 2, the arithmetic task, TTT task, interruptions, and points allocated were all the same as in Experiment 1. The only difference was a change in the experiment software that removed the task advancement asymmetry.

Specifically, the task advancement asymmetry observed in Experiment 1 was removed by providing placeholders for the next equation in no cue condition as well as the cue condition (see Table 4 and Fig. 6). As soon as a participant clicked the “correct” or “wrong” button for their current equation, a placeholder for the next equation would appear in the no cue condition. As a result, during the 1.5 second delay before they could actually interact with the placeholder, participants in both conditions could start moving their cursor to the placeholder while looking at the ‘thumbs up’ or ‘thumbs down’ feedback and the carryover number for the current equation. They could therefore advance in the task to the same degree.

3.2.5 Procedure

The procedure was the same as in Experiment 1, with the exception that materials explaining the no cue condition displayed the next equation placeholder at the steps appropriate for Experiment 2. The experiment was conducted in the same room as in Experiment 1, with the same arrangement of tables, chairs, and lighting. Experiment 2 was run by author EV.

3.3 Results

A one-way ANOVA revealed that deferral rate was not significantly higher in the cue condition (M=.33, SD=.31) than in the no cue condition (M=.38, SD=.31), $F(1,75)=0.231$, $p=.632$, $\eta_p^2=.003$ (see Table 2).

Twenty-six (64%) participants in the cue condition and 27 (69%) participants in the no cue condition made four or more deferrals of the interruption. Using these data, a two-way mixed ANOVA revealed that arithmetic speed was faster in the cue condition than the no cue condition, $F(1,51)=5.156$, $p=.027$, $\eta_p^2=.092$ (see Table 3). In addition, arithmetic speed was significantly faster when an interruption was active than inactive, $F(1,51)=51.487$, $p<.001$, $\eta_p^2=.502$. There was no interaction between condition and whether an interruption was active or inactive on arithmetic speed, $F(1,51)=1.267$, $p=.266$, $\eta_p^2=.024$.

Median values of responses by participants in the cue and no cue conditions to the six questionnaires are shown in Table 4. The Mann-Whitney U test revealed a trend for participants in the cue condition to find the arithmetic and TTT tasks easier than those in the no cue condition did ($.1 > p > .05$). No other differences were found across the two conditions for any of the questions (all remaining p values > .2)

3.4 Discussion

The results of Experiment 2 indicate that when participants' ability to advance in the task is equalized, by letting participants in both conditions move their cursor forward to the next input location at the same time, then there is no difference in deferral rate between participants in the cue and no cue condition. This finding lets us more confidently interpret the results of Experiment 1, as follows.

If an interruption happened during the 1.5-second wait in Experiment 1, then either of two factors may have brought about the findings of Experiment 1. First, during the 1.5-second wait, when only participants in the cue condition could see the next placeholder, a participant in the no cue condition fell one task step behind a participant in the cue condition. As a result, the participant in the no cue condition may have judged it less likely that they would be able to finish the page of equations (and so avoid having to remember the placeholder location and carryover number) before they were forced to respond to the interruption, and so they did not attempt to finish the page of equations. Second, a participant in the cue condition could proceed to the location of the next equation during the 1.5-second wait. If the participant in the cue condition was interrupted during the 1.5-second wait, they may have already firmly formed the intention to process the next equation rather than to respond to the interruption, and so may have been more likely to defer responding to the interruption until they had finished the whole page of equations. According to Gray and colleagues (Gray and Fu, 2004; Gray et al., 2006) one third of a second can be enough time to form an intention ("selection of interactive routine") which in the present case would be the intention to move the cursor to the next placeholder and complete the equation. Experiment 3 will test these explanations further.

As in Experiment 1, participants in Experiment 2 processed the arithmetic equations faster during the interruption lag, when Mr TT was waiting for them after interrupting, than outside the interruption lag. Unlike Experiment 1, however, in Experiment 2 participants in the cue condition processed the arithmetic equations faster overall, compared with participants in the no cue condition. It is unclear why this is the case.

4 Experiment 3

4.1 Introduction

Experiment 3 was a further test of whether the task advancement asymmetry rather than visual cues would explain the findings of Experiment 1. In Experiment 2, the task advancement asymmetry had been removed by removing the “disadvantage” experienced by participants in the no cue condition. In contrast, in Experiment 3, the task advancement asymmetry was removed by removing the “advantage” experienced by participants in the cue condition. Specifically, in Experiment 3, the location of the next placeholder was randomized across either the second or third summand of the equation, so that its location was always unpredictable (see Table 4). Participants in both the cue and no cue conditions had to wait for 1.5 seconds before the location of the placeholder for the next equation was indicated. If there is no difference in deferral rate between the cue and no cue conditions in Experiment 3, then it will seem even more likely that the results of Experiment 1 were due to task advancement asymmetries rather than to differences in visual cues.

A further difference is that Experiment 3 was conducted in Germany, in German, therefore providing an opportunity to test the robustness of our findings by sampling from a population in a different institution and working in different language.

4.2 Method

4.2.1 Power analysis

Using the effect size for visual cue found in Experiment 1 ($\eta_p^2 = .14$) an a priori power analysis for a between-subjects design was performed, with $1-\beta = .80$ and $\alpha = .05$. It resulted in a required sample size of 2 x 26 participants, or 52 in all.

4.2.2 Participants

Participants were 54 students from the University of Würzburg. Recruitment, assignment to conditions, and exclusion criteria were as for Experiment 1. All participants were recruited through an online sign-up system and they participated in exchange for either course credit or 7€ in cash. Table 1 provides a breakdown of participants by condition and gender for Experiment 3.

4.2.3 Design

The experimental design for Experiment 3 was the same as for Experiments 1 and 2: a between-subjects comparison of the cue and no cue conditions. Configuration files, counterbalancing, and assignment to conditions were the same as in Experiment 2.

4.2.4 Tasks

In Experiment 3, the arithmetic task, TTT task, interruptions, and points allocated were all the same as in Experiment 1, except for three major changes. First, because Experiment 3 was conducted with German-speaking participants in Germany, all labels in the software, the instructions, and questionnaires were translated into German. In addition, Mr TT's comments and vocalizations were translated to the same or similar comments and vocalizations in German with similar lengths and vocal expressiveness. However, the translation to German required the animations of Mr TT's face to change in order to match the German sound files.

Second, there was a change from Experiment 2 in how the task advancement asymmetry was removed. In Experiment 2, the task advancement asymmetry observed in Experiment 1 was removed by letting participants in both conditions start moving their cursor to an indicated placeholder location during the 1.5 second wait while they looked at the equation feedback and the carryover number. They could therefore advance in the task to the same degree (see Table 4).

In Experiment 3, the task advancement asymmetry observed in Experiment 1 was removed by making participants in both the cue and no cue conditions wait for 1.5 seconds before they knew where the placeholder for the next equation would be located (see Fig. 7). After a participant clicked the "correct" or "wrong" button for the current equation, they would have to wait for 1.5 seconds before the placeholder of the next equation became visible and active. In addition, the location of the next placeholder was randomized for each equation between the second and the third summand. As a result, in neither the cue nor the no cue condition could participants anticipate the position of the next placeholder and move the cursor to it. Therefore, participants in the cue condition no longer had an advantage over the no cue condition in when they could move their cursor to the next equation and no longer had an opportunity to form a stronger intention to proceed in the task.

The third change in Experiment 3 was the introduction of an additional experimental block (the "arithmetic-only block") before participants started with the three usual experimental blocks. The purpose of the arithmetic-only block was to secure a baseline measure of participants' accuracy and speed at doing the arithmetic task to ensure there had been no bias in allocating participants to the cue and no cue conditions, and to determine the impact of interruptions on arithmetic accuracy and speed. Accordingly, in the arithmetic-only block at the start of Experiment 3, participants worked only on arithmetic equations, before being instructed about Mr TT's interruptions.

4.2.5 Procedure

The procedure was the same as in Experiments 1 and 2, with the exception that it was conducted in German. The experiment took place in a room at the University of Würzburg that had a similar arrangement of tables, chairs, and lighting as at The University of Queensland for Experiments 1 and 2. Experiment 3 was run by authors MW and SH, who also ran Experiment 1. Given the addition of the arithmetic-only block, there was also a change in the order in which the participants were introduced to the two tasks and practiced the tasks. First, participants were introduced to, practiced, and completed the arithmetic-only block. Then they were introduced to the TTT task, practiced it, practiced both tasks together, and finally completed the three main experimental blocks.

4.3 Results

In the initial arithmetic-only block there was no significant effect for arithmetic speed (in milliseconds) between the cue condition (M=5852, SD=1153) and the no cue condition (M= 5883, SD=986), $t(50)=-.104$, $p=.917$. A one-way factorial ANOVA revealed that deferral rate was not significantly higher in the cue condition (M=.39, SD=.27) than in the no cue condition (M=.39, SD=.28), $F(1,50)=0.000$, $p=1.000$, $\eta_p^2=.000$ (see Table 2; the means of the two conditions were the same value).

Twenty-two (82%) participants in the cue condition and 21 (78%) participants in the no cue condition deferred the interruption four or more times. Using these data, a two-way mixed ANOVA revealed no difference in arithmetic speed across conditions, $F(1,41)=0.168$, $p=.684$, $\eta_p^2=.004$ (see Table 3). Arithmetic speed was significantly faster when an interruption was active than inactive, $F(1,41)=28.062$, $p<.001$, $\eta_p^2=.406$. There was no interaction between condition and whether an interruption was active or inactive on arithmetic speed, $F(1,41)=1.343$, $p=.253$, $\eta_p^2=.031$.

Median values of responses by participants in the cue and no cue conditions to the six Block-End questions are in the online appendix (Table A1). The Mann-Whitney U test revealed a trend for participants in the cue condition to find the arithmetic task easier, the screen layout more helpful and Mr TT more demanding than participants in the no cue condition did ($.1 > p > .05$). No other differences were found across the two conditions for any of the questions (all remaining p values $> .2$)

4.4 Discussion

Experiment 3 revealed no significant difference between the cue and no cue conditions when participants' ability to advance in the arithmetic task was equalized across conditions. Specifically, in both the cue and no cue condition, participants had to wait until the 1.5-second period for viewing the result of their decision about the current equation, and the true carryover number, before they could move their cursor to the placeholder for the next equation. The general layout of the cue condition, with previous equations preserved on the screen and with grey fields indicating the two potential locations for the elements of the remaining equations, did not make participants more likely to defer responding to Mr TT's interruption until they had finished the page of equations.

The initial arithmetic-only block did not reveal any difference in speed of responding to arithmetic between participants who were later assigned to the cue and no cue condition, indicating there was no sampling bias across conditions. In addition, unlike in Experiment 2, participants did not respond faster to arithmetic tasks in the main experiment when the visual cues were present.

Given the growing evidence that the findings of Experiment 1 were caused by a task advancement asymmetry in the arithmetic task across the cue and no cue conditions, it was important to determine whether the original result could be replicated. Accordingly, Experiment 4 was a partial replication of Experiment 1, in German. The arithmetic task advancement asymmetry was restored to see if participants in the cue condition would again be more likely to defer responding to Mr TT's interruption until they had finished the page of equations.

5 Experiment 4

5.1 Introduction

Experiment 4 was conducted to see whether the difference in deferral rate would return when the arithmetic task advancement asymmetry between the cue and no cue conditions was restored, but in a German version of the task. In addition, a further issue was explored in Experiment 4 that is not reported here, but that changed the method from Experiment 1 slightly. Participants not only experienced interruptions at the end of the 1st, 2nd and 3rd equation on a page, but also in the middle of the 3rd or 4th equation when they would be deeply engaged in calculating the true results of the equation. For present purposes, we report findings only for interruptions that occurred at the end of each equation, as for Experiments 1, 2, and 3. If the arithmetic task advancement confound explains the difference between the cue and no cue conditions in Experiment 1, then we would expect the difference to return in Experiment 4.

5.2 Method

5.2.1 Participants

Based on the statistical power obtained in Experiment 1 and the results of Experiment 1, 54 students from the University of Würzburg participated in the study. Recruitment, assignment to conditions, and exclusion criteria were as for Experiment 1. All students were recruited through an online sign-up system and participated in exchange for either course credit or 7€ in cash. Table 1 provides a breakdown of participants by condition and gender for Experiment 4.

5.2.2 Design

The experimental design for Experiment 4 was similar to the design for the previous three experiments: a between-subjects comparison of the cue and no cue conditions. The task advancement asymmetry present in Experiment 1 was reintroduced. A key difference from Experiment 1 was that some interruptions were added that occurred in the middle of the 3rd or 4th equations. There were 27 interruptions overall, with 15 interruptions at the end of the 1st, 2nd, and 3rd equations (rather than 21 in all other experiments) and 12 interruptions in the middle of the 3rd or 4th equation (results for interruptions in the middle of equations are reported elsewhere). In all other respects, configuration files, counterbalancing, and assignment to conditions were the same as in Experiments 2 and 3.

5.2.3 Tasks

In Experiment 4, the arithmetic task, TTT task, interruptions, and points allocated were all the same as in Experiment 1. All the instructions and materials were in German as in Experiment 3, but there was no initial arithmetic-only block. Therefore, the order of instructions varied slightly from Experiment 3 in that the instructions in Experiment 4 were given in an unbroken sequence.

5.2.4 Procedure

The procedure for Experiment 4 was the same as in Experiment 1. Participants were not told about the different possible interruption positions within an equation. The experiment was conducted in the same physical environment as for Experiment 3. Experiment 4 was run by authors SH and MW.

5.3 Results

A one-way factorial ANOVA revealed that there was a trend for deferral rate to be higher in the cue condition (M=.51, SD=.26) than in the no cue condition (M=.40, SD=.23), but that it did not reach significance at the .05 level, $F(1,49)=3.09$, $p=.085$, $\eta_p^2=.059$ (see Table 2).

Twenty-two (88%) participants in the cue condition and 20 (77%) participants in the no cue condition made four or more deferrals of the interruption. Using these data, a two-way mixed ANOVA revealed significantly faster arithmetic speed in the cue condition than in the no cue condition, $F(1,41)=6.350$, $p=.016$, $\eta_p^2=.134$ (see Table 3). Arithmetic speed was significantly faster when an interruption was active than inactive, $F(1,41)=28.420$, $p<.001$, $\eta_p^2=.409$. There was no interaction between condition and whether an interruption was active or inactive on arithmetic speed, $F(1,41)=2.208$, $p=.145$, $\eta_p^2=.051$.

Median values of responses by participants in the cue and no cue conditions to the six Block-End questions are shown in Table 4. The Mann-Whitney U test revealed no significant differences across the two conditions for any of the questions (all p values greater than .2)

5.4 Discussion

Experiment 4 showed that when the task advancement asymmetry was restored, there was a trend towards a higher deferral rate in the cue condition than in the no cue condition. Note, however, that Experiment 4 combined interruptions both at the end of equations (n=15 per block) and in the middle of equations (n=12) within each block of 27 interruptions. There were fewer end-of-equation interruptions in Experiment 4 (n=15) than in Experiment 1 (n=21), so Experiment 4 presents a less reliable measure of deferral rate for each participant. In addition, participants performed the arithmetic tasks faster when the visual cues were present than when they were absent.

6 Meta-analysis

Clearly, the two experiments in which the task advancement asymmetry was present (Experiments 1 and 4) showed either a fully significant effect or a trend for participants in the cue condition to be more likely to defer responding to the interruption. In contrast, the two experiments in which the task advancement asymmetry was absent (Experiments 2 and 3) showed no trend for participants in either condition to defer more or less than in the other.

Given that the results of Experiment 1 and Experiment 4 were similar, and in order to estimate overall effect sizes, we conducted two meta-analyses of the results: one for the two experiments in which the task advancement asymmetry was present, and the other for the two experiments in which the task advancement asymmetry was absent. The results are shown in a Forest plot in Fig. 8 (Cumming, 2013).

The overall effect size for the experiments in which the visual cue condition included the task advancement asymmetry was 0.171 with 95% CI [0.079, 0.263], indicating overall significance. For the experiments in which the visual cue condition did not include the task advancement the overall effect size was -.018 with 95% CI [-0.118, 0.082], indicating non-significance.

7 Microstrategies during the interruption lag

We conducted a post-hoc analysis of participants' activity during the interruption lag to identify the exact conditions under which participants responded to Mr TT's interruption, across the different experiments, conditions, and equations. A MatLab R2015a (MathWorks, Natick, MA) script extracted relevant data from the experiment log files. The resulting files were fed into the THEME6 Edu software (PatternVision Ltd, Reykjavik, IS), which detects temporal patterns in appropriately coded event sequences (Casarrubea et al., 2015; Magnusson et al., 2016) and thus also in our participants' behavior.

The four experiments were analyzed separately. We were interested only in participants' strategies during the interruption lag (Mr TT's first invitation to participants switching the task). Hence, search parameters were set so that the THEME6 software only returned patterns that lasted for 30 seconds or less and occurred at least three times in each dataset. The probability of random occurrence was set to <.005. We filtered the returned patterns by *invitation* of Mr TT as the start event of a pattern, and *task switch* of the participant towards the interrupting task as the last event. Finally, we grouped the returned patterns according to the participant's last action primary task before they turned to the interrupting task, as follows.

- Participant switched tasks after finishing the page
- Participant switched tasks immediately after the invitation
- Participant switched tasks after finishing a subtask without accomplishing a page finish (e.g. finishing one or two equations when interrupted after the first equation)
- Participant switched tasks in response to a warning by Mr TT (the last event before they attended to the interrupting task was a warning by Mr TT)
- Participant was forced to switch tasks by the program because they ignored Mr TT's warnings until a black screen blocked the primary task.

Hereafter, we refer to the above five patterns as *microstrategies* as the decision to take them would have occurred in the 1/3 to 3 second timeframe (Gray and Fu, 2004; Gray et al., 2006). The frequencies of microstrategies across cue vs. no cue conditions for interruptions at equation 1, 2, and 3 are shown for each experiment in Fig. 9 and numerical results are given in the online appendix (Table A2). There are no results for equation 4 because there were no interruptions after equation 4.

Clearly, the choice of microstrategy depended on which equation participants were working on when Mr TT invited them to play TTT. In all four experiments, the closer participants were to the fourth and final equation on the page, the more likely they were to finish the page of equations before switching tasks. However, participants rarely deferred responding to the interruption to the extent that they were forced to switch tasks. In the cue conditions of Experiments 1 and 4, where the cue was associated with the task advancement confound, participants were more likely to finish the page of equations before switching and were less likely to switch immediately after Mr TT's invitation, when compared with the no cue condition. Finally, participants in Experiment 3 and 4, both conducted in the German language, were more likely to delay their switch until receiving the warning that Mr TT would soon start without them than were participants in Experiments 1 and 2, both conducted in the English language.

8 General Discussion

The overarching hypothesis motivating this series of studies was that participants who perform a task with an interface containing visual cues that emphasize its upcoming steps, will defer an interruption more frequently compared with participants who perform the task with an interface containing weak visual cues only. The hypothesis was initially motivated by empirical evidence found by Grundgeiger et al. (2013) that nurses were more likely to defer an interruption until they had completed their current task if they could see visual cues for the next steps of their current task.

At face value, the results of Experiment 1 appeared to support the hypothesis. However, there was a possible confound in the setup of our experiment. In the cue condition, when the participant had finished an equation and Mr TT was interrupting, the placeholder of the next equation immediately became visible, although it was disabled. Participants could then position the cursor above the placeholder, ready for the placeholder to become enabled 1.5 seconds later. By contrast, in the no cue condition the placeholder for the next equation was not immediately visible. Therefore, for 1.5 seconds participants in the no cue condition could not see the exact location where they should move their cursor which made it more difficult for them to advance in the task.

To determine whether the task advancement asymmetry had caused the higher rate of deferring a response to the interruption in the cue condition, we conducted three more experiments. Their results affirm our assumption that the task advancement asymmetry and not the visual cues (compare the upper and lower part of Fig. 2) led to the differences in deferral rate. The task advancement asymmetry therefore acted as a confound with the cue. In Experiment 2 and Experiment 3, two different ways of eliminating the confound removed any statistically significant difference between the cue and no cue conditions, but when the confound was restored in Experiment 4, a trend towards greater deferral rate in the cue condition returned. In summary, in Experiments 2 and 3, where participants in both conditions could or could not see the next placeholder, there were no significant differences between cue and no cue conditions, whereas in Experiments 1 and 4, where the placeholder was present in the cue condition but not in the no cue condition, participants were more likely to defer in Experiment 1, and there was a similar trend in Experiment 4.

We also investigated whether the presence of the visual cues would make participants speed up their responses to each arithmetic task. The pattern of results was not easily interpretable, but there was either a trend or significant effect for participants to respond faster to the arithmetic tasks when the visual cues were present, except in Experiment 3 in which participants performed the initial arithmetic-only block. In the latter case, the initial arithmetic-only block may have given participants enough practice to remove any differences in response time later in the experiment. Against the idea that Experiment 3 participants had more practice, however, is the trend for responses to be slower overall in Experiment 3 rather than faster. Consistent over all four experiments, however, are further findings that responses to the arithmetic tasks were faster when Mr TT's interruption was active, and that the latter effect was not influenced by the presence or absence of the visual cues.

8.1 Theoretical implications

The visibility of the next placeholder, and its use in helping participants move their cursor in anticipation of the next arithmetic task, clearly has an effect on participants' tactics for handling the interruption. The low-level structure of the arithmetic task appears to exert an influence on higher-level tactical decisions about the interrupting task. There are two possible theoretical explanations for this finding.

A first explanation lies in the fact that when faced with alternative methods to reach a goal, participants usually choose alternatives imposing low cognitive effort (e.g., Gray, 2000; Kool et al., 2010). In addition, they also prefer to persevere with the task on which they are currently working (Wickens and Gutzwiller, 2015), as long as the task appears to be related to their goal (Simon, 1959). However, participants will switch tasks if offered a better alternative that achieves the same goal with less cognitive effort. Because our participants were required to perform the interrupting TTT task, their only choice was exactly *when* to engage with the interruption, which they probably did when it cost them the least cognitive effort.

After participants in the no cue condition of Experiments 1 and 4 finished an equation, they had to wait for 1.5 seconds until the next placeholder became visible and active. If an interruption occurred, then around the start of the 1.5-second interval they would be hearing Mr TT calling them. In contrast, in the cue condition the next placeholder become visible immediately, even though it was inactive for 1.5 second, and participants had probably started moving the cursor to the next placeholder. Therefore, when the interruption occurred, participants in the no cue condition probably would not have established their intention to proceed with the next equation, whereas participants in the cue condition probably had already formed that intention. From the perspective of externalised cognition (Navarro-Prieto et al., 1999) the presence of the placeholder may reduce a participant's need for deliberation about their next action. As participants started to engage with the next equation, their intention to persevere and finish this subtask was presumably strong enough that they ignored Mr TT for a while. This first explanation points to the visibility of the placeholder itself as accounting for differences between the cue and no cue conditions in each experiment.

A second explanation lies in the fact that in the no cue condition the invisibility of the placeholder for 1.5 seconds creates a discontinuity between two subtasks. Interruptions occurring in-between subtasks are perceived as less annoying (Monk et al., 2004). According to Iqbal and Bailey (2005) the period between two subtasks imposes relatively low mental workload. Participants in the no cue condition may have experienced a drop in mental workload when they were waiting for 1.5 seconds for the placeholder to become active and visible, during which time they only had to attend to the one-digit carryover number. If they heard Mr TT's invitation at this point, they may have been more disposed to switch to the interruption (Bogunovich and Salvucci, 2011) The findings of Katidioti and Taatgen (2014) strengthen this potential explanation. They found that if there are short delays in the primary task (3 seconds), participants are more likely to switch to an interrupting task, even if they are currently under high working memory load from the primary task.

With the present data it is not possible to determine exactly what caused the effect seen in Experiments 1 and 4: (a) the visibility of the placeholder in the cue condition stimulating the participant's engagement with the next arithmetic task, (b) the short delay in the visibility of the placeholder in the no cue condition creating a gap between tasks making a task switch more likely, or (c) a combination of both factors. This is a question for future studies.

8.2 Strategies for handling prospective memory tasks

Each participant's experimenter-imposed goal was to receive as many points as possible. When Mr TT called the participant, they could choose amongst different strategies to handle the interruption. One strategy was to *defer* the interruption and finish a page of equations first, to avoid a high cognitive load. This strategy was also described in the findings of Brixey et al. (2008), Salvucci and Bogunovich (2010), and Grundgeiger et al. (2010). A disadvantage of deferring was that the participants had to complete the remaining equations on the page under time pressure to avoid the risk that Mr TT would start the game without them (indeed, participants performed the arithmetic task faster when Mr TT was calling them).

An alternative strategy was for participants to immediately *engage* with the TTT game, to avoid the risk of Mr TT starting the game without them. The disadvantages of engaging with the TTT game were, first, the higher cognitive load of remembering the current placeholder location and carryover number during the TTT game until the arithmetic task resumed and, second, the risk of losing points at resumption if the placeholder location and carryover number had been forgotten.

The analysis of microstrategies in Fig. 9 indicates that participants were more likely to finish the page of equations the closer they were to the last equation. In addition, in Experiments 1 and 4, participants benefiting from the cue and the associated task advancement asymmetry were more willing than participants in the no cue condition to finish the page of equations when interrupted after equation 1 or 2, as well as after equation 3. The microstrategies can be viewed from the perspective of research on hard and soft constraints (Gray and Fu, 2004; Gray et al., 2006). In the present experiments, the hard constraints were the fixed properties of the task structure, the event timing, and the confound associated with the cue. According to Gray and Fu (2004) and Gray et al. (2006) a soft constraint is the participant's objective of minimizing time on a task, rather than minimizing memory load. Unlike most experimental paradigms testing the soft constraints hypothesis, our experimental paradigm does not offer the participant a *certain* way to minimize time on any aspect of the tasks. The only interactive option open to the participant in the present experiments is their decision exactly when to switch to the TTT task after Mr TT's invitation.

On the one hand, switching immediately saves time in proceeding to the TTT task and removes the need to consider whether an attempt to complete the page of equations will be successful, but the participant is burdened with remembering the current placeholder location and carryover number when resuming the arithmetic task. Moreover, by switching immediately, participants in the no cue condition avoid the 1.5 second wait without cues for their next step.

On the other hand, delaying the switch to the TTT task and attempting to complete the page of equations puts pressure on participants to complete the equations before they are forced—at some uncertain point—to move to the TTT task, but it offers the *potential* reward that the participant is not burdened with remembering the placeholder location and carryover number when they resume the arithmetic task. The latter potential reward does have a time benefit – if the participant successfully finishes the page of equations they will start a new page at resumption, and will avoid the prospect of forgetting the carryover information and wasting time at the resumption of the arithmetic task trying to find the correct combination. (Recall that points gained for finishing a page of equations or for correctly recalling the placeholder location and carryover number at resumption had been deliberately set to be equivalent, so as to avoid favoring one strategy over the other through points alone.)

It is unclear whether participants who deferred switching to TTT and tried to finish the page of equations were primarily motivated by (a) removing memory load by finishing the page of equations and therefore having no carryover memory load at resumption or (b) the chance that they would forget the placeholder location and carryover number at resumption and therefore incur a time cost while guessing at them. The first option would be consistent with the finding by Borst et al. (2013) that participants switching tasks can carry only one problem state from one task while another task is performed without costs to accuracy—the present task requires participants to retain two problem states (placeholder location and carryover number). The second option would reflect individual differences in ability to handle distraction (Furnham and Strbac, 2002). Only further studies could clarify whether participants' strategies were consistent with the soft constraints hypothesis or whether memory minimization played a role.

In summary, consistent with the findings of Dobbs and Reeves (1996) we observed that the participants planned actions and created different strategies to handle the interruptions. The strategies and actions appeared to be based on each participant's conscious or preconscious metaknowledge of their individual prospective and working memory ability, arithmetic fluency, and ability to manage distraction, given the point in the task at which the interruption occurred.

8.3 Practical Implications

Interruptions in the workplace are associated with a greater level of frustration, stress and the feeling of a greater time pressure (Mark et al., 2008). If a worker typically completes a current task or goal before they attend to an interruption from a co-worker, there may be fewer negative consequences and workers may have a greater feeling of control over their work. Bakker and Demerouti (2007) observed that a higher level of individual control over work is associated with fewer negative health outcomes, even if the control involves a high workload. So by using a deferral strategy, workers may not only avoid additional cognitive load but also gain a sense of control over their work.

In the present series of studies we directly tested the effect of visual cues on interruption management, but found that the immediate ability to progress the primary task was a stronger motivator to defer interruptions than the mere presence of visual cues relating to the next steps of the primary task. Accordingly, this series of studies suggests that workers will manage the timing of interruptions more effectively if they anticipate being able to complete their primary task quickly and easily.

A practical suggestion from our findings is that office work interfaces such as ordering forms installation wizards, or digital check lists in safety critical workplaces should display the next steps in a work task and thus make it easy for workers to advance to later steps. First, in some cases this may allow task steps to be completed effectively, supporting the strategy of deferring an interruption. Second, this may allow workers to resume the interrupted task more effectively (Hodgetts and Jones, 2006).

8.4 Limitations and future research

There are several limitations of the present studies that suggest directions for future research. First, we have described the experimental paradigm as a primary task that is periodically interrupted, but it could be described as task switching or task interleaving. As Janssen et al. (2015) point out "interruptions are only one form of the perhaps broader category of multitasking" (p. 3). Below we note where our research is interruption-specific and where it has commonalities with multitasking research. A common topic of discussion in interruption research is the properties a secondary task should have to be called an interruption, with the result that there are many different definitions of an interruption (for an overview in healthcare, see Grundgeiger et al., 2015; Grundgeiger and Sanderson, 2009). For some authors, a defining characteristic of an interruption is that it is an unanticipated change in tasks (Brixey et al., 2007; Wickens and Gutzwiller, 2015). In the present series of experiments, the participants expected an interruption sooner or later, and each interruption involved the same kind of task. Therefore, our experimental paradigm had features of task-switching, even though participants had discretion over exactly when they would switch tasks. A further difference is that participants did not have to remember to resume the primary task, as is the case in some interruption paradigms (e.g., Dodhia and Dismukes, 2009), but instead only had to remember how to resume the task efficiently. Our experimental paradigm also has aspects of task interleaving research, where people's strategies are analyzed concerning their choice of natural break points (Janssen et al., 2012) to orient to an interrupting task once it occurs or recurs.

A second limitation is the generalizability of the results. The research was initially motivated by Grundgeiger et al. (2013) ICU study and in our experimental paradigm we captured some characteristics of the situation described, where the nurses who saw the alarm limits tabs were more likely to defer the outgoing nurse's interruption. Even though Mr TT's interruptions were intended to be social in nature, people are likely to respond to human colleagues and computer characters quite differently. Moreover, Mr TT had quite an insistent demeanor when required to wait. Participants might respond differently to a different "personality" and different levels of apparent urgency. Further research should vary the urgency and type of interruptions, since these factors influence people's responses (Ho et al., 2004).

A third limitation is that although many factors were varied about the interruption, such as game difficulty, game speed, and the time when interruptions occurred, interruptions in workplaces occur unpredictably and are not uniform in their nature (Mark et al., 2005). In addition, our participants were relatively limited in their choice of strategies for handling each interruption. Ultimately, they could not ignore the interruption, because the primary task would eventually be shut off, forcing them to turn to the interrupting task.

8.5 Conclusion

Recent research has suggested that visual cues in a primary task can facilitate participants' resumption of the primary task after an interruption. However little is known about exactly how visual cues influence participants' interruption management strategies. We found that simply providing visual cues about the remaining stages in a task did not increase the probability that participants would defer interruptions until the task was complete. However, a visual cue associated with the ability for participants to take the next step in their execution of the task did increase the probability that participants would defer interruptions. Outcomes from the present and future experiments could help designers design equipment that supports underlying tasks in a robust manner.

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Table 1 Participants included in the analysis of each experiment. “Task advancement asymmetry” refers to whether the primary task interface made the location of the next placeholder visible at a different time across cue conditions (present) or at the same time (absent).

Experiment	Expt 1	Expt 2	Expt 3	Expt 4
Language	English	English	German	German
Task advancement asymmetry	Present	Absent	Absent	Present
Participants run	79	79	54	54
Participants included	72	77	52	51
Cue (total)	36	38	26	25
Females	22	28	18	18
Males	14	10	8	7
No Cue (total)	36	39	26	26
Females	24	28	13	18
Males	12	11	13	8

Table 2 Deferral rate, expressed as the proportion of interruptions for which participants deferred responding to the interruption while they completed the page of equations. Entries are mean [95% CI]

	Expt 1	Expt 2	Expt 3	Expt 4
Language	English	English	German	German
Task advancement asymmetry	Present	Absent	Absent	Present
Cue	*.466 [.377, .554]	.347 [.246, .449]	.392 [.285, .499]	+.517 [.409, .625]
No Cue	.249 [.152, .346]	.381 [.281, .481]	.392 [.279, .505]	.397 [.306, .488]

+ $.1 > p > .05$, * $p < .05$.

Table 3 Speed at assessing each arithmetic equation, averaged for cue and no cue conditions, and whether interruption is active or inactive. Data are mean [95% CI] in milliseconds.

	Expt 1	Expt 2	Expt 3	Expt 4
Language	English	English	German	German
Task advancement asymmetry	Present	Absent	Absent	Present
Interruption active	§	§ #	§	§ #
Cue	4157 [3823, 4491]	3864 [3562, 4166]	4533 [4133, 4932]	4252 [3906, 4597]
No Cue	4642 [4215, 5069]	4253 [3957, 4549]	4564 [4155, 4973]	4694 [3940, 5048]
Interruption inactive				
Cue	4878 [4452, 5303]	4397 [4036, 4758]	5267 [4903, 5631]	4547 [4233, 4860]
No Cue	5111 [4567, 5654]	4984 [4630, 5338]	5034 [4661, 5407]	5217 [4897, 5538]

$ indicates significant ANOVA main effect of cue condition (cue vs. no cue), # indicates significant ANOVA main effect of interruption (active vs. inactive).

Table 4 Outline of the configuration of the arithmetic primary task in the transition between arithmetic tasks, across the four experiments.

	Expt 1	Expt 2	Expt 3	Expt 4
Language	English	English	German	German
Task Advancement Asymmetry	Present	Absent	Absent	Present
Cue condition				
Icons for elements of all four equations	Yes	Yes	Yes	Yes
Delay before placeholder enabled	1.5 sec	1.5 sec	1.5 sec	1.5 sec
Next placeholder visibility	Visible	Visible	Not visible	Visible
Next placeholder enabled/disabled	Disabled	Disabled	N/a	Disabled
Next placeholder location predictability	Predictable	Predictable	Unpredictable	Predictable
No cue condition				
Icons for elements of all four equations	No	No	No	No
Delay before placeholder enabled	1.5 sec	1.5 sec	1.5 sec	1.5 sec
Next placeholder visibility	Not visible	Visible	Not visible	Not visible
Next placeholder enabled/disabled	N/a	Disabled	N/a	N/a
Next placeholder location predictability	Predictable	Predictable	Unpredictable	Predictable

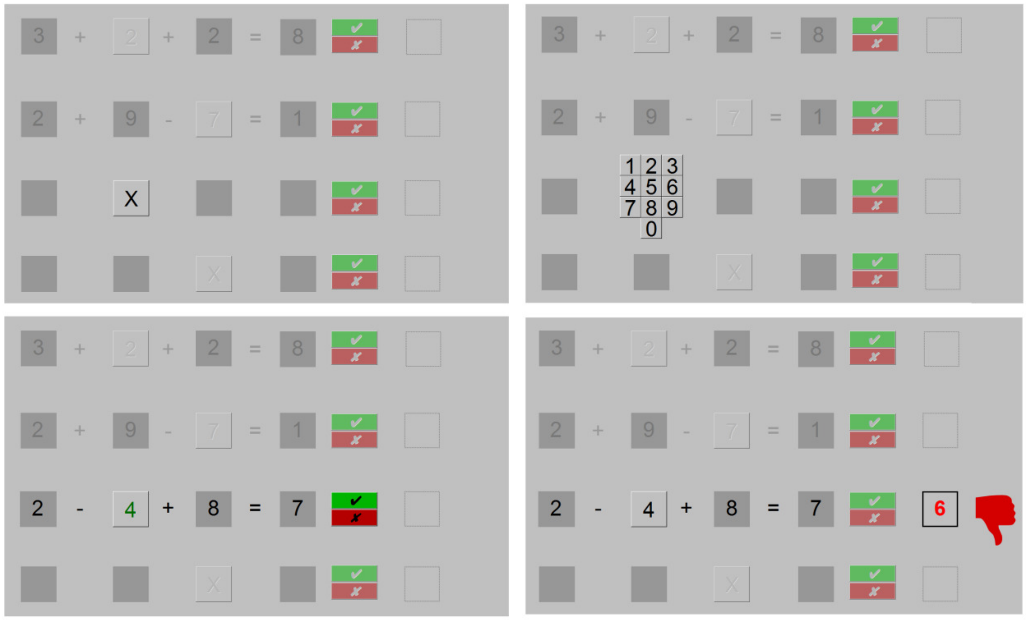

Fig. 1. A page of the arithmetic task in the cue condition, showing four task steps. Top left: participant is about to start third equation on page by clicking on “X”. Top right: number pad appears and participant selects carryover number remembered from previous equation on page. Bottom left: once carryover number is selected, full equation appears. Participant decides if equation is correct or incorrect, and clicks on correct (green) or incorrect (red) button. Bottom right: participant receives feedback on their decision (thumb up or down) and the correct answer to the equation appears (carryover number), which the participant carries down to the next equation.

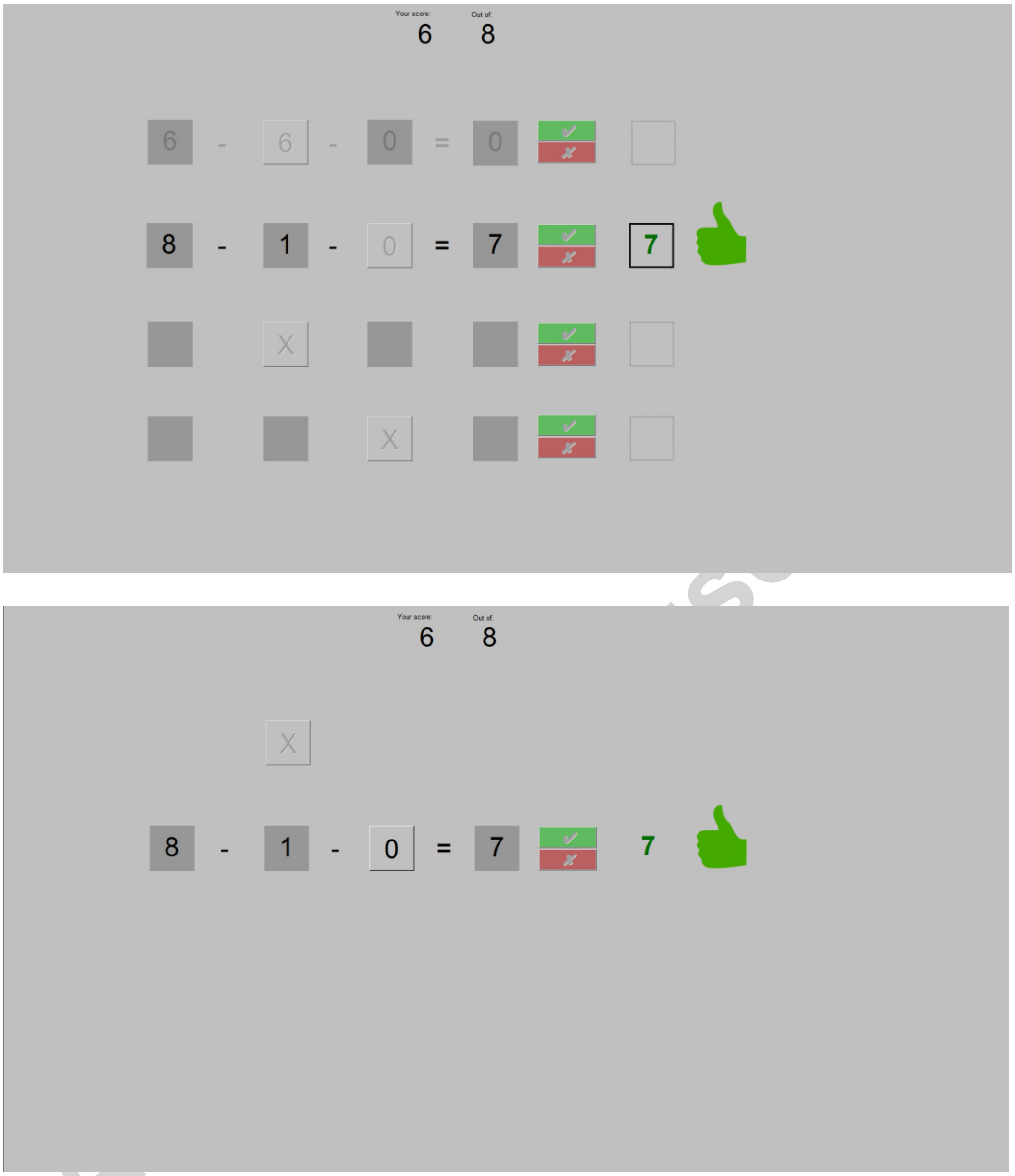

Fig. 2. Display for arithmetic task in Experiments 1 and 4, showing the cue condition (top) and no cue condition (bottom). Previous equation values and future equation locations are shown in the cue condition only. Even though not visible in the no cue condition, the approximate locations of future placeholders were predictable as they occurred in turns on the second and third summand position of an equation.

Fig. 3. Layout of experiment with primary task (arithmetic) on right desk and interrupting task (Tic-Tac-Toe) on left desk.

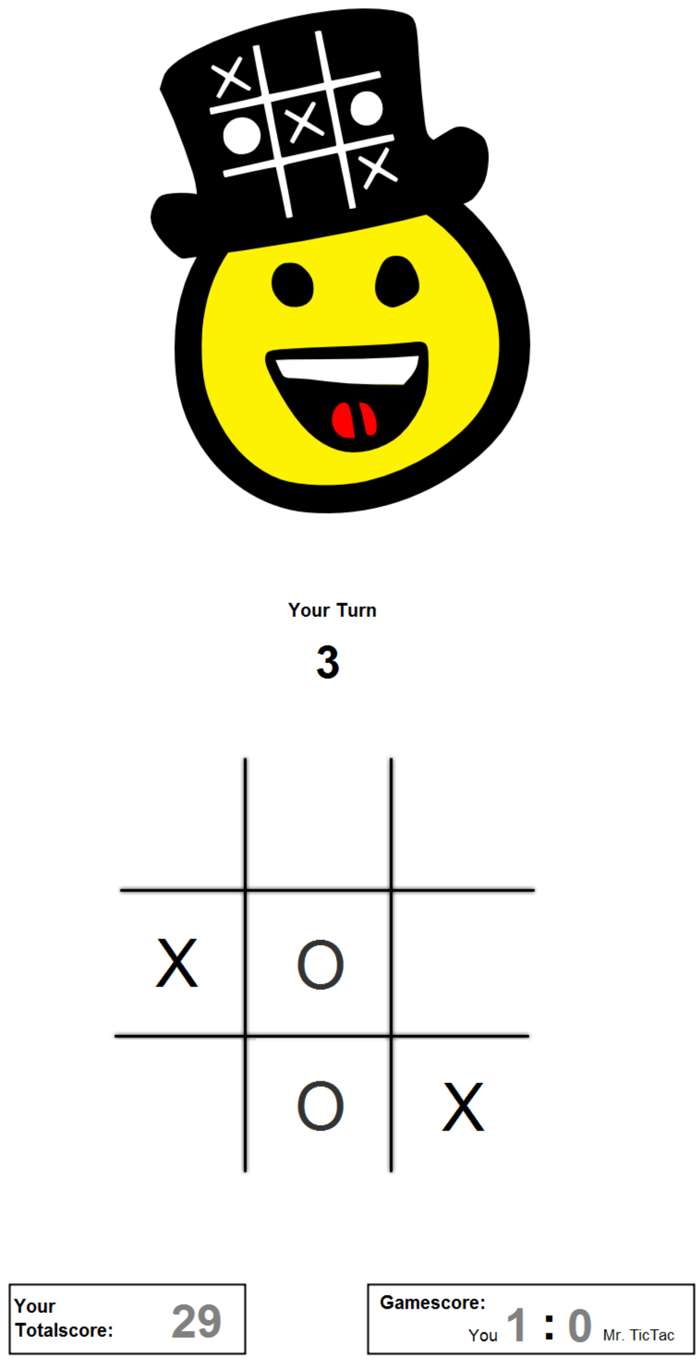

Fig. 4. Detail of Tic-Tac-Toe screen and Mr TT.

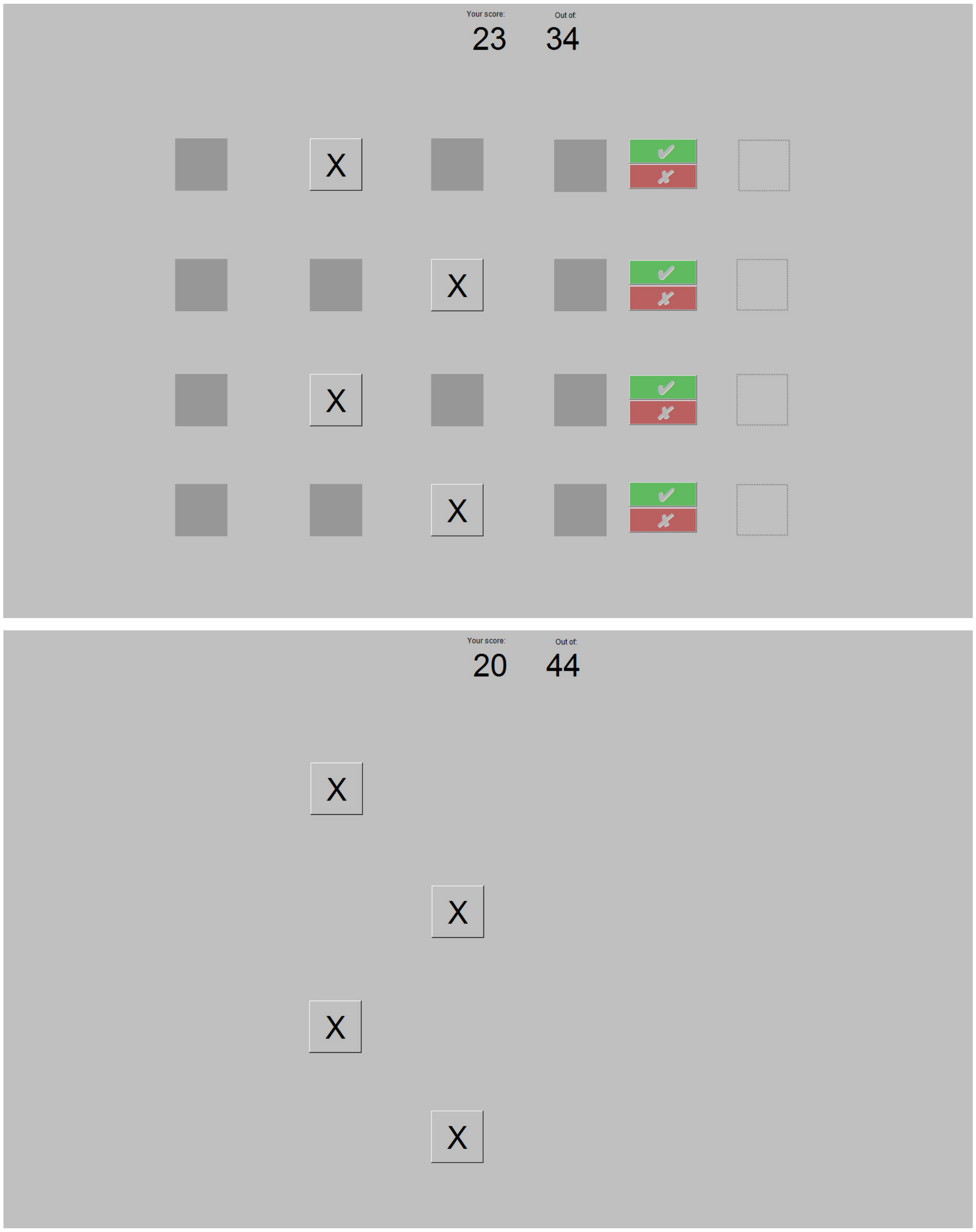

Fig. 5. Layout of primary task screen on resumption, if the participant had not finished a page prior to the interruption. Participant had to remember placeholder location and carryover number. Top screen: cue condition. Bottom screen: no cue condition.

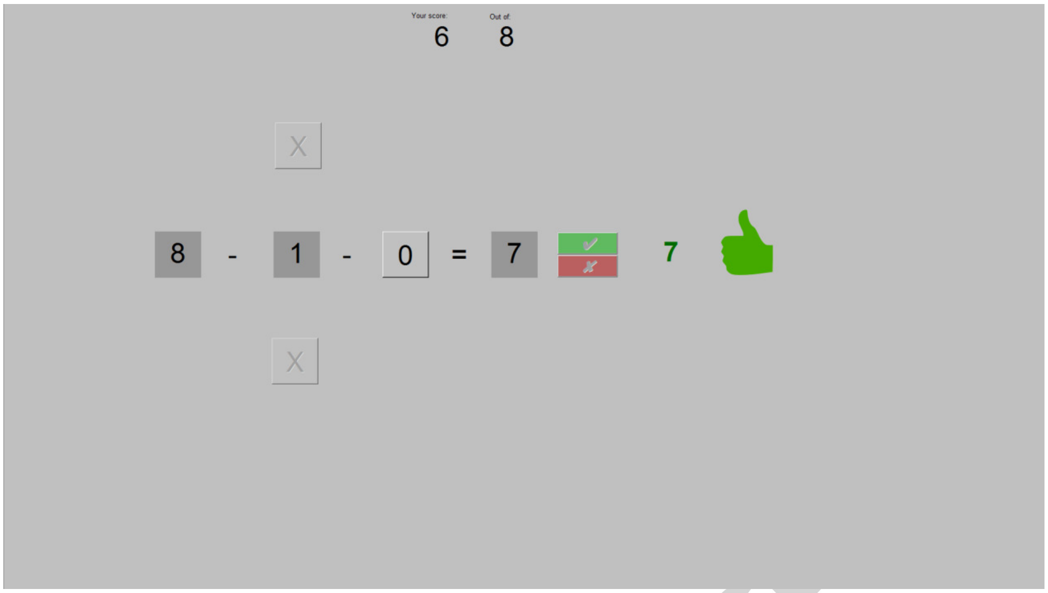

Fig. 6. Revised layout in Experiment 2 of no cue condition screen. The placeholder for the next step is visible.

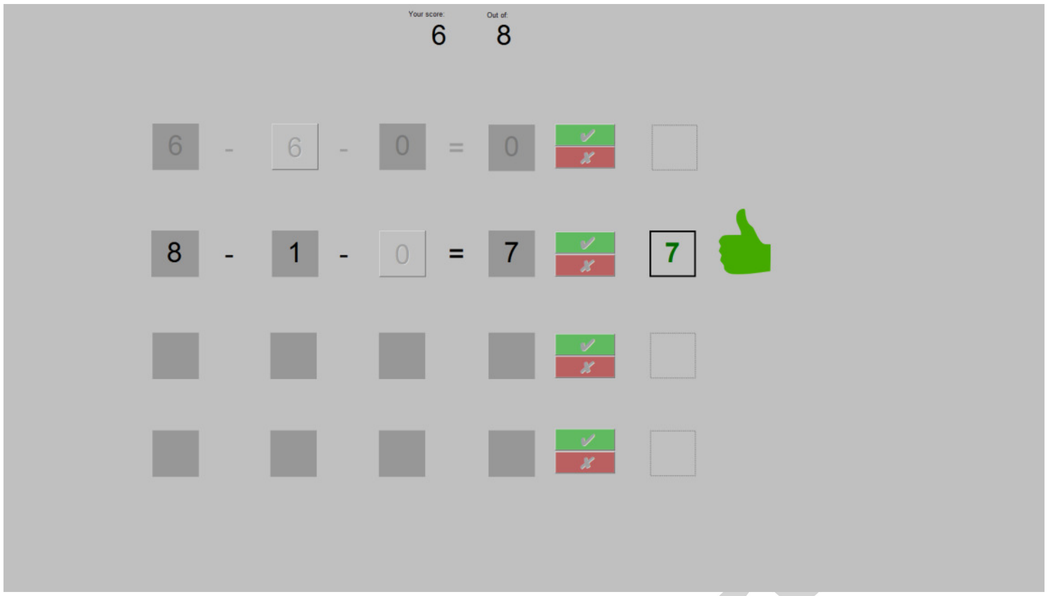

Fig. 7. Revised layout of cue condition screen in Experiment 3. Location of placeholder field for next equation is not visible and is unpredictable.

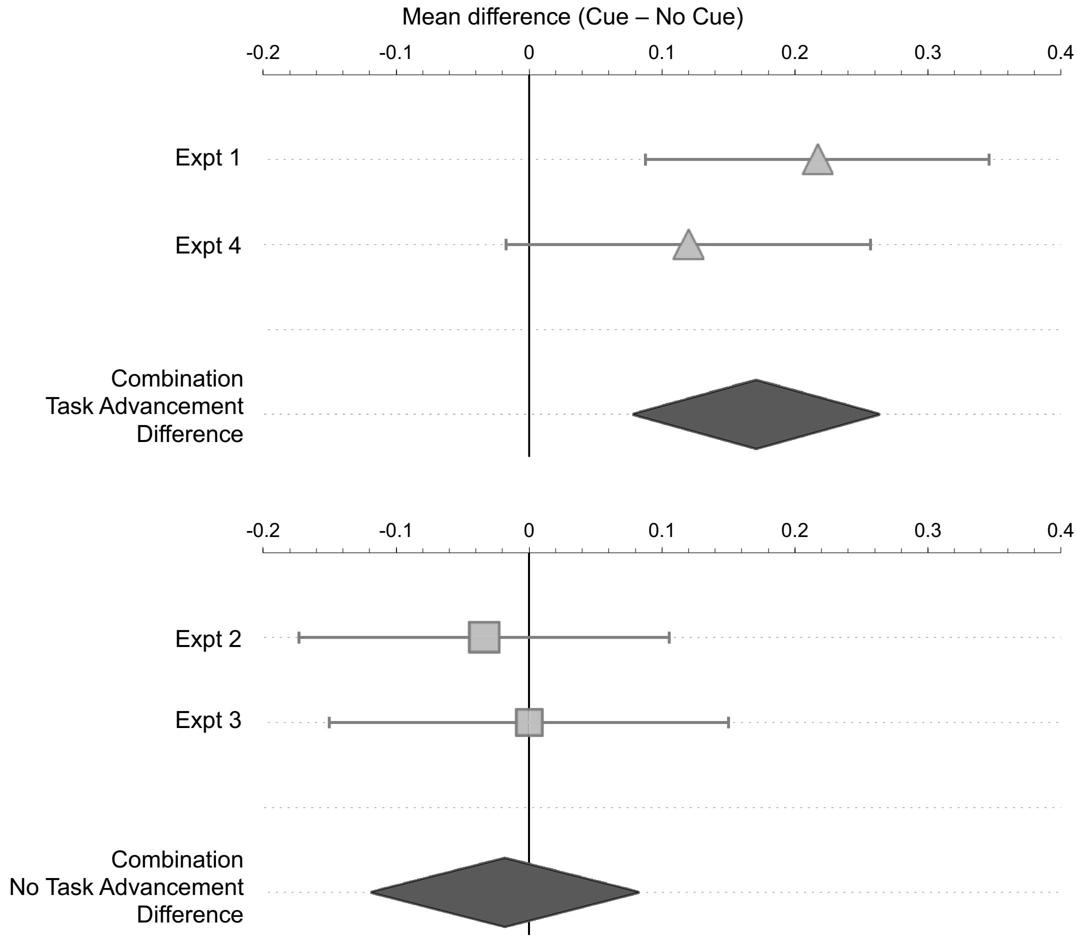

Fig. 8. Forest plots for meta-analyses of Experiment 1 and Experiment 4 where the task advancement asymmetry was present (top) and of Experiment 2 and Experiment 3 where the task advancement asymmetry was absent (bottom). Light grey markers show the difference between the means of the cue and no cue conditions for each experiment, and the range lines show the 95% CI for the difference. Dark grey shapes indicate mean and confidence interval for each pair of experiments.

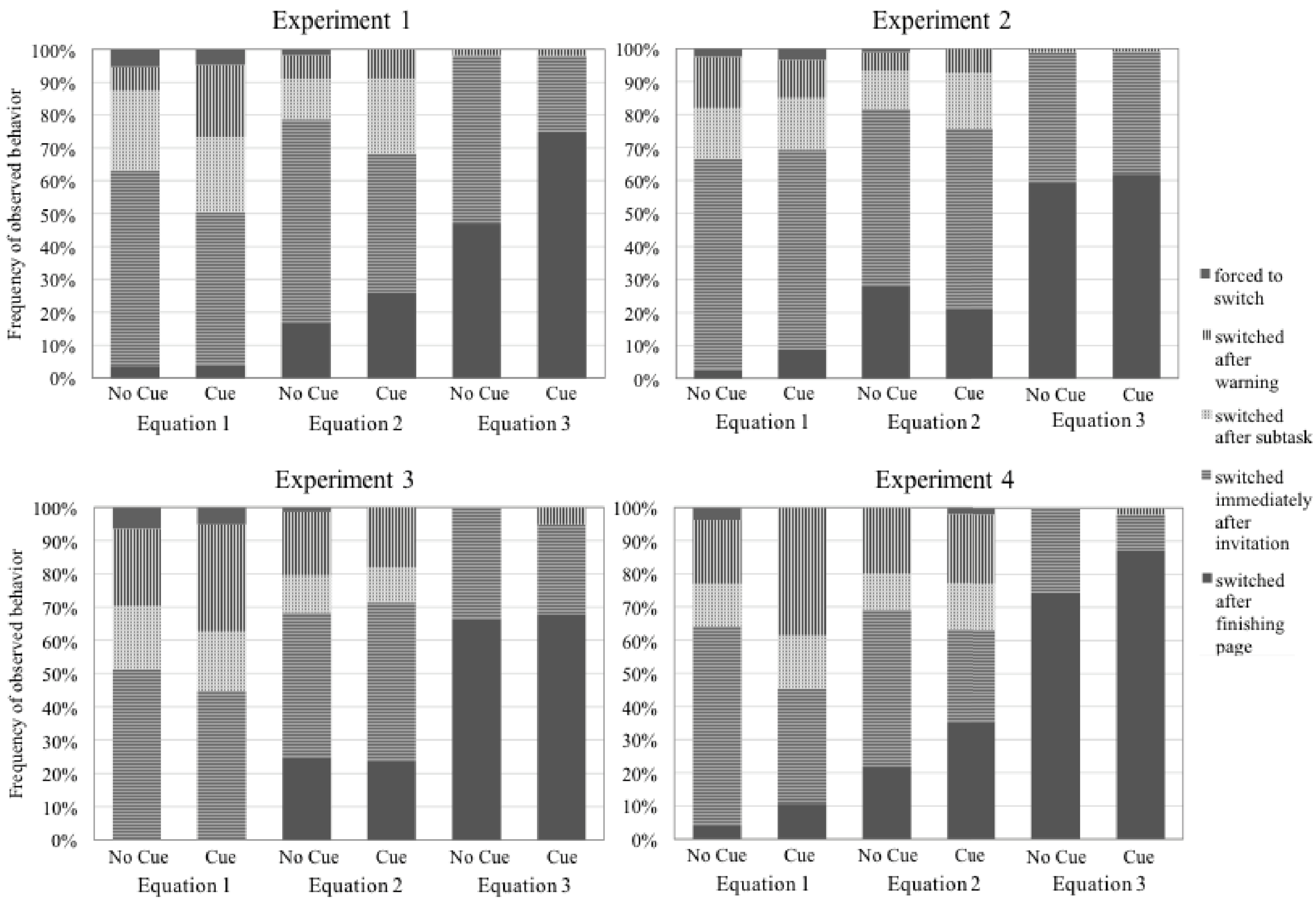

Fig. 9. Bar charts show frequencies for participants' microstrategies during the interruption lag for all four experiments. The data are separated by cue vs. no cue condition and by the equation after which the interruption occurred. A table with numerical values is provided in the online appendix (Table A2).

Highlights

- Visual cues about upcoming primary tasks may encourage people to defer interruptions.
- In four experiments we tested the role of cues vs. no cues during the interruption lag.
- Cues were confounded with a greater opportunity to make progress in the primary task.
- Deferrals were no more frequent with cues vs. no cues if confound was removed.
- Interruption–management microstrategies revealed sensitivity to time or memory costs.