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Forgetting during interruptions: The role of goal similarity

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Abstract

Resuming an interrupted task requires remembering the goals that governed behaviour immediately before the interruption. Here we examined whether forgetting of goals can be mitigated when goals of the interrupting task are related to the existing goals of the interrupted task. Participants performed a sequence task in which consecutively performed operations were denoted by letters. The sequence task was occasionally interrupted by a secondary task, with operations also involving processing of letters. The tested hypotheses were that resumption of the primary sequence task would be facilitated if, within the interrupting task, either the letters processed (Experiment 1) or the operations denoted by these letters (Experiment 2) matched the goals immediately preceding the interruption. Both experiments found fewer errors at resumption when either the letters processed, or the operations performed, used letters processed immediately before the interruption when compared to a control condition involving a random letter from the sequence task. These results indicate that forgetting of goals is moderated by the similarity of the goals pursued across interrupting and interrupted tasks, although the effect does not seem to be modulated by maintenance of the specific goal which preceded an interruption.

Keywords: Interruptions, Memory for goals, Rehearsal, Interference

Forgetting during interruptions: The role of goal similarity

Interruptions are a ubiquitous feature of today's lives. Any complex behaviour we engage in, ranging from trivial chores of everyday life to performing demanding tasks in safety-critical environments – for example in health care, transport or control-centre settings – is likely to be at least occasionally interrupted by various types of electronic alerts, phone calls, or other manifestations of increased social interconnectedness and associated demand for our attention from other people. As a result, our performance in the primary, interrupted task often suffers from the requirement to engage in a secondary task such as fending off some call for our attention. Research has amply documented that interruptions lead to costs in the form of not only slowing down when the main task needs to be resumed (Hodgetts & Jones, 2006a; 2006b; Labonté et al., 2019; Monk et al., 2004; Radović & Manzey, 2019; see Trafton & Monk, 2007), but also increased chances of committing errors in the primary task (Altmann & Hambrick, 2017; Altmann et al., 2014; 2017; Li et al., 2008). But are all interruptions created equal? Does it matter for the performance in the primary task what kind of a secondary task is performed during the interruption interval? Here we aimed to assess the hypothesis that contents of the interrupting task do matter. Specifically, we investigated the possibility that some secondary tasks – those having similar goals to the ones that govern the primary task – reduce the negative impact an interruption might otherwise have.

The most common way of investigating the impact of interruptions is to give participants a procedural task that requires them to perform a set of subtasks in a particular order and then occasionally interrupt this primary task by a requirement to complete a certain secondary task. Of interest then is how the requirement to complete the secondary task affects performance in the primary task for a subtask immediately following the resumption of the primary task, compared to standard subtasks not preceded by an interruption. The most common observation from employing this kind of paradigm is that it takes longer to perform a subtask immediately after an interruption – a so-called resumption lag (e.g., Hodgetts & Jones, 2006a, 2006b; Trafton et al., 2003). While this extended time necessary to perform the primary task obviously constitutes a cost to performance, such a cost is not unique to the case of interruptions. A literature on task switching (see Koch et al., 2010, for a review) – a case in which two consecutive subtasks are either changed or switched in the course of performing a procedural task – documents the cases of extended reaction times after task switches, and it could be argued that interruptions are a special case of task switching (see Hirsch et al., 2023, for a more detailed discussion). Here resuming the primary task after an interruption would mean switching from a task set of the secondary to the primary task, generating a task switch cost that is absent when the primary task continues uninterrupted. However, recent advances in research on the impact of task interruptions tend to focus on a unique signature of interruptions – not only do they slow down performance at resumption of the primary task, but also lead to a number of errors, and more specifically sequence errors that manifest in participants performing an incorrect subtask when the primary task is resumed.

The focus on sequence errors due to interruptions to procedural task has gained prominence with the development of a novel paradigm by Altmann et al. (2014). In the UNRAVEL task, participants are asked to perform a sequence task with seven different subtasks. Participants see displays consisting of a central frame and two characters, one letter and one digit. For each display, participants need to perform a single operation such as deciding whether a letter in a particular display is underlined or in italics, or deciding whether a digit is even or odd. Importantly, the seven to-be-performed subtasks are described by unique letters that together give rise to the acronym UNRAVEL. So, for example, the underlined-or-in-italics operation is denoted by the letter U, while the even-or-odd operation is denoted by the letter E. There are seven unique operations and participants are instructed to perform them in the sequence defined by the UNRAVEL acronym, starting with the U operation and going back to the U operation after performing the L operation. To perform this task, participants need to mentally keep track of their position in the sequence of subtasks.

Crucially, in the UNRAVEL paradigm participants are sometimes interrupted while performing the primary sequence task, immediately after performing a random subtask. During interruptions, participants are asked to perform a secondary task such as copying letters or digits displayed on the computer screen. Altmann et al. (2014) showed that such interruptions – even if only very brief, lasting less time than one operation in the primary task, and simple, requiring participants merely to copy two characters – lead to a significant decrement in performance in the primary task as evidenced by an increase in the rate of sequence errors (performing an incorrect subtask) at resumption.

Given the robust effects of interruptions on sequence errors observed in the UNRAVEL task, the question to be asked is what factors determine the rates of those errors. What are the conditions under which one is particularly likely to err on the subtask one is supposed to perform immediately after an interruption? Not surprisingly, research on this topic has so far been inspired by previous studies focused on interruption costs in the form of resumption lags. Altmann et al. (2014; see also Altmann et al., 2017) assessed the effect of the duration of interruptions and found that longer interruptions lead to more sequence errors when the task is resumed, paralleling findings from studies examining resumption lags (e.g., Monk et al., 2008). Radović and Manzey (2022), with a German adaptation of the UNRAVEL task, examined the complexity of the cognitive operations performed during interruptions and found that more complex operations increase the rate of sequence errors at resumption, again paralleling the patterns observed for resumption lags (e.g., Cades et al., 2007; Hodgetts & Jones, 2006a; Monk et al., 2008). However, Radović and Manzey also examined another factor, which previous studies (Ratwani et al., 2008) suggested was a determinant of interruption-dependent impairment – similarity between the primary and the interruption task. The focus here was on similarity in terms of the types of material processed. The adapted UNRAVEL task engaged verbal codes, and the interruption tasks were manipulated to require processing of either verbal or spatial information. In two experiments, Radović and Manzey found no evidence that similar codes across the primary and the interruption tasks increase the rate of sequence errors at resumption.

The main question driving the present study is also concerned with the role of similarity between the primary and interrupting tasks in determining the disruptiveness of interruptions. However, rather than focus on particular material or codes engaged in different tasks, we were interested in a more direct similarity between the goals behind a particular subtask in the primary sequence task on the one hand and those behind the secondary task performed during the interruption on the other.

To understand this kind of similarity relationships, it is necessary first to describe the theoretical apparatus specifically proposed by Altmann and Trafton (2015; see also Altmann et al., 2017) to describe the mechanisms of interruption-related impairment in a sequence task such as the one used in the UNRAVEL paradigm. The assumption of this framework is that performance in a sequence task engages two memory systems, semantic and episodic memory. First, the sequence is stored in semantic memory and performing any subtask from this sequence (e.g., U) automatically primes all other subtasks, with a diminishing gradient as activation spreads from the next subtask (N), then the one after that (R), and so on. When the interruption occurs (after U), this activation of all primed subtasks fades, most markedly for the correct to-be-performed subtask (N) that was activated to the greatest extent. This fading means that, following the interruption, the priming of the correct subtask is lower than it would be without the interruption and this may sometimes lead to participants erroneously choosing the next most activated subtask (R), resulting in the error of skipping one subtask. Indeed, the analysis of sequence errors in Altmann et al. (2017) showed that such errors of skipping, referred to here as errors of the lag +1, were markedly more frequent than errors of different lags. However, one exception was the rate of errors of the lag -1, repetitions of the already performed subtask, which were actually the most frequent of all sequence errors.

To account for lag -1 errors, the framework postulates a crucial involvement of an episodic memory system. Altmann and Trafton (2015) proposed that participants maintain the last operation they needed to perform in their episodic memory. Once the interruption ends, they use this episodic memory representation – in conjunction with their memory representation of the entire sequence – to derive the next to-be-performed subtask. However, even a short delay (such as that occasioned caused by an interruption) allows for some forgetting of episodic representations, which could result in erroneous retrieval not of the last performed subtask but the one which immediately preceded it. This erroneous retrieval misleads participants into repeating the last subtask once the primary sequence task is resumed after the interruption – making an error of lag -1. Crucially, in this model, forgetting of episodic representations is due to a process of decay – episodic representation is forgotten as a function of the duration of the interruption. This accounts for a common observation that longer interruptions are more disruptive than shorter ones (Monk et al., 2008), also in terms of resulting sequence errors (Altmann et al., 2017).

The ubiquity of sequence errors with lag -1 in the UNRAVEL task points to the crucial importance of an episodic memory system in dealing with interruption costs. In the formulation of an influential memory-for-goals framework (Altmann & Trafton, 2002), dealing with an interruption requires holding in episodic memory a goal that was achieved just before the interruption, while pursuing the goal of the secondary task. However, it is worth noting that even long interruptions, simultaneously maximizing the fading of priming in semantic memory and the decay of goals in episodic memory, do not lead to particularly high levels of sequence errors at resumption. From this, it is clear that a compensatory mechanism must be upholding the activation of goals during interruptions. Many current theories of working memory (an episodic system for storing information for a short period of time) assume that forgetting is at least to some extent counteracted by restorative processes, such as rehearsal of verbal information (i.e., subvocal repetition of to-be-remembered information, Lucidi et al., 2016) or attentional refreshing (i.e., a brief re-orientation of attention to to-be-remembered information that serves to strengthen its memory representation, Camos et al., 2009). In relation to interruptions, Altmann et al. (2017) argued that decay of episodic representations of the last performed operation is minimised – and thus errors of repetition at resumption at least some extent avoided – because during interruptions the last performed operation is actively rehearsed. A questionnaire administered to participants who performed the UNRAVEL task revealed that 83% of them reported the use of rehearsal strategy in this task.

The outline of the theory of sequence errors in the interruption task developed by Altmann and Trafton (2015) allows the formulation of predictions as to how similarity across the primary sequence task and the interruption task may affect the costs of interruptions. This theory explains why similarity in terms of engaged codes – verbal vs. semantic – seems not to matter, as shown by Radović and Manzey (2022). Within currently prominent models of working memory that assume forgetting via decay, such as the time-based resource-sharing model of Barrouillet et al. (2004), forgetting is solely a function of the proportion of time for which an attentional bottleneck is engaged by a distracting task. During this time, attention cannot be devoted to operations of rehearsal and/or refreshing that would support decaying representations. From this it follows that more complex secondary tasks should exacerbate interruption costs, because they demand more processing time and thus maximise forgetting of goals from episodic memory, but no effect of similarity in terms of codes is to be expected (consistent with the results obtained by Radović & Manzey, 2022).

The restorative processes engaged in supporting decaying goal representations do leave open a gate for the role of similarity, however: more specifically, the similarity of goals across the primary and secondary tasks. If an active strategy of maintaining the last realised goal contributes to performance in the primary task, then it seems likely that the secondary task performed during the interruption could facilitate this process if it employs representations that are the same as to-be-rehearsed representations from the primary task. In other words, assume that participants strive to remember either the letter that denotes the subtask they had just performed before the interruption occurred, or a specific cognitive operation required by this subtask. In this case, a secondary task that requires processing of that very same letter, or performing the very same kind of task, could facilitate setting up of the rehearsal process and thus more effectively counter decay in episodic memory, reducing the rate of repetition errors once the sequence task is resumed. For example, if participants who have just completed the subtask indicated by the letter “E” in the UNRAVEL task are required to process the same letter during the interruption, it is less likely that “E” will decay and be forgotten during that period. Thus, when the interruption is ended, "E” will be available to return to.

In the current study we assessed the role of similarity between representations processed during interruptions and those of the subtasks of the primary sequence task. We adapted the UNRAVEL task into Polish by developing a different acronym encompassing a set of seven operations – MILONGA. In Experiment 1 the secondary task introduced multiple trials of a visual search task during the interruption period. In this task participants were asked to find a letter that defined one of the four experimental conditions. In the *other* condition, the sought-for letter was not used in the MILONGA task. In the *random* condition, the sought-for letter was one of the letters denoting a subtask of the MILONGA task, but it was never either of the letters referring to the subtasks that preceded or followed the interruption. In the *pre-interruption* condition, the sought-for letter was the letter that denoted the subtask participants performed before the interruption. In the *post-interruption* condition, the sought-for letter was the letter that denoted the subtask participants should perform after the interruption. Experiment 2 used a similar procedure but instead of performing a visual search task for letters, participants were instructed to perform the operations required in the subtasks denoted by these letters in the sequence task.

The main focus of the study was the comparison of the pre-interruption condition to the remaining conditions. We hypothesised that if, when interrupted, participants try to maintain their position within the MILONGA sequence by rehearsing the letter denoting the last performed subtask, then the processing of the same letter within the secondary task should facilitate this rehearsal process in the pre-interruption condition of Experiment 1, reducing the rate of sequence errors once the primary task is resumed. Similarly, performing the very subtask denoted by the same letter in Experiment 2 should likewise facilitate the rehearsal process, reducing the rate of sequence errors once the primary task is resumed. Given that the contribution of episodic memory to dealing with interruptions is evidenced by the number of lag -1 sequence errors at resumption, we would expect that facilitated rehearsal would specifically reduce the rate of such errors.

Experiment 1

Method

Participants. Sixty participants were recruited via the Prolific platform and performed the task online in exchange for monetary compensation. Two participants were excluded for not following task instructions. Thus, the final sample consisted of fifty-eight participants (age: M = 26, SD = 7.1; gender: 36 males, 22 females). The study was approved by the ethics committee at the SWPS University (37/2018).

Materials. A Polish adaptation of the UNRAVEL task, employing the MILONGA acronym, was used in the present experiment. The task consisted of a series of displays, presenting a rectangular black frame on a white background, together with one letter and one digit. The letter and the digit were presented in two out of six possible locations on the screen: inside the frame, below it, or above it, and either on the left or the right, with the constraint that always one and only one character was displayed inside the frame and always one character was presented on the left and the other on the right side of the display (see Figure 1, for an example). The set of letters used consisted of A, B, Y, and Z, while the set of digits consisted of 2, 3, 7, and 8. Letters were presented either with an accent mark above it or in italics. One of the characters was always presented either in indigo or pink font, while the other was presented in black font. The subtasks participants were asked to perform were defined by the MILONGA acronym, which in translation required participants to decide whether: 1) M: the digit was smaller or greater than five, 2) I: one of the characters was presented in indigo or pink font, 3) L: a letter or a digit was presented on the left side of the frame, 4) O: a letter was close to or far from the beginning of the alphabet, 5) N: a digit was odd or even, 6) G: a character displayed outside the frame was above or below it, 7) A: a letter was presented with an accent mark or in italics. Participants provided their responses by pressing one of two response keys, of which one was always a letter from the MILONGA acronym that defined the particular subtask – for example, for the M operation the key M stood for *mniejsze*, meaning *lower* (here: than five) in Polish – while the other was a different unique letter (e.g., W for *większe*, or *higher*). Performing one subtask of the MILONGA task is described as a single experimental trial. The main sequence task was presented in six blocks, each consisting of 16 iterations of the acronym, which meant a total of 112 trials of the primary task in one block (672 trials total).

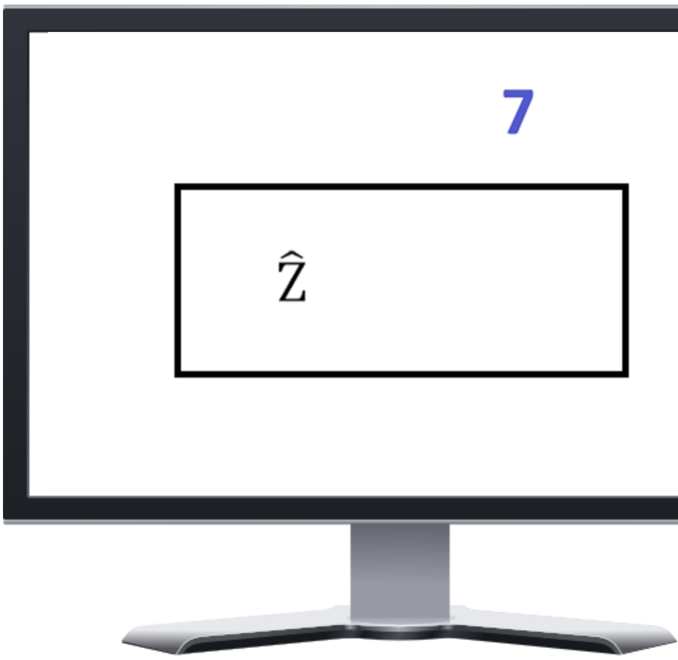

Figure 1. An example display from the MILONGA task showing an *odd* digit *greater than 5*, presented in *indigo* and *above* the frame, and a letter *close to the end* of the alphabet, presented on the *left* side of the display, and with an *accent*.

The main sequence task was occasionally interrupted by a secondary task. In the secondary task, participants were first presented with a single letter, displayed for two seconds, which they were then instructed to identify from among a set of four letters displayed simultaneously on the screen and numbered from one to four. The other letters in each display were taken from among letters not included in the MILONGA task or any of potential responses in sequence operations. The duration of the secondary task was set to 8 seconds, with as many self-paced search trials as fitted into this interval. The occurrence of interruptions was determined randomly, with each operation in the main sequence task having a 1 in 8 (12.5%) chance of being followed by an interruption. This meant that interruptions on average occurred a little less often than once per the MILONGA sequence, although there were no imposed limits of how many times one sequence could be interrupted. The type of the interruption – as described in the next section – was also determined randomly, which means that all experimental conditions were intermixed.

Design. A single independent variable was manipulated – the relationship between the to-be-identified letter in the secondary task to the just performed operation in the MILONGA task. This variable had four levels, with the to-be-identified letter coming from outside responses possible in the MILONGA task (the *other* condition), being one of the seven letters comprising the MILONGA acronym but not matching the operation that was either performed just before or to be performed just after the interruption (the *random* condition), being the letter that denoted the operation performed just before the interruption (the *pre-interruption* condition), or being the letter that denoted the operation to be performed right after the interruption (the *post-interruption* condition). The main dependent variable was the rate of sequence errors in the trials of the main sequence task that immediately followed the interruptions.

Procedure. Before participants were asked to perform the main sequence task, a training session was administered, where they first learned the individual subtasks of the sequence task and then performed four cycles of seven trials of the task. During this training session, participants were also interrupted four times and asked to perform the secondary task. Participants were explicitly instructed that the purpose of the study was to assess their ability to resume the correct position of the sequence task after the interruption, for which they should depend on their memory only. After training, participants completed six blocks of the sequence task. Self-paced pauses in-between blocks were provided, during which the reminder of the subtasks and the corresponding answers were displayed.

Results and discussion

The rates of sequence errors following immediately after interruptions and in four subsequent subtasks are presented in Figure 2. It can be seen that sequence errors were committed mostly in trials immediately following an interruption, after which performance quickly levelled off. Given that the focus was on sequence errors caused by interruptions, the proportions of those errors on the first trial after interruption was analysed as a function of experimental condition (other, random, pre-interruption, post-interruption) with a one-way ANOVA, $F(3, 171) = 2.71$, $p = .047$, $\eta^2 = .045$, which showed that these conditions differed from each other. Post-hoc tests with Bonferroni corrections revealed that only one set of conditions reliably differed from one another – there were fewer sequence errors in the pre-interruption condition than in the random condition, $t(57) = 2.78$, $SE = .01$, $p = .036$, $d = 0.365$. All other comparisons were not significant (lowest p = .536).

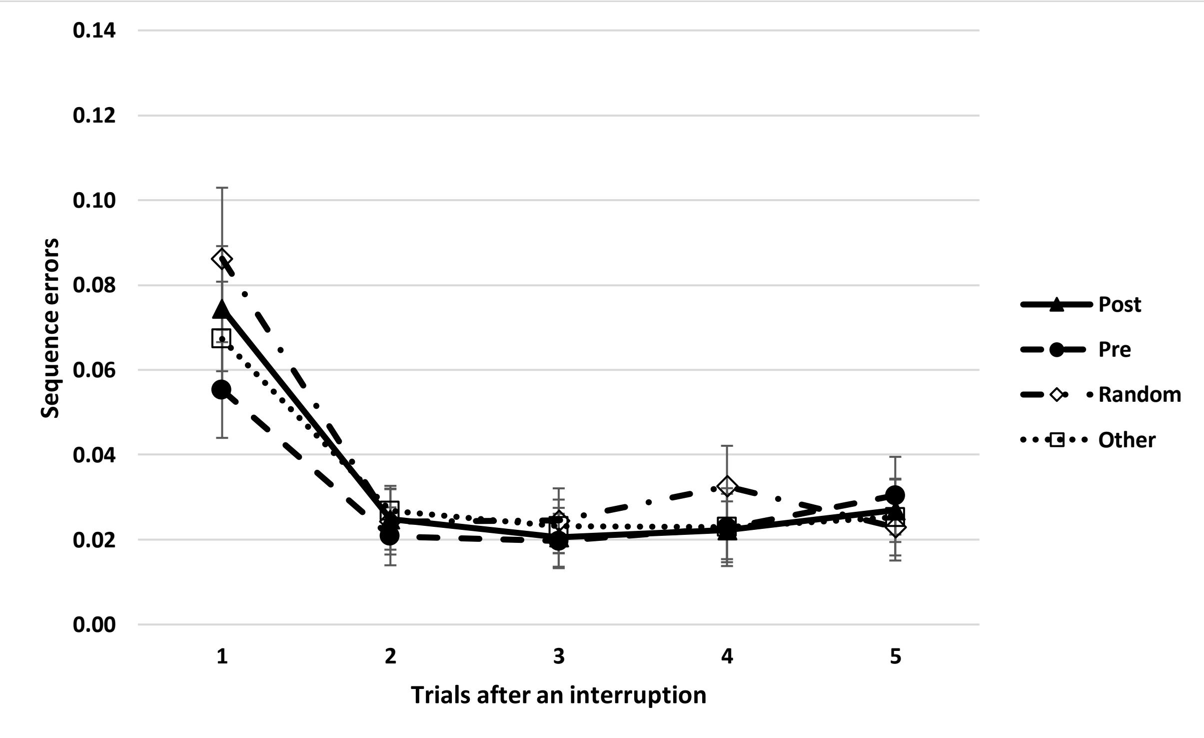

Figure 2. Proportions of sequence errors after resumption of the primary task (out of all responses made after resumption) as a function of experimental condition in Experiment 1. Error bars denote standard errors.

Figure 3 presents a distribution of sequence errors made immediately after an interruption as a function of lag from the correct response, with lag -1 meaning a repetition of the operation that preceded the interruption and lag +1 meaning skipping one operation when the task was resumed after the interruption. Two things are of interest in the plot. First, it is apparent that for the pre-interruption and the random conditions the distribution of sequence errors peaks at lag -1, with the other conditions showing a less pronounced peak. While this pattern resembles the usual pattern of errors documented with the sequence task (Altmann et al., 2017), it is worth noting that errors in the pre-interruption condition are clearly inconsistent with our initial hypothesis – we expected lag-1 errors to be reduced in this condition due to more efficient retrieval of goals from episodic memory. Second, the post-interruption condition also has a relatively high proportion of errors at lag -1 but also a more pronounced peak at lag +1, which clearly differs from all other conditions[1].

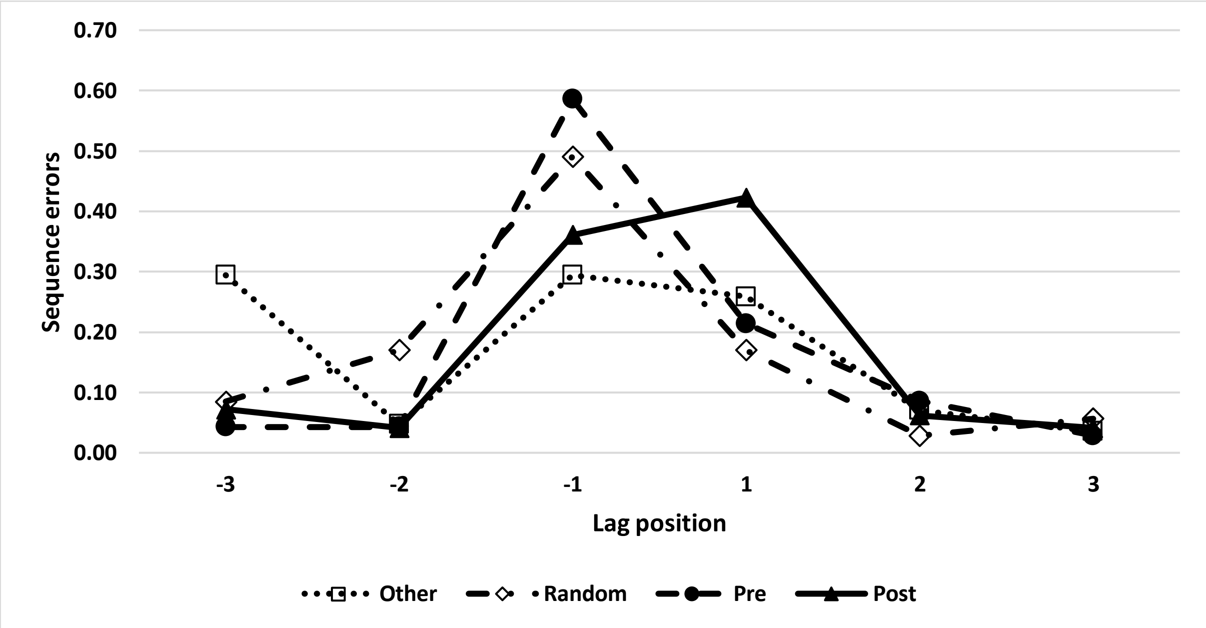

Figure 3. Proportions of sequence errors after resumption of the primary task (out of all sequence errors) as a function of experimental condition and the lag from the correct response in Experiment 1.

[1] The data could not be subjected to a statistical analysis due to a large number of missing cells at participant level. The same issue applies to sequence error distributions in Experiment 2.

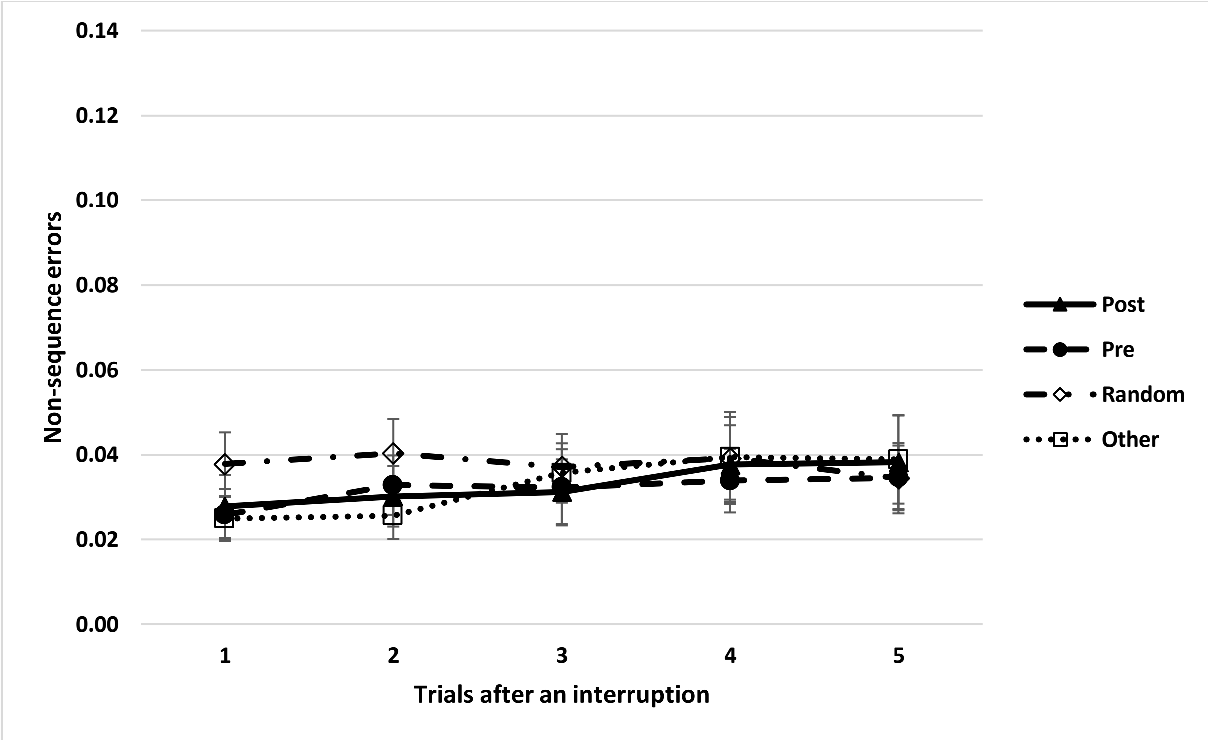

Figure 4. Proportions of non-sequence errors after resumption of the primary task (out of all responses made after resumption) as a function of experimental condition in Experiment 1. Error bars denote standard errors.

Although the focus of the study was on sequence errors, for completeness we also analysed two other dependent variables. First, Figure 4 presents non-sequence errors, again for up to five trials following an interruption. As can be seen, non-sequence error rates were generally low and not affected by the presence of interruptions. A one-way ANOVA found no difference in non-sequence errors on trials immediately following interruptions, $F(3, 171) = 1.46$, $p = .226$, $\eta^2 = .025$. Second, we also looked at reaction times for the first subtask after an interruption (see Table 1), with the exclusion of sequence errors, and found them not to differ significantly across conditions, $F < 1$. This shows that the pattern of sequence errors after interruptions was not mirrored in the patterns of resumption times. Finally, we also analysed the average number of visual search trials participants were able to perform within 8 seconds of the interruption period across experimental conditions. A one-way ANOVA showed significant differences across conditions, $F(3, 171) = 13.86$, $p < .001$, $\eta^2 = .196$. Bonferroni-corrected post-hoc comparisons showed this stemmed predominantly from a lower number of trials completed in the other condition ($M = 5.93$) than in all other conditions ($M = 6.18$, p < .001, for the pre-interruption condition; $M = 6.30$, $p < .001$, for the post-interruption condition; $M = 6.14$, $p = .002$, for the random condition). Additionally, the average number of trials was slightly higher in the post-interruption than the random condition, $p = .043$. These results seem to suggest that participants were delayed in setting a task set for the visual search task that required them to process a letter that was from the outside of the set of letters used in the primary sequence task.

Here we tested a hypothesis that when the main task is interrupted, performing a secondary task that requires maintaining a goal congruent with the last goal of the interrupted task would facilitate performance – minimise the rate of sequence errors – when the main task is resumed. The results were only partly consistent with the hypothesis. When there was a match in terms of the letter that denoted the last performed subtask and the one that needed to be identified in the secondary task, the rate of sequence errors at resumption was reduced but only in comparison to the random condition. From this, it is not entirely clear whether the consistency of goals across the main and the secondary task facilitates performance, or there is something particularly disruptive about the random condition. Moreover, the distribution of sequence errors as a function of lag did not support our hypothesis that consistency of goals would reduce errors of lag -1, which would indicate less forgetting of these goals, maintained in episodic memory, in the course of an interruption. If anything, for the pre-interruption condition the peak of errors at lag -1 was the most apparent out of all conditions.

One further interesting feature of the results which emerged post-hoc was an apparent change in the lag of sequence errors in the post-interruption condition. In this condition participants committed errors at a rate similar to the rates in all other experimental conditions, but these errors were qualitatively different inasmuch as they were most often the errors of skipping one operation of the main task, rather than repeating an operation that preceded the interruption. This observation is generally consistent with the premise of the model developed by Altmann et al. (2017), where performing an operation primes the next step in a sequence. Interestingly, though, here this priming seemed to occur not due to performing operations per se but due to processing of letters that denote subtasks in the sequence task. This is consistent with the idea that the acronym used in the main task remains stored in semantic memory and priming operates at the level of this acronym denoting operations. There is, however, insufficient data from this study – in terms of the number of errors of different types per condition – to be confident in drawing conclusions from this one experiment.

Experiment 2

In Experiment 2 we made another attempt at elucidating the role of similarity across the goals organizing the primary sequence task and those implemented in the secondary, interrupting task for performance when the primary task is resumed. In Experiment 1, this similarity was manipulated at the level of letters denoting subtasks in the primary task and targets of a visual search in the secondary task. However, what is maintained in memory when the primary task is interrupted might not be letters but rather the actual goals of subtasks denoted by these letters and realised before the interruption commenced. If participants maintain goals (e.g., lower or higher than five) rather than the letters that denote them (M), then any effect of similarity to to-be-identified letters in the secondary task would be limited. A stronger manipulation of similarity would be to require participants to actually perform particular operations in the secondary task that either match or mismatch the subtasks maintained in episodic memory during interruptions.

Accordingly, in the present experiment we implemented a manipulation of similarity in terms of the operations rather than the letters denoting subtasks. Here, during interruptions participants were asked to perform operations indicated by a letter that either matched the letter denoting the subtask completed prior to the interruption (the *pre-interruption* condition), matched the letter denoting the subtask to be performed following the interruption (the *post-interruption* condition), or matched another letter from the sequence task (the *random* condition). If the last performed operation is maintained in episodic memory during interruption, we would expect this maintenance to be facilitated when the same goal needs to be realised in the secondary task, facilitating performance at resumption in the pre-interruption condition compared to other conditions.

Method

Participants. Sixty-one participants (age: M = 27, SD = 7.84; gender: 41 males, 20 females) completed the experiment in exchange for monetary compensation. One participant with error rates exceeding 50% of resumption trials was excluded, leaving 60 participants for the analyses. All participants were recruited via the Prolific platform and performed the task online.

Materials, design, and procedure. The same main sequence task was used here as in Experiment 1. The only change pertained to the secondary task. It started with the presentation of a letter, which denoted one of the subtasks from the primary sequence task. Four displays from the sequence task were then presented and for each of them participants were asked to perform the same operation denoted by the letter presented at the beginning of the secondary task. The primary task was resumed after the fourth trial of the secondary task. The design of the experiment included a single independent variable defined by the relationship between the letter used in the secondary task to the operation performed before the interruption commenced. There were three experimental conditions: pre-interruption, post-interruption, and random. The *other* condition was not included in the present experiment because letters from outside the acronym did not define any subtasks that could be executed during interruptions and thus the random condition served as the only baseline condition in the present design. The use of three rather than four experimental conditions meant also that participants were now randomly interrupted on average on 9.4% of the sequence task trials. Apart from the details of the secondary task, all other elements of the procedure were the same as in Experiment 1.

Results and discussion

The rates of sequence errors following immediately after interruptions and in four subsequent subtasks are presented in Figure 5. The proportions of those errors on the first trial after interruption was analysed as a function of experimental condition (random, pre-interruption, post-interruption) with a one-way ANOVA, $F(2, 118) = 3.76$, $p = .026$, $\eta^2 = .06$, which showed that these conditions differed from one another. Planned comparisons revealed that sequence error rates in the random condition were higher than either those in the pre-interruption, $t(59) = 2.52$, $p = .015$, $d = 0.325$, or post-interruption, $t(59) = 2.27$, $p = .027$, $d = 0.293$, conditions.

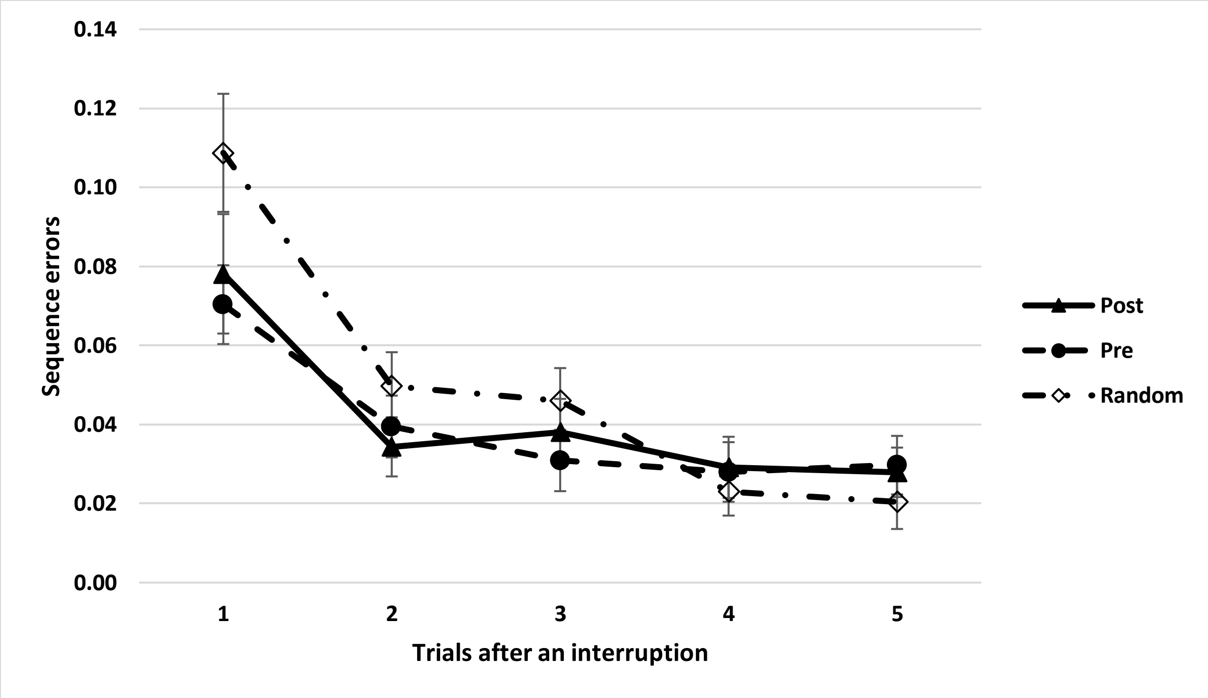

Figure 5. Proportions of sequence errors after resumption of the primary task (out of all responses made after resumption) as a function of experimental condition in Experiment 1. Error bars denote standard errors.

Figure 6 presents a distribution of sequence errors as a function of lag from the correct response. From these, it is clear that distributions for the pre-interruption and random condition peak at lag -1, while the distribution for the post-interruption condition peaks at lag +1. Overall, these distributions are similar to those observed in Experiment 1. They suggest firstly that a reduction of sequence errors in the pre-interruption condition may not be a result of facilitated maintenance in episodic memory, in which case a reduction of lag -1 errors would be expected. Second, they confirm that performing a subtask denoted by a particular letter primes the semantic memory representation of the next subtask in a sequence, which leads to an increased probability of making a lag +1 error in the post-interruption condition, where the goal realised during interruption actually primes the wrong subtask at resumption.

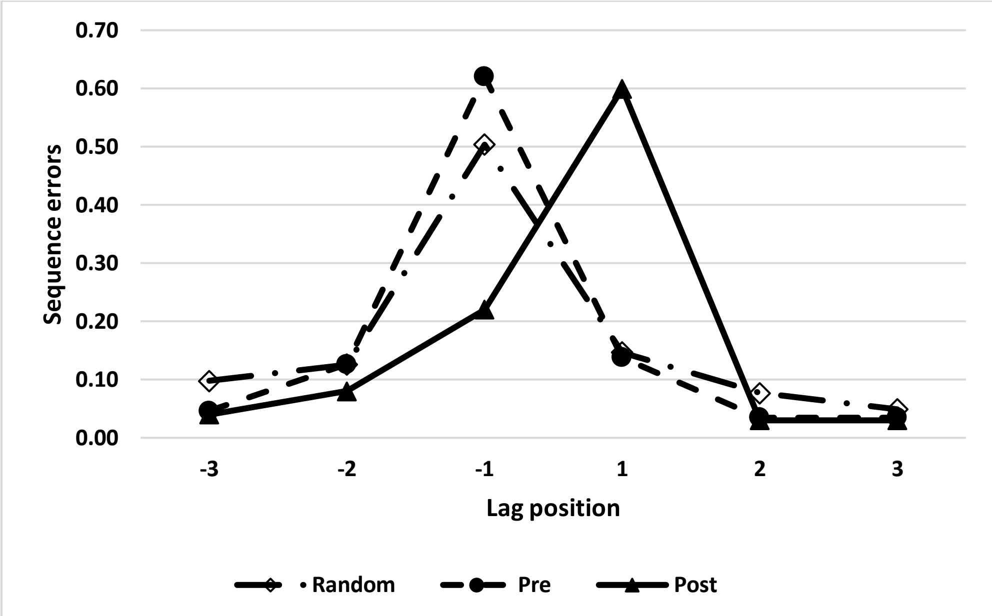

Figure 6. Proportions of sequence errors after resumption of the primary task (out of all sequence errors) as a function of experimental condition and the lag from the correct response in Experiment 2.

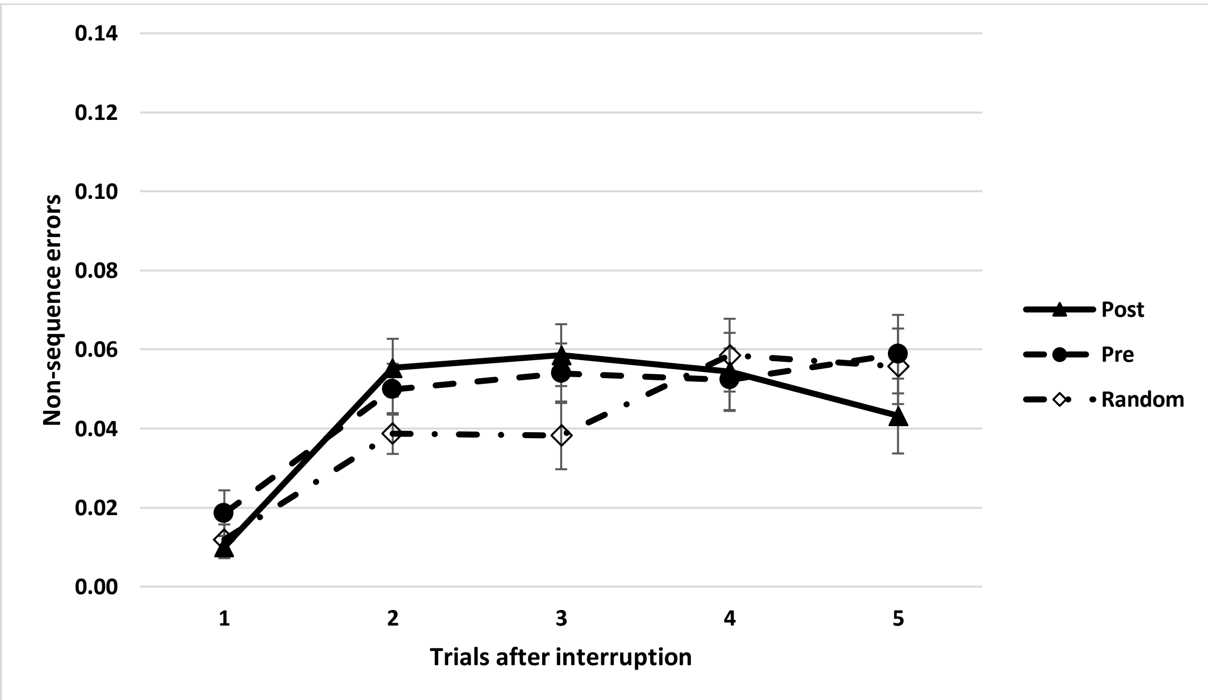

Figure 7. Proportions of non-sequence errors after resumption of the primary task (out of all responses made after resumption) as a function of experimental condition in Experiment 2. Error bars denote standard errors.

Apart from sequence errors, several other dependent variables were also analysed. First, Figure 7 presents non-sequence errors for up to five trials following an interruption. A one-way ANOVA on rates immediately following interruptions showed no differences across experimental conditions, $F(2, 118) = 1.75$, $p = .179$, $\eta^2 = .029$.

Second, we again looked at reaction times for the first subtask after an interruption, with the exclusion of sequence errors (see Table 1), and found that this time, unlike in Experiment 1, they differed across conditions, $F(2, 118) = 6.29$, $p = .003$, $\eta^2 = .096$. Bonferroni-corrected post-hoc tests showed only that reaction times were faster in the post-interruption condition than in either the pre-interruption, $p = .002$, or the random condition, $p = .062$ (with the latter result being non-significant after a Bonferroni correction). One thing to note is that this result differs from the pattern of sequence errors because the reduced rates of sequence errors in the pre-interruption condition – relative to the random condition – were in no way mirrored in the reaction times. Thus, it is not simply that a condition in which lower rates of sequence errors are observed is generally easier, facilitating also faster resumption of the primary task as reflected in lower reaction times. Instead, the facilitation found for the post-interruption condition, i.e., the reduction of errors, may reflect a different mechanism. Based on the model developed by Altmann and Trafton (2015) it is possible to argue that while sequence errors reflect predominantly failures of episodic memory, reaction times reflect the operations of the semantic system, where performing the next subtask of the primary task during the interruption primes the corresponding goal and thus facilitates resumption.

Finally, it is worth noting a difference in methodology between Experiments 1 and 2. While in Experiment 1 the duration of interruptions was set, here the duration of interruptions was determined by the time it took to perform four operations of a particular subtask. Thus, while in Experiment 1 we analysed the number of trials performed in a particular time period, here we analysed the time to complete four trials of the interruption tasks across experimental conditions. Figure 8 presents those results, which were analysed with a 3 (condition) x 4 (trial) ANOVA. This yielded a significant main effect of condition, $F(2, 118) = 23.46$, $p < 001$, $\eta^2 = 0.012$, a significant main effect of trial, $F(3,177) = 234.11$, $p < .001$, $\eta^2 = 0.683$, and a significant interaction, $F(6, 354) = 29.06$, $p < .001$, $\eta^2 = 0.034$. Figure 6 clearly shows that differences across conditions were limited to the first of the four interruption trials, where participants were slower in the random condition than in both the pre-interruption, $p < .001$, and the post-interruption, $p < .001$, conditions. The difference in this trial across the latter conditions was not reliable, p = .068. This slowing in the random condition likely reflects the need to retrieve from memory the task set that differs both from the task set that has been already completed and the next to-be-performed subset, which remains primed. It needs to be noted that this pattern mirrors the pattern observed for sequence errors, which could be taken to suggest that sequence errors following interruptions are more common in the random condition simply due to an additional decay of goals that is a function of slowing down on the first trial of an interruption. While possible, we think this explanation unlikely because the additional time cost observed in the random condition is relatively minor. An approximately 1 second of slowing down on the first trial means that the duration of the entire interruption in the random condition is only about 15% longer than the corresponding durations in the pre- and post-interruption conditions.

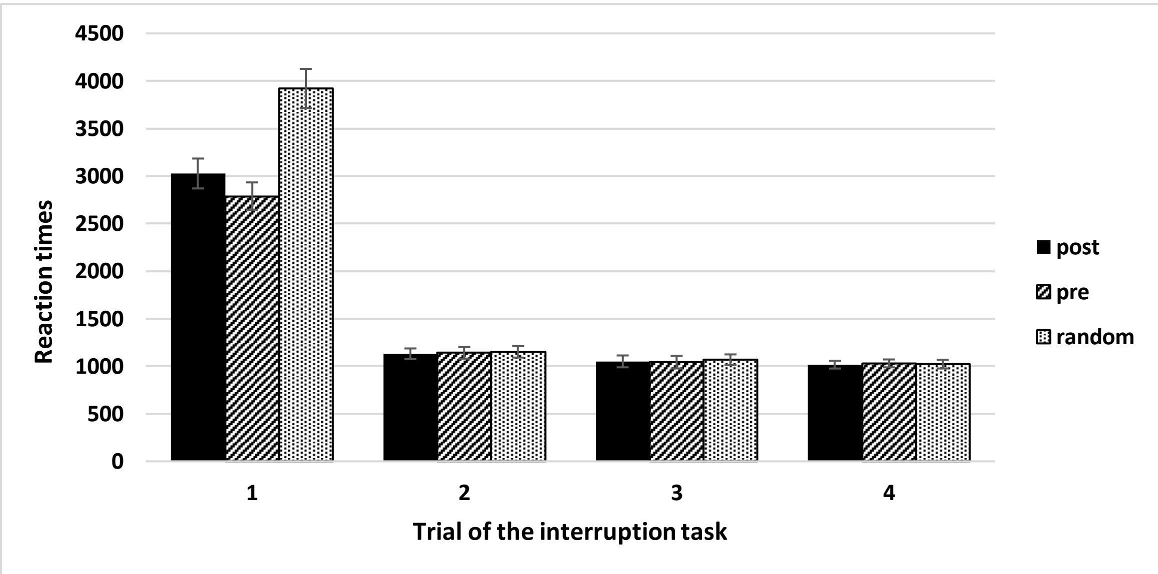

Figure 8. Reaction times in the four trials of the interruption task as a function of the experimental condition – post-interruption, pre-interruption, and random – in Experiment 2. Error bars denote standard errors.

To summarise, here we again hypothesised that similarity across goals maintained for the purpose of performing the secondary task and the last realised goal in the interrupted task would benefit performance when the primary task is resumed by virtue of facilitating episodic maintenance of goals during interruptions. However, the results proved to be largely inconsistent with this prediction. Sequence errors were committed less often when such a match was present in the pre-interruption condition compared to the random condition, where goals used for the interruption task matched a random subtask from the primary sequence task. This pattern would be predicted if processing a certain goal during the secondary task helped maintain it in memory also for the purpose of resuming the main task. However, the same pattern of reduced sequence errors also emerged when goals used for the interruption task matched the operation that needed to be performed at resumption of the primary task in the post-interruption condition, which was not predicted. Moreover, the distribution of errors again showed no reduction in lag -1 errors for the pre-interruption condition, which would expected if retrieval of suspended goals would be facilitated in this condition.

The comparable facilitation of task resumption in the pre- and post-interruption conditions – compared to the random condition – implies one of at least three scenarios. First, participants, when performing the secondary task, could maintain via rehearsal both the pre- and post-interruption operations in episodic memory, in which case similarity of the secondary task goal to either of these operations would have some power of facilitating maintenance. This solution seems overcomplicated, as it is unclear what additional benefit would stem from maintaining two goals compared to a much simpler task of always remembering just the last realised goal. Second, participants could differ in their strategies, with some trying to maintain the just realised operation and some trying to maintain the operation that should be performed at resumption (see Altmann & Trafton, 2015). This solution does not, however, address the issue of the distribution of errors – why there is no specific reduction of lag -1 errors for the pre-interruption condition, which at least for some participants should facilitate goal maintenance. Third, it could also be that it is not that pre- and post-interruption conditions are made easier because the process of episodic maintenance is facilitated for both of them, but that the random condition is particularly difficult because the process of forgetting is exaggerated there. We discuss this possibility in greater length in the General Discussion. Finally, other, more complex scenarios could of course be devised, such as participants rehearsing – if possible – how the task performed at interruption relates to the next subtask to be performed in the primary task (e.g., “next”), and only rehearsing the to-be-performed operation if this is not possible. Ultimately, this issue awaits future research that would additionally probe participants’ strategies.

General Discussion

It has long been known that interrupting a primary task with a requirement to perform a secondary task impairs performance when the primary task is resumed (Hodgetts & Jones, 2006a). Recent years have seen that such impairment can take a form of increased rate of errors in executing a correct operation in a procedural sequence task (Altmann et al., 2014). Here we assessed whether an overlap in goals pursued across interrupted and interrupting tasks modulates such an impairment. We specifically hypothesised that the congruency of goals pursued in the interrupting task on the one hand and maintained in episodic memory in the service of accurate resumption on the other would prove beneficial, preventing forgetting of goals from the interrupted, primary task and thus allowing for a reduced rate of sequence errors when this task is resumed. In two experiments, we used an adaptation of a sequence task used to investigate interruptions (Altmann et al., 2014), where operations are defined by specific letters that together create an acronym specifying a sequence of operations. In this task, we varied the relationship across goals pursued in the secondary, interrupting task and goals defined for the primary sequence task. We found that the rate of errors at resumption was indeed related to the specific goals realised during the interrupting task.

In Experiment 1, we investigated the role of overlap in terms of letters denoting subtasks in the primary sequence task and those used in the secondary task. We found that the rate of errors at resumption was lower when the goal in the secondary task overlapped with the last goal realised in the primary sequence task rather than with a random goal from the sequence. In Experiment 2, we investigated the role of an overlap not only in terms of letters denoting operations but in terms of the operations themselves. Here we found that the rate of errors was again lower when the secondary task goal overlapped with the last goal realised in the primary sequence task rather than with a random goal from the sequence, but we also found the same reduction when this goal of the interrupting task overlapped with the goal that should be realised only after resumption. These results confirm that the contents of the interrupting task – or, more specifically, the relationship of the goals pursued in the interrupting task to the goals of the interrupted task – do matter when the primary task needs to be resumed. However, the pattern of these results does not confirm our initial hypothesis of benefits accruing from a specific overlap between the goal realised just before the interruption and the goal pursued during interruption.

We built our initial hypothesis based on the assumption that the last realised goal before the interruption is rehearsed during interruption and this rehearsal counters forgetting of this goal, preventing errors at resumption. We speculated that this rehearsal process should be facilitated when the same goal – either in the form of a letter denoting an operation in the sequence task (Experiment 1), or in the form of an actual to-be-performed operation (Experiment 2) – would organise performance in the interrupting task. While both experiments did find a reduction of errors in this pre-interruption condition, when compared against the baseline of random goals pursued in the interrupting task, such reduction was not specific: Experiment 2 showed a similar reduction in the post-interruption condition, when goals pursued in the interrupting task overlapped with the next goal, to-be-performed after resumption of the interrupted task. It seems, then, that the reason why some types of goals pursued during interruptions modulate the rate of errors at resumption is not related to a rehearsal process supporting the last realised goal.

Additional evidence against the rehearsal account of our results comes from a pattern of sequence errors participants committed across experimental conditions in both experiments. We expected facilitated rehearsal to reduce the rate of lag -1 errors specifically, which are errors assumed to stem from lapses of maintenance of goals in an episodic memory system (Altmann & Trafton, 2015). This result failed to materialise in either of our experiments, with the pre-interruption condition showing a pronounced peak in terms of sequence errors at resumption precisely at lag -1. It is worth noting that this is not because this measure is insensitive to experimental manipulation. Both experiments showed a pattern of altered sequence errors in the post-interruption condition, where the peak was shifted to lag +1 errors. This we interpret as consistent with the contribution of the semantic system to performance in the sequence task, where realizing the goal of the next subtask during interruptions primes the following subtask, which – when executed – constitutes a lag +1 error.

What is then the reason for changes in task performance at resumption if not the modulation of the rehearsal process? Clearly, the types of goals pursued during interruptions do matter for episodic forgetting of goals of the primary task – the mechanism by which errors arise at resumption (Altmann & Trafton, 2007). It is worth noting, however, that rehearsal is not ubiquitously agreed to be relevant to forgetting. Although there are models of working memory in which rehearsal is deployed to counter forgetting that accrues from decay of representations maintained in working memory (see Camos, 2015, for a discussion), it has also been argued that rehearsal is epiphenomenal and may play no role in modulating forgetting by countering decay (Lewandowsky & Oberauer, 2015). In interference models of forgetting in working memory, forgetting occurs because of interference from concurrent or immediately consecutive stimuli with to-be-maintained memoranda, and in many such models the degree of forgetting is determined by the similarity of memoranda and distractors (Nairne, 1990; Oberauer et al., 2012). Rehearsal plays no role in such models of forgetting because they assume no decay that rehearsal would need to counteract. It is then perhaps worth looking at the interruption task through the lens of interference theory. From this perspective, the issue becomes not why certain goals pursued in the interruption task may support the process of countering decay, but why some such goals cause greater interference than other goals. One possibility is that it is not that in the pre- and post-interruption conditions the maintenance of goals during interruptions is supported, but rather that in the random condition this maintenance is particularly vulnerable to interference.

It is one of the premises of the interference theories that the similarity of memoranda and distractors that cause dislocation of attention from memoranda matters a lot for the process of forgetting (although note that such similarity relationships are not straightforward and have been critiqued elsewhere, Beaman & Jones, 2016). On the one hand, when distractors come from the same domain as memoranda, interference processes are presumed to be exacerbated (Turner & Engle, 1989). Thus, for example, processing letters when letters need to be maintained is more disruptive than processing digits. From this perspective, processing letters from the sequence task during interruptions should be particularly disruptive for memory of goals. While Experiment 1 did have a comparison between the random condition, using such sequence letters in the interruption task, and the other condition, where letters were taken from outside the sequence task, this did not yield a reliable difference in terms of errors at resumption, albeit the means were in the expected direction. Possibly, the manipulation in Experiment 1, with only letters – not operations – overlapping across the interrupted and interrupting task was too weak to reliably demonstrate increased interference for the random condition. Importantly, however, increased similarity across memoranda and distractors does not always exacerbate forgetting. When these are taken from the same domain and presented in close temporal proximity – with distractors immediately following a similar to-be-remembered element – interference may be reduced (Oberauer, 2009; Piątkowski et al., 2022). This is because similar distractors have numerous features overlapping with their respective memoranda and these features become strengthened when a distractor is processed.

The process of strengthening of features overlapping across goals realised in the interrupted task and those pursued in the interrupting task could – on the basis of the interference theory – account for the pattern of reduced errors in the pre-interruption conditions of Experiments 1 and 2. But what about the comparable reduction for the post-interruption condition of Experiment 2? If the already realised goal from the primary task needs to be maintained in memory during interruption, then why would a dissimilar goal matching the next to-be-realised goal interfere less with it despite having no common features? The important point may be here that, according to some versions of interference theory, what is stored in memory are not so much individual features of memoranda but rather bindings (Oberauer, 2019); for example between memoranda and context in which they were presented. Arguably, contexts associated with consecutive letters in a sequence should be highly similar to each other due to repeated processing of the exact same sequence in the course of the experimental task. If interference is understood in its contextual form, then the expected pattern would be that distractors – in this case goals pursued in the interrupting task – should be disruptive for memory of the to-be-maintained goal to the extent to which these goals are similar in terms of their features, defining their domain, but dissimilar in terms of associated contextual features, determined by their position within a sequence. This would account for reduced interference when both goals in the interruption task come from positions nearby from the position of the last realised goal, as compared to other positions from the same sequence.

At this point, the interference account of forgetting of goals due to interruptions remains only a tentative proposal to account for the surprising patterns resulting from the current Experiment 2. The decay-plus-rehearsal model, on which current theorizing about interruptions in the sequence task is based (Altmann et al., 2017), remains a viable framework and specific experiments would need to be devised to explicitly contrast these two approaches. One idea could be to directly test one of the main tenets of interference theory – that varied distractors cause more interference than constant distractors due to stronger contextual bindings of new stimuli (Oberauer & Lewandowsky, 2008). Adapted to the interruption task, the interference theory would thus predict that varying goals pursued during interruptions should lead to more forgetting of the last realised goal in the interrupted task – and thus more errors at resumption – than a repeated pursuit of the same goal. This and other contrasting predictions of decay and interference models of forgetting remain to be tested in future experiments. The conclusion of the present study remains that – although the underlying mechanism is yet to be determined – the disruptiveness of interruption is at least to some extent the function of what goals organise performance of the interrupting task.

Data availability statement

The data that support the findings of this study are openly available on osf at http://doi.org/10.17605/OSF.IO/7Y2ZS.

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	Other	Pre-interruption	Post-interruption	Random
Experiment 1	3305 (195)	3151 (150)	3143 (146)	3188 (153)
Experiment 2	-	2789 (100)	2307 (171)	2632 (124)

Table 1. Mean resumption times – times to perform a subtask immediately after an interruption – as a function of the type of interruption in Experiments 1 and 2. Standard errors of the means are given in parentheses.