Errors in Prospective Memory

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Zusammenfassung
Prospektives Gedächtnis beschreibt die Fähigkeit Intentionen zu einem späteren Zeitpunkt als Reaktion auf einen Hinweisreiz auszuführen. Derartige Aufgaben finden sich zahlreich in Alltags- wie auch Arbeitskontexten, waren aber im Gegensatz zum retrospektiven Gedächtnis lange Zeit nicht im Fokus der Forschung. Erst die Arbeit von Harris (1984) und insbesondere der Artikel von Einstein and McDaniel (1990) wurden Ausgangspunkte eines sich stetig vergrößernden Forschungsfeldes. Aufbauend auf dieser Forschung werden im Rahmen dieser Dissertationsschrift fünf Journal-Artikel präsentiert und verknüpft, die das Verständnis zum prospektiven Gedächtnis durch die Betrachtung von möglichen Fehlern erweitern.

Die erste Studie beschäftigt sich mit der Frage ob zusätzliche kognitiven Ressourcen benötigt werden um eine Intention zwischen dem Hinweisreiz und ihrer Ausführung aufrecht zu erhalten. Die Folgerungen von Einstein, McDaniel, Williford, Pagan, and Dismukes (2003), die eine derartige Aufrechterhaltung vorschlugen konnten nicht repliziert werden. In der zweiten Studie konnte gezeigt werden, dass Unterbrechungen zwischen Hinweisreiz und Ausführung der Intention insbesondere dann negative Folgen zeigen, wenn sie mit einem Kontextwechsel verbunden sind. In den Studien drei bis fünf stand das irrtümliche Ausführen von beendeten prospektiven Gedächtnisaufgaben im Zentrum der Untersuchung. Hier konnte nicht nur gezeigt werden, dass die bisherige Theorie zur Vorhersage derartiger Fehler, die vor allem auf Unterdrückung der Reaktion beruht (Bugg, Scullin, & Rauvola, 2016), mit den Ergebnissen speziell zu deren Prüfung entworfener Experimente nicht zu vereinbaren ist. Darüber hinaus wurde im Rahmen der Untersuchungen eine Modifikation der Theorie ausgearbeitet, die besser geeignet erscheint sowohl bisherige Ergebnisse als auch die hinzugekommenen Experimente vorherzusagen.

Über alle fünf Artikel wird zusätzlich verdeutlicht, dass der Moment in dem der Hinweisreiz präsentiert wird eine noch größere Rolle zu spielen scheint, als durch bisherige Forschung deutlich geworden ist.

Content

Introduction

In everyday life, we frequently have to remember to do something in the future such as sending an urgent email as soon as the meeting is over. Such prospective memory tasks are common and can range from the trivial to vitally important tasks, such as taking or administering medicine. In more abstract terms, prospective memory tasks can be described as an intention, which is associated with a specific cue or time to retrieve and execute the intention (Einstein & McDaniel, 1990). As common as such prospective memory tasks are and as personal experience has taught us, errors in prospective memory tasks are bound to occur. However, as well-known as prospective memory tasks are and as critical as they can be, research on prospective memory was nearly non-existent prior to 1990 (Einstein, 2014; Harris, 1984). Since then research in this area has steadily increased, generating and improving theories (e.g., Einstein et al., 2005; Einstein et al., 2003; Marsh, Cook, & Hicks, 2006a). Due to the importance of prospective memory tasks in day to day activities and in the workplace (Dismukes, 2008; Kliegel, McDaniel, & Einstein, 2008; Marsh et al., 2006a; McDaniel & Einstein, 2007), research also occurred in safety-critical domains such as aviation (Dismukes, 2006; Dismukes & Nowinski, 2007; Dismukes, Young, Sumwalt, & Null, 1998) or in healthcare (Grundgeiger, Sanderson, Beltran Orihuela, et al., 2010; Grundgeiger, Sanderson, & Dismukes, 2014; Grundgeiger et al., 2013) which shows increasing awareness for research in prospective memory errors in these settings.

This thesis presents a series of five papers of experimental research with a focus on provoking and observing error occurrence in prospective memory tasks with the aim to gain a better understanding of prospective memory as a whole. These papers focus on the prospective component of prospective memory tasks, the notion that something has to be done, rather than the retrospective component, specifying what has to be done (Cohen, Dixon, Lindsay, & Masson, 2003). By observing constraints of successful prospective memory performance and by identifying and manipulating factors, which affect this performance, underlying cognitive processes of prospective memory can be better understood. Therefore, to expand the knowledge on prospective memory two different types of prospective memory failures are being considered.

The first type of prospective memory failure, the omission error, are instances where the prospective memory task is not executed in response to the cue, even though it should be (Kliegel, Martin, McDaniel, & Einstein, 2001), such as forgetting to take prescribed medicine after breakfast. Most studies report prospective memory performance rather than omission error as dependent variable. This phrasing is also used throughout this text.

The second type of prospective memory failure is the commission error, an instance where the prospective memory task is no longer active but the intention is still executed in response to a no longer relevant cue (Scullin, Einstein, & McDaniel, 2009), such as taking medicine after the treatment has been discontinued. New insights about mechanisms in prospective memory can be generated by provoking both kinds of errors by applying experimentally established manipulations such as dividing attention by introducing an additional task, as well as devising new manipulations to address specific research questions.

Using both error types as a measure for the influence of different manipulations on prospective memory tasks throughout this thesis, consistent effects in this area of research are demonstrated and integrated to establish empirically sound mechanisms. The main focus of the thesis is a better understanding of the moment of intention retrieval of active as well as no longer active prospective memory tasks and the influence of different manipulations during the delay until the intention can be implemented.

This thesis consists of three major sections: First, a theory section to give an overview of previous research on prospective memory and the derived research questions. Second, the synopsis of the empirical studies to present the specific hypotheses for the subsequent experiments, as well as their methods and results, followed by a brief discussion for each individual study. Within the text, the five presented papers are referenced as Study 1 to 5. Third, the general discussion is used to illustrate the reasoning in the series of conducted studies as well as to address the impact of the conducted experiments and their relevance in relation to previous research. A newly created account for commission error occurrence introduced within the papers is discussed in more detail and future directions for research are presented.

In the following theory section, the general concept of prospective memory is introduced in more detail using a summary of relevant literature on this topic. Concurrent theories on prospective memory as a whole, as well as theories covering certain aspects of the concept are introduced and the accompanying paradigms used within this area of research are presented. Theories and concepts with direct ties to the papers are discussed in more detail while other areas of the field, not covered by the presented research, are only mentioned briefly. Due to the focus of this thesis on experimental data, the theory section is especially focussed on the respective paradigms used in laboratory research.

Prospective Memory

As stated previously, a prospective memory task consists of a prospective component, the notion that something has to be done as well as a retrospective component, specifying what has to be done (Cohen et al., 2003). The instruction to immediately recall several items can therefore not be considered a prospective memory task (Harris, 1984), because there is no prospective component, but only a retrospective one. The prospective component is therefore used as the main distinction of prospective memory from retrospective memory (McDaniel & Einstein, 2007). To be a prospective task, instead of a delay before the execution of a retrospective task, prospective memory tasks are embedded within an ongoing task (Einstein & McDaniel, 1996; McDaniel & Einstein, 2000). In laboratory settings, prospective memory experiments therefore consist of an ongoing task that has to be worked on continuously during the experiment. These tasks are simple with a high frequency of trials, such as lexical decision tasks, colour-matching tasks, or other tasks, which are suited for two-choice input. The prospective memory task is introduced as an additional task such as pressing the “6” key in response to a specific cue (Einstein & McDaniel, 1990). The specific cue used and the associated action are dependent on the experimental paradigm. This, so-called, retrieve-execute paradigm allows for the immediate execution of the associated prospective memory task (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000).

The retrieve-execute paradigm can be considered the most basic type of prospective memory task, in laboratory as well as applied settings. Several of its features are discussed in more detail to demonstrate further assumptions and previous findings on prospective memory tasks. Adaptions of this paradigm are presented with the underlying research questions, which made the adjustment necessary. This process is used to highlight the research questions for this thesis.

The detection of the cue itself is a relevant factor for prospective memory performance (Smith & Bayen, 2006). The cues are part of the ongoing task, i.e., a lexical decision task, but require a prospective memory response, usually a designated key on the keyboard, instead of an ongoing task response. The multiprocess view of prospective memory (McDaniel & Einstein, 2000), which separates prospective memory retrieval in a spontaneous process for focal and salient cues and in a resource-demanding process for nonfocal prospective memory tasks. The multiprocess view is well established in prospective memory research (e.g., Bugg & Ball, 2017; Scullin, McDaniel, & Shelton, 2013; Walser, Goschke, & Fischer, 2014) and is used as a basis for the present thesis. As predicted by the multiprocess view, using focal cues, such as specific words result in better prospective memory performance compared to nonfocal cues such as a specific syllable in a word (Scullin, McDaniel, Shelton, & Lee, 2010). If the cue is nonfocal, prospective memory performance is not only lower, but also associated with increased ongoing task reaction times, which are considered as monitoring costs (McDaniel & Einstein, 2000; Smith, 2003; Smith & Bayen, 2004). These costs occur when participants cannot rely on spontaneous retrieval without costs to the ongoing task, because the relevant feature of the cue for the prospective memory task has to be processed in addition to the ongoing task (Einstein & McDaniel, 2005; Einstein et al., 2005). Even though the multiprocess view has been challenged (e.g., Smith, Hunt, McVay, & McConnell, 2007), it is generally agreed upon in this field of research and supplies an empirically tested theory on the effects of cue focality and salience (McDaniel & Einstein, 2000; Walser, Plessow, Goschke, & Fischer, 2014).

However, as discussed by Einstein et al. (2000) it is often not possible to directly implement the prospective memory task, especially in applied settings (Dismukes et al., 1998; Grundgeiger, Sanderson, MacDougall, & Venkatesh, 2010). Accordingly, the retrieve-execute paradigm was extended to the so-called delay-execute paradigm. This paradigm utilizes highly salient cues such as a red screen, which cannot be missed, therefore the intention should always be spontaneously retrieved as predicted by the multiprocess view of prospective memory (McDaniel & Einstein, 2000). But the execution of the intention has to be delayed until a second condition is met, the so-called window of opportunity, which by itself is no prospective memory cue (i.e., the “6” key has to be pressed after the screen turns red, but only after the question type of the ongoing task changed). All interpretation as well as possible processes after the cue can therefore be based on the notion that the intention has been successfully retrieved (Einstein et al., 2000) and subsequent processes such as maintenance of a retrieved intention can be manipulated (Einstein et al., 2000). Einstein et al. (2003) suggested the active maintenance view, which states that the intention has to be periodically activated during the delay to be executed during the window of opportunity, by depending on strategic retrieval and contextual cueing. Strategic retrieval is considered as a resource-demanding process, which searches the memory for unfinished intentions such as the prospective memory task (Einstein et al., 2003; Ellis, 1996; Kvavilashvili, 1987). Contextual cueing describes an association between the intention that has to be executed and the ongoing task, this association is formed as soon as the cue is observed (Einstein, McDaniel, Smith, & Shaw, 1998; Marsh, Cook, & Hicks, 2006b; Nowinski & Dismukes, 2005). This idea is in line, but not identical to the influence of task context as shown by Cook, Marsh, and Hicks (2005). However, some studies showed an increase in the reaction time of the ongoing task trial directly after the cue, which has been classified as intention retrieval (Ball, Knight, Dewitt, & Brewer, 2013), an orientation reaction in response to a salient stimulus (Walser, Fischer, & Goschke, 2012), or an resumption lag caused by a very brief interruption (Monk & Kidd, 2008). Intention retrieval, orientation reaction and resumption lag have not yet been assessed and compared within a single study. Especially if the intention is retrieved and reformulated as suggested by Ball et al. (2013), no active maintenance of the intention would be predicted.

The active maintenance view (Einstein et al., 2003) and the retrieve and reformulate view (Ball et al., 2013) are addressed and empirically tested in Study 1. The influence of possible manipulations during the retrieval are discussed in more detail in the subsequent section on omission errors.

Omission Errors

Research with the delay-execute paradigm has shown that delaying the intention by as little as ten seconds lowers prospective memory performance significantly. However longer delays of up to 40 seconds did not result in significantly worse prospective memory performance compared to the 10 seconds delay (Einstein et al., 2000). The prospective memory performance in this paradigm is considered resource dependent (Kliegel & Jäger, 2006; McDaniel, Einstein, Stout, & Morgan, 2003).

Einstein et al. (2003) showed that more omission errors occurred if a divided attention task was active during the delay between the prospective memory cue and the window of opportunity. There was also a decrease in ongoing task accuracy during the delay. It should be noted that the accuracy is descriptively lower in all delay conditions (5, 15, 40 seconds) but the largest difference is observed in the five second delay condition (Einstein et al., 2003; Experiment 2 and 3). Due to the aforementioned effect of the salient cue on ongoing task reaction times, the errors in the ongoing task might have been caused by the salient cue rather than by active maintenance of the intention. In combination with a divided attention task, participants have to coordinate ongoing task, divided attention task and the prospective memory task at the same time. This experimental situation is not suited for parallel multitasking (Fischer & Plessow, 2015) and should result in delays or errors in the ongoing task due to the additional load due to coordination of the tasks. To replicate the effect of divided attention and to allow for a more selective manipulation of the cognitive load than used by Einstein et al. (2003) we conducted Study 1, in which the cognitive load was manipulated either by an additional task or by a change in the time available for each ongoing task trial.

The introduction of the delay-execute paradigm allowed for a better fit between applied settings and the laboratory to investigate highly demanding prospective memory tasks. In example, delays between cue and window of opportunity are common for nurses in different situations in their workplace (Ebright, Patterson, Chalko, & Render, 2003; Tucker & Spear, 2006). In addition to the delay itself, interruptions in the ongoing task during the delay are common in applied settings (Biron, Lavoie-Tremblay, & Loiselle, 2009), but the influence of these interruptions on prospective memory performance has mainly been demonstrated in laboratory experiments (Cook, Meeks, Clark-Foos, Merritt, & Marsh, 2013; Trafton & Monk, 2007). Grundgeiger, Sanderson, MacDougall, et al. (2010) showed that interruptions during the delay between prospective memory cue and window of opportunity in real life settings are often handled differently. Nurses have been shown to use three different strategies to cope with interruption. First, acknowledging, such as giving the reading on a monitoring device without stopping the ongoing task. Second, multitasking, such as giving a report to a doctor while preparing a set of tools for an operation. Third, interrupting the ongoing task, such as stopping the preparation of tools and helping a colleague to lift a patient. The strategy used is either chosen by the nurse or is dictated by the respective context.

This selection might be influenced by interindividual differences, as suggested in the study by Ball et al. (2013), which suggested that working memory capacity acted as a moderator on prospective memory performance in interrupted trials. Participants with higher working memory capacity had better prospective memory performance, extending the finding that working memory capacity affects delayed intentions (Einstein et al., 2000). In addition there is some indication that the effect of forced interruptions can be counteracted by an external reminder (McDaniel, Einstein, Graham, & Rall, 2004) or by informing participants in advance about the context for intention implementation (Cook et al., 2013).

A next meaningful step in understanding the effect of interruptions on prospective memory tasks in applied settings is to test if the three observed strategies to cope with interruptions (acknowledging, multitasking, and interrupting) can be used in laboratory settings. To further differentiate the effect of interruptions, we tested the effects of three distraction types (acknowledging, multitasking and interrupting) as observed in a clinical setting (Grundgeiger, Sanderson, Beltran Orihuela, et al., 2010) on prospective memory performance in Study 2.

Commission Errors

In contrast to omission errors where an action is erroneously not executed, commission errors are instances in which the action is executed even though the prospective memory task should no longer be executed (Scullin, Bugg, & McDaniel, 2012; Scullin et al., 2009; Walser et al., 2012). To observe commission errors in laboratory settings, participants are instructed about an ongoing task as well as a prospective memory task. This prospective memory task is subsequently instructed to be no longer relevant using three different manipulations. However, former prospective memory cues still occur during the ongoing task, which allows to detect commission errors. To this end, the prospective memory task can be declared as being (1) suspended, indicating that the task is still relevant but should not be executed in the phase of the experiment with former prospective memory cues, increased reaction time was observed for the former prospective memory targets (Scullin et al., 2009). The prospective memory task can also be declared (2) cancelled, instructing the participants that the prospective memory task should no longer be executed before a prospective memory cue has been presented during the ongoing task. Finally, the prospective memory task can be declared (3) finished, allowing execution of the prospective memory task before participants are instructed to no longer react to the prospective memory cue. Using the retrieve-execute paradigm, several studies have been conducted to compare the effect of these manipulations as well as other influences on commission error occurrence, as described below.

The most consistent effect found is that a significantly larger proportion of participants make at least one commission error if the prospective memory task has never been executed, compared to participants who executed the prospective memory task (Bugg & Scullin, 2013; Scullin & Bugg, 2013; Scullin et al., 2012). Cancelling the prospective memory task directly after the instructions, or showing no prospective memory cue before in the ongoing task before declaring it finished (Bugg & Scullin, 2013; Bugg et al., 2016), has been considered in terms of the Zeigarnik effect (Zeigarnik, 1938). However, as shown by Bugg and Scullin (2013), the Zeigarnik effect is not suited to explain this effect, because commission errors still occurred in response to a previously not presented target, after the intention could be executed to a second target. The tension of not executing the intention should have been resolved by the reactions to the presented target and therefore not promote commission errors for the not presented target.

The finished instructions appear to facilitate deactivation of the prospective memory task, as reduced or no aftereffects are found, compared to suspended or cancelled instructions (Scullin et al., 2009). The decrease in aftereffects for finished prospective memory tasks appear not to decrease with time, but with repeated exposure to the no longer relevant cue (Walser et al., 2014). This finding was extended to the occurrence of commission errors by Scullin and Bugg (2013), finding no differences in commission error occurrence after a short delay between the finished instructions (40 trials) and a long delay (258 trials). Several studies report no commission errors at all after finished instructions (Bugg & Scullin, 2013; Experiment 1 and 2; Scullin, Bugg, McDaniel, & Einstein, 2011; Scullin et al., 2009; Experiment 2). However, other studies from the same laboratories found nearly a quarter of participants making commission errors (Scullin & Bugg, 2013), and more than a third of participants in a sample of older adults (Scullin et al., 2012) or even two thirds in another sample of older adults (Bugg et al., 2016; Experiment 1). However, even though the ratio of participants with commission errors after finished instructions varies (Bugg, Scullin, & McDaniel, 2013; Scullin et al., 2012; Scullin et al., 2009), the number of participants with commission errors after cancelled instructions reliably increases by a similar degree (Bugg et al., 2013; Bugg et al., 2016) and therefore produce a very consistent difference between both manipulations.

The mechanism why the cancelled and finished instructions result in differences in commission error occurrence has not yet been agreed upon. It appears necessary to investigate the process in more detail, especially in regard to the retrieval of the process and possible failures of intention inhibition (Bugg et al., 2016).

In addition to the influence of different instructions for the prospective memory task, such as declaring it finished or cancelling it, other instructions also affect commission error occurrence. Bugg et al. (2013) reported more commission errors after finished instructions in young as well as older adults after using implementation intentions for the prospective memory task, compared to standard prospective memory and finished instructions. In contrast, Bugg et al. (2016) used a novel strategy referred to as forgetting practice in which participants were presented with former prospective memory cues and practiced to give an ongoing task response. Using forgetting practice resulted in nearly no commission errors for finished prospective memory instructions. Relative to significantly higher commission rates for the same experimental design and material within the same paper, but not within one experiment (Bugg et al., 2016). This result can partly be explained by the decreasing aftereffects of no longer relevant intentions (Walser et al., 2014), which can be considered as an indicator for deactivation. However, this training might also affect commission error occurrence because the instruction to not execute the intention has been repeated and processed several times.

Based mainly on the differences found between younger and older adults the dual mechanism account was proposed (Bugg et al., 2016; Scullin & Bugg, 2013), which suggested a two-step mechanism for commission errors to occur. First, the intention associated with the prospective memory task is spontaneously retrieved in response to the salient cue. Second, the action has to be suppressed in a resource-demanding process. If this suppression fails, the intention is executed and a commission error occurs. The primary role of suppression is based on the study by Scullin et al. (2012), reporting significantly lower scores in a compound measure for inhibition ability in older adults making commission errors, compared to older adults without commission errors. It should be noted that this effect could not be replicated in a later study (Bugg et al., 2013) and has not been tested in younger adults. The aspect of spontaneous retrieval of no longer active intentions is in line with the multiprocess view (McDaniel & Einstein, 2000). However, it remains unclear if the retrieval can be influenced by other factors. The dual mechanism account predicts that the prospective memory task as well as the intention are spontaneously recalled and can only be prevented from execution by inhibition processes. The results of Bugg et al. (2016) could not conclusively show if a warning that irrelevant cues still occur can significantly affect commission error occurrence.

The subsequent idea behind Study 3 was threefold. First, to transfer the experimental setup and manipulations used to observe commission errors from the retrieve-execute paradigm to the delay-execute paradigm. By introducing a delay between cue and window of opportunity this setup enables a first direct test of the dual mechanism account, as the delay could be used to suppress the execution of the no longer relevant prospective memory task. Second, this paradigm shift also allows to record a type of reaction time, which could not be meaningfully measured and interpreted in the retrieve-execute paradigm, the ongoing task reaction time for the cue and subsequent trials, which are normally masked by the commission error itself. Finally, this delay enabled the use of interruption or divided attention manipulations between cue and window of opportunity (which were also used in Study 1 and 2) which allows to test if these manipulations also affect commission errors occurrence. An interesting aspect of provoking commission errors in this paradigm is that in contrast to delay-execute prospective memory tasks, the intention is not predicted to be maintained as proposed by the active maintenance view (Einstein et al., 2003). However, the intention is predicted to be spontaneously recalled by the dual mechanism account (Bugg et al., 2016) and the multiprocess view (McDaniel & Einstein, 2000).

In Study 4 a different approach was used to test the predictions of the dual mechanism account within the retrieve-execute paradigm. If suppression of the intention is critical for commission error occurrence (Scullin et al., 2012), then a short delay after cue presentation should be sufficient for suppression and should therefore result in fewer commission errors. This proposition is based on studies showing that such a response lag as short as 400ms can remove focality effects in prospective memory tasks (Loft & Remington, 2013). The idea is further supported by J. R. Simon, Acosta, Mewaldt, and Speidel (1976) and Hubner and Mishra (2013), showing that delays of less than 500ms can be sufficient to suppress irrelevant stimuli for a Simon task (J.R. Simon & Wolf, 1963). By forcing participants to delay their input even longer, using one or two seconds, we can examine whether this response lag is used by the participants to suppress the execution of the no longer active prospective memory task, as predicted by the dual mechanism account (Bugg et al., 2016).

Finally, in Study 5 two manipulations with the aim to increase commission error occurrence within the retrieve-execute paradigm were implemented. The experiment was set up to test the predictions of the dual mechanism account against the predictions of a modified dual mechanism account which was established in Study 4.

In this experimental setup, the commission error rate should be increased based on predictions of the dual mechanism account (Bugg et al., 2016) by allowing slips of hand to cause a commission error once the cue appears, by using a key configuration which should prevent any chance to suppress the intention after the cue occurs. In contrast to the rather deliberate input in previous prospective memory research i.e., to move a finger from the arrow-keys to the letter “Q”, which might take enough time to suppress the erroneous intention successfully, the setup in Study 5 allowed the execution of the commission error by a twitch of a finger. The second manipulation used was an additional counting task to increase cognitive load, which was also used in Study 1 and 2 to influence prospective memory performance as well as commission error occurrence in the delay-execute paradigm in Study 3. The results of Study 4 were used to propose a modified dual mechanism account for commission error occurrence, which is also taken into account in Study 5. The account itself and its relevance to prospective memory research and prior research are described in more detail in the discussion section of this thesis as well as in the respective articles. An overview of all studies is given in Figure 1.

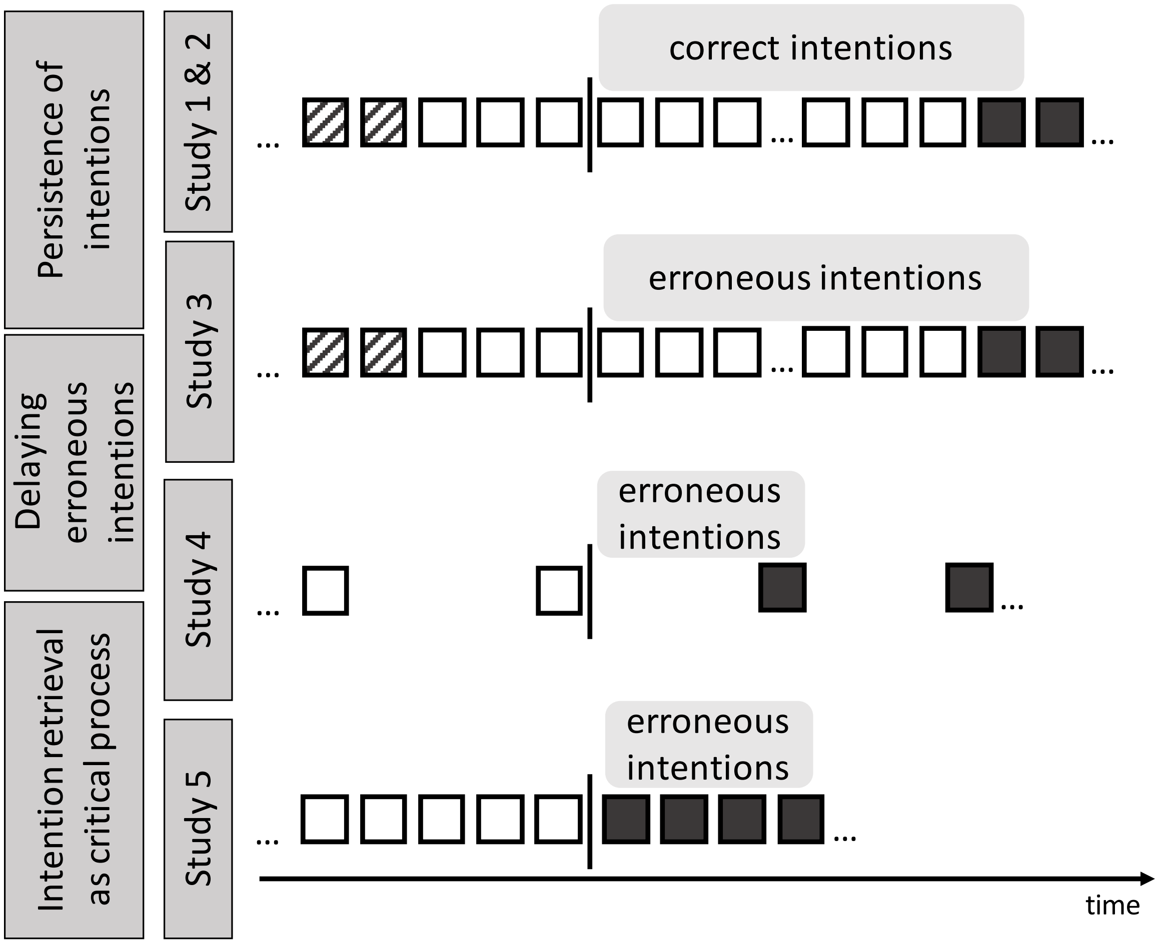

Figure 1. Overview of the overarching research questions for Study 1 – 5 and their respective simplified paradigms. Squares represent ongoing task trials, if colored in grey they contain the window of opportunity to execute the (no longer relevant) prospective memory task. The vertical lines represent the prospective memory cue.

Synopsis of empirical studies

Study 1: Assessing the role of active maintenance in the delay-execute paradigm using different cognitive load manipulations

Research question

Einstein et al. (2003) showed the potentially negative influence of an additional task on prospective memory performance and suggested the idea of a resource-demanding active maintenance process during the delay between cue and window of opportunity. Study 1 was conducted to compare the predictions of this active maintenance view and the retrieval-and-reformulation view (Ball et al., 2013). We implemented different methods of increased cognitive load manipulations to observe their effect on prospective memory and ongoing task performance. With the aim to show, that even with the use of a more sensitive measure and analysis compared to (Einstein et al., 2003), the intention is not actively maintained but reformulated after cue presentation. The predictions for the reaction time patterns in the ongoing task are shown in Figure 2.

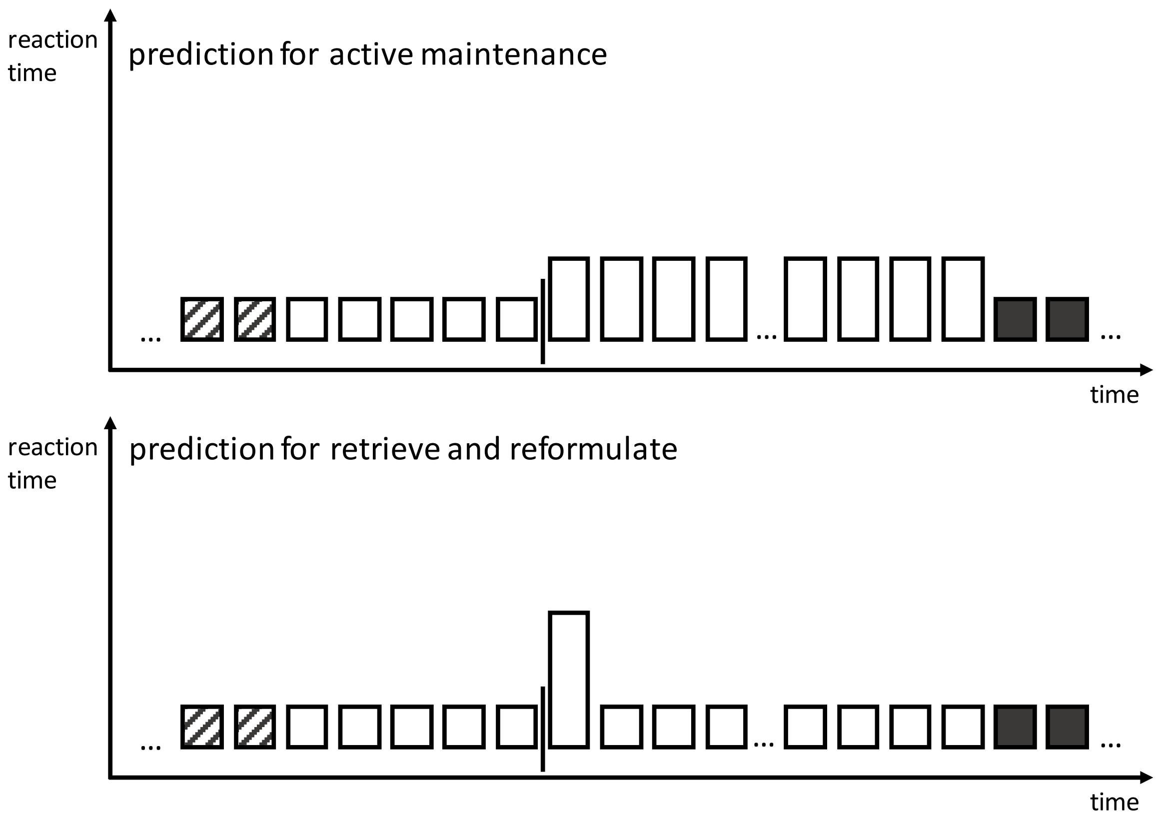

Figure 2. Predictions of ongoing task reaction times based on active maintenance view and retrieve and reformulate view. Squares represent ongoing task trials, their height the expected relative change in reaction time.

Study

In two experiments, we compared the performance in a standard delay-execute prospective memory task against two different manipulations with increased cognitive load. For the first manipulation, we used an additional counting task to divide attention in the ongoing task blocks with a prospective memory cue. This manipulation was realized in Experiment 1 and 2, with a more difficult divided attention task in the latter. For the second manipulation, used in both experiments, the time available for each ongoing task trial was reduced from five to three seconds for the entire experiment in one experimental group. In this manipulation the overall duration for each part of the experiment was the same as in the other groups, resulting in a higher frequency of trials within the same time frame relative to the other groups, which should increase cognitive load. Experiment 2 was a replication of Experiment 1 with a more demanding divided attention task.

For Experiment 1 a fourth group also worked on the ongoing task with divided attention task, but was not instructed about the prospective memory task and told to ignore the red screens, which served as prospective memory cue for the other groups. This No-prospective memory group allowed comparisons of orientation and startle reactions in response to the salient cue without possible intention retrieval.

In Experiment 1, we observed no difference in prospective memory performance between the three groups with a prospective memory task, with a mean prospective memory hit rate of about 90%. All four groups, including the No-prospective memory group showed significantly slower reactions to the ongoing task trial following the red screen. However, the subsequent trial (i.e. the second ongoing task trial after the red screen) did not differ significantly from the trial prior to the red screen.

The results were replicated in Experiment 2 with no significant differences in prospective memory performance between the groups and an identical pattern for the reaction times in the ongoing task following the prospective memory cue. We proposed that the pattern in ongoing task reaction times is not only an indication of no active maintenance of the intention during the delay, but also an indication of a retrieval and reformulation process of the prospective memory task. The retrieval and reformulation process appears to be additive to the reaction time increase in the No-prospective memory group due to orientation or startle reactions. The consistent reaction time pattern can be considered as an indication for retrieval and reformulation (Ball et al., 2013), however there was no decline in prospective memory performance as suggested by the active maintenance view (Einstein et al., 2003).

Overall, the results indicate that even small differences in the manipulations might affect prospective memory performance, as the negative effect on prospective memory of a divided attention task during the delay and the window of opportunity as reported by Einstein et al. (2003) was not replicated. The effect was not observed in Experiment 1 and 2 when the divided attention was only active up to the window of opportunity, which might have served as an additional cue to execute the intention. The effect of both manipulations on the ongoing task accuracy was also inconsistent across both experiments, indicating that the cognitive resources were not sufficiently reduced to affect prospective memory performance. The main result of Study 1 is the consistent reaction time pattern following the prospective memory cue, which seems to be relevant for retrieval and reformulation of the intention.

Discussion

Study 1 indicated that the intention is not actively maintained during the delay as suggested by Einstein et al. (2003); instead, a significant increase in reaction time only for the ongoing trial directly after the cue was observed. This delay is assumed to be an effect of reformulating the intention (Ball et al., 2013) to allow for spontaneous recall during the window of opportunity, in addition to a reaction time increase due to an orientation (Walser et al., 2012) or startle reaction (Monk & Kidd, 2008) to the salient cue. Contrary to the observation by Einstein et al. (2003), who reported lower prospective memory performance when a divided attention task was active during the delay and the window of opportunity, this effect was not observed in Study 1. This difference might have been caused by the fact that the divided attention task was only active up to the window of opportunity serving as a cue to execute the intention. Finding this conflicting result does not only show the importance of replication as a scientific concept, but also highlights that prospective memory processes appear to be influenced by the timing of manipulations such as divided attention. The manipulation of divided attention, as well as the observed pattern for reaction times following the cue were therefore further investigated in the subsequent studies.

Study 2: The effects of different distractions on remembering delayed intentions

Research question

Because there was no significant influence of a divided attention task on prospective memory performance in Study 1, which might have been caused by the timing of the onset and end of the additional task, the original manipulation of Einstein et al. (2003) as well as other manipulations, derived from applied settings were used in Study 2. The underlying idea of the experiments was to quantify the negative influence of these manipulations on prospective memory performance and to incorporate the idea that a change of context due to an additional task might decrease prospective memory performance.

Study

In Experiment 1a and 1b of Study 2, we tested the effect of three different distractions types (acknowledging, multitasking, and interrupting) derived from applied settings (Grundgeiger, Sanderson, Beltran Orihuela, et al., 2010) on prospective memory task performance in a within-design using the delay-execute prospective memory paradigm. Acknowledging did not significantly lower prospective memory performance in both experiments. Multitasking during a part of the delay between cue and window of opportunity lowered prospective memory performance significantly compared to the baseline condition in Experiment 1a. Interrupting participants during the delay between cue and window of opportunity resulted in even worse prospective memory performance compared to multitasking as well as compared to all other conditions.

Due to the negative influence of interruptions on prospective memory performance, we addressed the change of context that is inherently different in the interrupting condition compared to the acknowledging and multitasking manipulations in Experiment 2. Participants worked on a prospective memory task, which was either combined with or without interruption during the delay as within-factor. Context change was manipulated between groups either using a pen and paper interruption as in Experiment 1a and 1b in the context change group, or working on a digital version of the same task on a second screen in the group without context change. We found the predicted interaction of context change and interruption but no main effects for the factors.

As in the previous studies, an analysis of the reaction time in the ongoing task trial directly following the cue and the subsequent trial showed a significant increase in ongoing task reaction time and a return to the level prior to the cue. As before, this pattern was considered to show an indication that no active maintenance occurred during the delay, but instead that retrieval and reformulation of the prospective memory task took place.

In summary Experiment 1a and 1b showed negative effects of different distraction types on prospective memory performance, especially if interruptions occurred during the delay between cue and window of opportunity. Surprisingly this effect, which has been reported in other studies (e.g., Einstein et al., 2003; Monk, Boehm-Davis, & Trafton, 2002) could not be replicated in Experiment 2, even though we observed the predicted interaction effect of context change and interruption. The absence of the interruption effect might be attributed to differences in interrupting task performance but cannot be considered conclusive.

Discussion

The results of Study 2 showed that different distraction types as observed in applied settings (Grundgeiger, Sanderson, MacDougall, et al., 2010), diminish prospective memory performance differently. In contrast to Study 1 the result of lower prospective memory performance during multitasking could be replicated by using the same timing for the multitasking manipulation as Einstein et al. (2003). Especially noteworthy was the significantly worse prospective memory performance after an interruption during the delay between cue and window of opportunity relative to other distraction types. By further investigating the influence of context change during an interruption we found a significant interaction, showing that an interruption with a change of context lowered prospective memory performance more, relative to an interruption with no context change.

Combined with the results of Study 1 the proposal by Einstein et al. (2003) that the degree of context change might affect prospective memory performance, was supported. In this line of reasoning, an additional digital monitoring task, even though it increases the cognitive load, might lower the degree of context change during the delay relative to an interruption with divided attention. The additional task can therefore serve to minimize context change and therefore prevent a decline of prospective memory performance, which would have been predicted due to increased cognitive load (Ball et al., 2013; Einstein et al., 2003; Kliegel & Jäger, 2006; McDaniel et al., 2004; Rendell, Vella, Kliegel, & Terrett, 2009). The additional task might also serve as a cue for the window of opportunity if the end of the additional task and the window of opportunity overlap, which occurred in Study 1.

The increase in reaction time for the ongoing task trial directly after the cue was once again observed and showed the same pattern as in Study 1, further contradicting the active maintenance view. The distraction types, due to their later onset in Study 2, did not affect the proposed reformulation of the intention. Interestingly the distractions still lowered prospective memory performance, but only in Experiment 1a and 1b when the context was changed. This indicates that the intention to execute the prospective memory task can still be influenced by manipulations during the delay, even though it was reformulated following the presentation of the cue. Even though the analysis of reaction times in Study 1 and 2 did not support the active maintenance view (Einstein et al., 2003), the newly formed intention still appears to be susceptible to interruptions, especially with a change of context.

Study 3: Commission errors in delay-execute prospective memory tasks

Research question

Study 1 and 2 focussed on the occurrence of omission errors in prospective memory and potential influences on their occurrence by investigating the influence of different cognitive load manipulations as well as context change. For Study 3 we transferred research questions and established results from the retrieve-execute paradigm into delay-execute prospective memory tasks. The main aim was to replicate the reaction time pattern observed in prospective memory tasks in response to a no longer relevant cue as well as to test whether an interruption during the delay increases or lowers commission error occurrence. We were also interested to see if commission errors would occur at all in this paradigm, due to the long delay (45 seconds) between cue and the window of opportunity to execute the prospective memory task.

Should commission errors occur, we aimed to replicate the main effect from retrieve-execute commission error research, finding more participants making a commission error after the prospective memory task has been cancelled, relative to a group, which executed the prospective memory task and was subsequently told that it was finished (Figure 3). This shift in paradigm would also allow to test the predictions of the dual mechanism account directly, due to the delay between cue and window of opportunity.

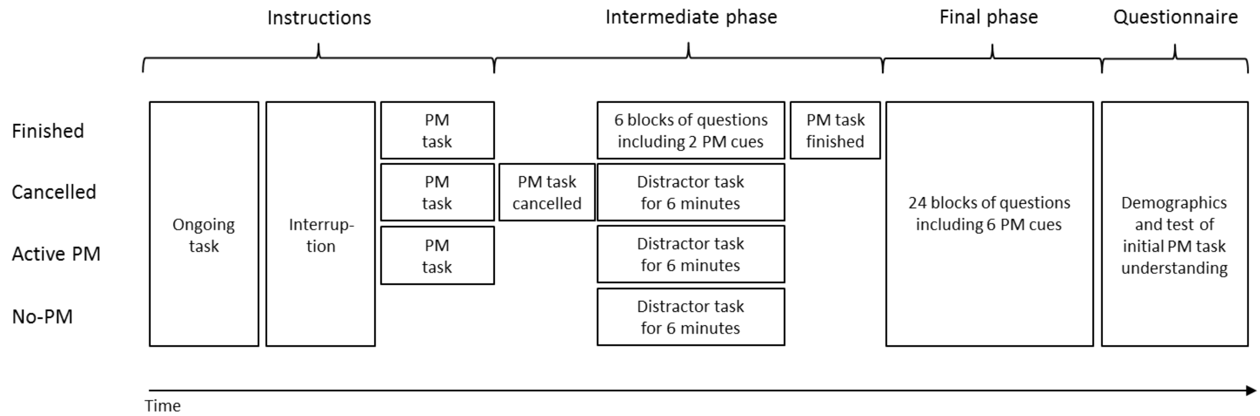

Figure 3. Design and procedure of Experiment 1 in Study 3.

Study

In Experiment 1, we not only observed that commission errors occurred at all, which by itself is surprising given the delay between cue and window of opportunity. A higher percentage of participants making commission errors after the prospective memory task was cancelled, relative to a group with a finished prospective memory task. Commission errors within the cancelled group occurred significantly less if an interruption occurred during the delay. The prospective memory performance in the group with active prospective memory task was descriptively better without the interruption.

In addition, the pattern for ongoing task reaction times after the former prospective memory cue indicated a startle or orientation reaction in the group with the finished prospective memory task and the group without prospective memory task, but additional increases in reaction time in the group with active and with cancelled prospective memory instructions. These similarities in response time patterns in prospective memory performance as well commission error occurrence suggest a similar mechanism for retrieval, reformulation and implementation.

In Experiment 2, we replicated the effect of more participants with commission errors in the cancelled prospective memory group relative to the finished prospective memory group. For the interruption manipulation the same pattern as in Experiment 1 was observed. Prospective memory performance was significantly better in the active prospective memory group for the cues without an interruption, while in contrast significantly fewer commission errors were committed for the cues with an interruption in the cancelled and finished groups.

The reaction time result patterns for the groups with active, cancelled and finished instructions were also replicated and a significantly higher increase in reaction time in the cancelled condition relative to the finished condition was observed. As a further research question, we introduced a divided attention manipulation to a group with cancelled and with finished prospective memory instructions, therefore reducing cognitive resources available during the entire phase of the experiment with no longer relevant prospective memory cues. This manipulation resulted in close to zero participants with commission errors in both groups. The participants with commission errors made these significantly more often if no interruption occurred during the delay.

Overall both experiments indicated that commission errors consistently occur in the delay-execute paradigm and are similarly affected by cancelled and finished instructions as reported in retrieve-execute prospective memory tasks. The analysis of reaction times showed that the prospective memory task is at least partially deactivated for participants with finished instructions, showing significantly lower increases in ongoing task reaction time compared to groups with an active or cancelled prospective memory task (Figure 4).

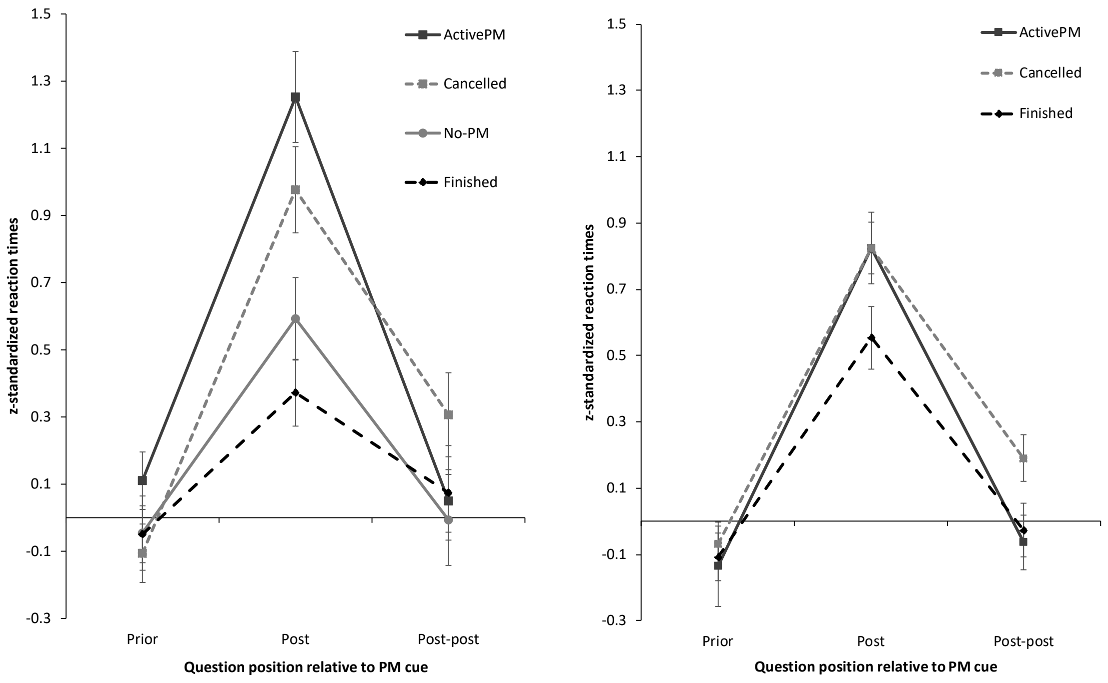

Figure 4. Z-standardized reaction times of Experiment 1 (left) and 2 (right) in Study 3, separated by question position relative to the PM cue (prior, post, post-post) and PM task status (finished, cancelled, active PM, No-PM). Error bars represent SE.

We reduced available cognitive resources during the phase with no longer relevant prospective memory cues by adding a divided attention task. This manipulation resulted in fewer participants with commission errors in the group with cancelled as well as in the group with finished instructions relative to the groups without an additional task.

Discussion

In Study 3 the delay-execute paradigm was used to investigate commission errors by declaring the prospective memory task as cancelled or finished, while still presenting the former prospective memory cues during the ongoing task. The idea behind this change from prospective memory performance to commission errors was based on the research question to investigate if the delay-execute paradigm could even be used to explore commission errors and apply similar manipulations as used in Study 1 and 2. In addition, the reformulation of the intention following the cue would be of particular interest in commission error research as the deactivation of the no longer relevant intention might be observed, even if no commission errors would have been committed during Study 3.

However, foremost and surprisingly, commission errors occurred despite a delay of 40 seconds between the former cue and the window of opportunity. In addition, significantly fewer participants made commission errors after they executed the prospective memory task and were told it was finished relative to participants, who were told that the prospective memory task was cancelled without executing it. Prior to this study, this effect has only been examined and reported in retrieve-execute prospective memory tasks (Bugg & Scullin, 2013; Scullin et al., 2012). As seen in Study 1 and 2 an increase in reaction time in the ongoing task trial following the cue can be interpreted as retrieval and possible reformulation of the intention as suggested by Ball et al. (2013). This pattern was also observed for no longer relevant cues in Study 3, but in addition could be used to differentiate between the groups with cancelled and finished instructions. In the cancelled condition, the increase in reaction time was significantly higher compared to the finished condition. The increase in the group with finished instructions did not significantly differ from a group without a prospective memory task, which was also realised for this study due to the results of Study 1. Finding the same reaction pattern in both groups further supports the idea that the increase is partly caused by an orientation (Walser et al., 2012) or startle reaction (Monk & Kidd, 2008).

However, the higher increase in the cancelled group can be interpreted as erroneous retrieval and reformulation of the intention, which precedes the commission errors during the window of opportunity. Because there was no significant difference in the pattern of the group with cancelled instructions relative to a group with an active prospective memory task, this result shows clear parallels to the retrieval reported in Study 1 and 2. Overall, we concluded that the prospective memory task is still active for the group with cancelled instructions and subsequently recalled and reformulated after the cue (Ball et al., 2013). In contrast, the participants in the finished group either partially deactivated the prospective memory task as suggested by Walser et al. (2012) or even deactivated it completely as reported by Scullin et al. (2009) and Marsh, Hicks, and Bink (1998). It has to be noted that, as in the retrieve-execute paradigm the occurrence of errors cannot be solely attributed to the respective manipulations. These results contradict the dual mechanism account and indicate that the moment of intention retrieval is more critical to commission error occurrence than a subsequent phase in which suppression could occur.

As additional manipulation, we therefore used a divided attention task, similar to Study 1 and Study 2 for a group with cancelled and a group with finished prospective memory instructions. Due to the effects of reduced cognitive resources on prospective memory performance it appeared sensible to transfer this manipulation to commission errors in the delay-execute paradigm. Contrary to results from retrieve-execute prospective memory tasks (Bugg et al., 2013; Scullin et al., 2012) we found no increase in commission error occurrence, but significantly fewer participants in the cancelled condition with divided attention relative to the group without additional task, the same pattern was found descriptively in the finished group. This pattern is similar to the effect of interruptions on prospective memory performance in Study 1 and 2. For an active prospective memory task the interruptions lowered the prospective memory performance, but in turn also lowered commission errors occurrence.

Therefore, the apparent influence of spontaneous retrieval and susceptibility of the reformulated intention by distractions during the delay, as formulated for prospective memory tasks in the discussion for Study 2, is mimicked in commission error occurrence as indicated by the results of Study 3.

Even though the effect of more participants with commission errors after cancelled relative to finished instructions appears to be robust across paradigms, this effects fails to explain why only a part of the participants within the groups actually commits commission errors.

Study 4: Commission errors with forced response lag

Research question

Finding commission errors in the delayed-execute paradigm in Study 3 indicated that the delay of 40 seconds between cue and window of opportunity was not used to suppress the execution of the prospective memory task, contrary to the predictions of the dual mechanism account. To further test the dual mechanism account we introduced a new type of manipulation in commission error research by implementing a short response lag before input is possible for every trial. This manipulation should significantly lower commission error occurrence by creating an opportunity to suppress the action, because the failure to suppress the intention, as introduced by the dual mechanism account, should not occur, due to the additional time available solely for the suppression process.

Study

Three experiments were conducted in the retrieve-execute paradigm, either allowing for an instant response after an ongoing task question, or using a response lag of one (Experiment 1) or two seconds (Experiment 2 and 3) before the answer choices were shown and input was accepted by the system. Based on the dual mechanism account, participants should have enough time to suppress the execution of the intention, which should result in no commission errors in the groups with response lag (Figure 5).

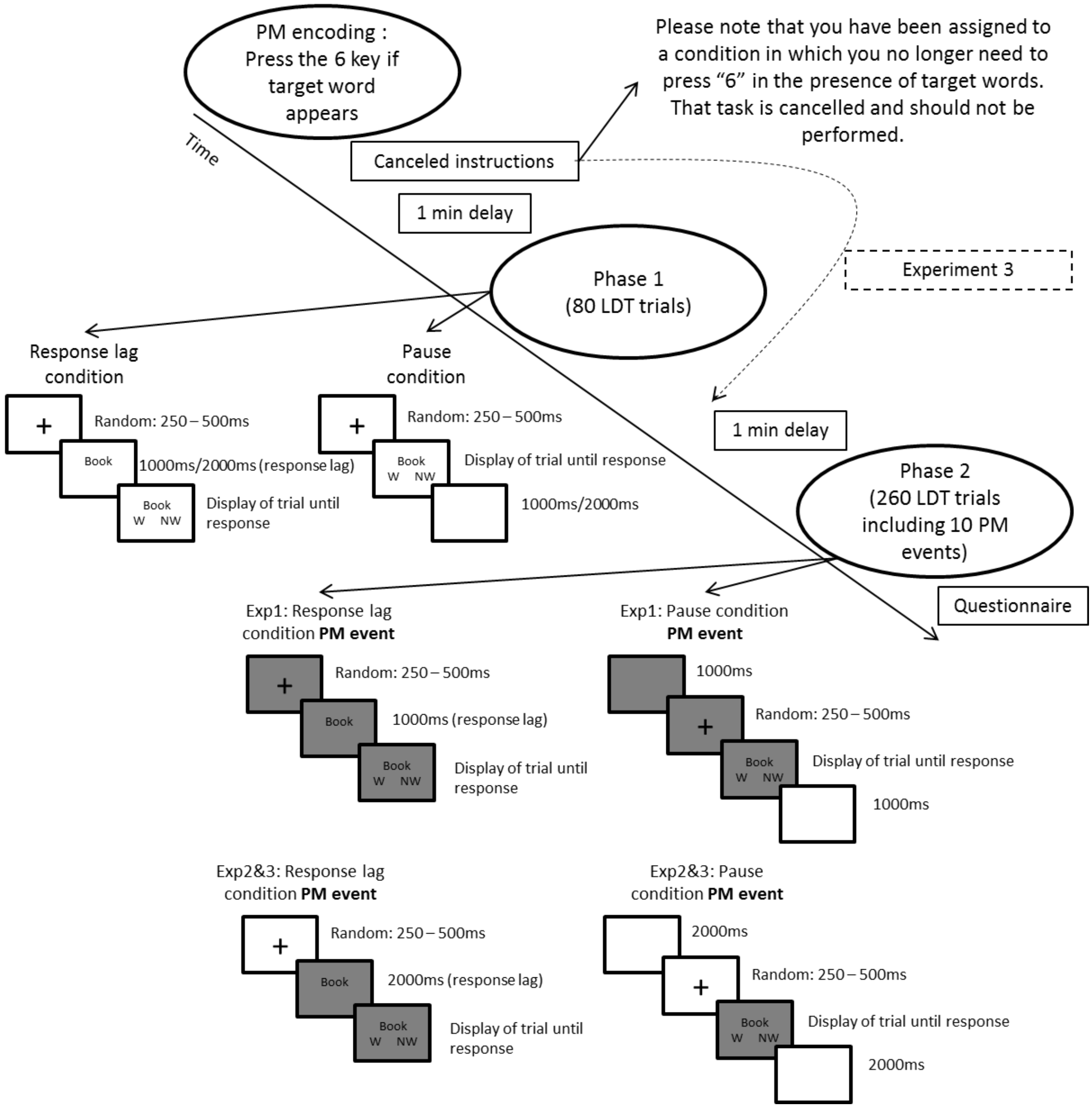

Figure 5. Design and procedure of Experiment 1, 2, and 3 in Study 4.

In Experiment 1, we used two groups with cancelled prospective memory instructions, allowing either an instant response or allowed responses only after the response lag had passed. Contrary to the dual mechanism account, commission error rates in both groups did not differ significantly, even after removing all participants making errors during the response lag. Ongoing task reaction time and accuracy showed significantly better results for the response lag group, indicating that the additional time was used to improve ongoing task performance, but not for the suppression of the former prospective memory task.

To elaborate on the previous results the experiment was repeated, but the response lag was extended to two seconds in Experiment 2, to allow additional time for suppression. The third group with response lag and finished prospective memory instructions was added to validate the research by replicating the effect of commission error differences between cancelled and finished instructions. The results matched those of Experiment 1 with no significant differences in commission error occurrence between both cancelled groups and better ongoing task performance in the response lag group. There were no commission errors in the group with finished instructions and response lag, replicating the aforementioned effect, while ongoing task performance was significantly better than in the cancelled group without response lag.

Experiment 3 was a direct replication of Experiment 2, but the study was conducted online to allow for a larger sample. By increasing sample size in both cancelled groups, the problem of insufficient power to find a difference in commission error occurrence between both groups could be addressed. The group with finished instructions was also realized to test if the effect of more commission errors after cancelled relative to finished instructions could be replicated in a less controlled setting. We found no difference between both cancelled groups and even a descriptively higher proportion of participants with commission errors in the response lag group compared to the group without response lag. The effect of fewer commission errors after finished instructions was also replicated. In addition, the pattern of better ongoing task performance in terms of reaction times and accuracy in the response lag groups was replicated as well.

In summary, the predictions of the dual mechanism account did not match the results for commission error occurrence in all three experiments. While the ongoing task performance was significantly better in all groups with a response lag of one or two seconds, this additional time did not significantly reduce commission error occurrence. We formulated a modified dual mechanism account of commission error occurrence, which suggests an additional tagging process during the retrieval of the intention. This tagging process is dependent on the cognitive resources available during spontaneous retrieval of the intention. The intention can be tagged as “not to be executed” if sufficient cognitive resources are available, but is tagged as “to be executed” if cognitive resources are insufficient. We propose that this mechanism contributes to commission error occurrence and is well suited to address the results of Experiment 1 to 3 as well as several other findings, which were not in line with the dual mechanism account.

Discussion

Study 4 was set up to follow up on the differences between the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013) and the results obtained in Study 3, by using the retrieve-execute paradigm. The main aspect of the dual mechanism account, failed suppression of the intention as the prerequisite for a commission error, did not match the results of commission errors being implemented 40 seconds after the no longer relevant cue in Study 3.

By introducing a response lag manipulation, which consisted of a fixed delay (one or two seconds) before the experimental setup reacted to input for the ongoing task, suppression of a no longer relevant prospective memory task should have been possible according to the dual mechanism account (Bugg et al., 2016). The response lag was selected to be longer than the delay used by Loft and Remington (2013) which was sufficient to remove focality effects in active prospective memory tasks. This suggests that there should have been enough time to (erroneously) retrieve the intention but also for further processing and, critically, suppression of the intention. This reasoning is also supported by the results of J. R. Simon et al. (1976), showing that the influence of an irrelevant cue can be suppressed with a very short delay in a

Simon task. With a response lag as short as 200ms cognitive resources could be allocated to consistently remove the effects of irrelevant cues, as long as the response lag is predictable (Hubner & Mishra, 2013).

Finally, the significantly better performance in the ongoing task in terms of speed and especially accuracy in the groups with response lag relative to the groups, which could answer instantaneously, demonstrates that the participants used the response lag in favour of the task, instead of just waiting for the lag to pass.

To account for these results we suggest a modified dual mechanism account of commission error occurrence, which cannot only explain the reported effects but is also consistent with most other commission error research, as discussed in more detail in the general discussion. This account extends the dual mechanism account by a critical phase in the moment of retrieval, which is dependent on the available cognitive resources during retrieval. The intention is spontaneously retrieved but an additional tagging process of the intention in correspondence to available cognitive resources takes place. The intention is correctly tagged as “not to be executed” if sufficient cognitive resources are available, but if cognitive resources are low, the intention is incorrectly tagged as “to be executed”. The important aspect of this tag is, that it appears to be relatively stable over time, which would account for errors with the response lag manipulation, but also for commission errors in the delay-execute paradigm in Study 3.

The dual mechanism account only considered the ability to suppress an intention as relevant to prevent commission errors, even though only one study could show this effect in older people (Scullin et al., 2011), which could not be replicated in a subsequent experiment (Bugg et al., 2013). The idea of inhibition ability as a relevant predictor for commission errors is based on higher commission error rates in older relative to younger adults (Scullin et al., 2011), even though inhibition ability was not compared between both age groups within the study. For the modified dual mechanism account, interindividual differences are also considered, due to the proposed dependency on cognitive resources of the tagging process.

Study 5: The role of response suppression in the occurrence of commission errors: The effect of divided attention and response ease

Research question

For Study 3 and 4 the dual mechanism account predicted a decrease in commission error occurrence for certain manipulations, which did not match the empirical data. To this end, a modified dual mechanism account was proposed in Study 4, which should be directly compared to the dual mechanism account. Therefore, Study 5 was set up in a way, in which the dual mechanism account predicts an increase in commission error occurrence in two groups, while the modified dual mechanism account predicts an increase in only one of the groups. This comparison is therefore more meaningful to test both accounts than an additional replication of the previous results.

Both accounts predict higher commission error rates with a divided attention manipulation. However, the dual mechanism account predicts more commission errors for a, so-called, slip manipulation, in which a twitch of the thumb is sufficient to cause a commission error, because there is not enough time to suppress the execution of the intention (Figure 6). The modified dual mechanism account does not predict more commission errors for this manipulation because the intention will not be set to be implemented due to enough cognitive resources available in the moment of retrieval.

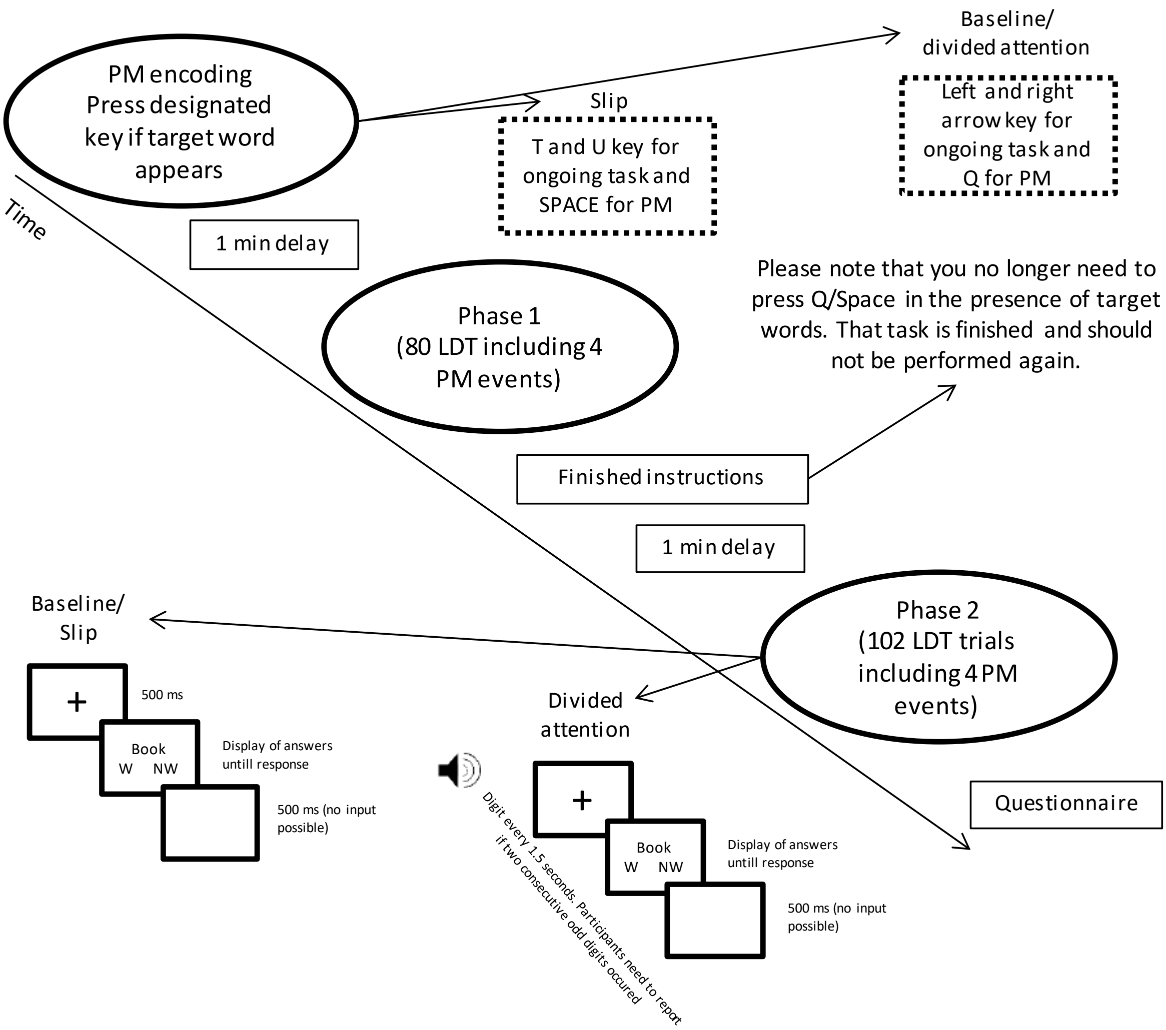

Figure 6. Design and procedure of Study 5.

Study

Three experimental groups were set up, in which the participants worked on the same ongoing and prospective memory task, which was first executed and later declared finished. The baseline group used both hands on the arrow keys of the keyboard to work on the ongoing task, and the “Q” key for the prospective memory task. The slip group used both hands on the “T” and “U” keys for the ongoing task and the SPACE bar for the prospective memory task, resulting in their thumbs resting on the prospective memory key during the experiment. The divided attention group worked on a digit counting task during the experiment using their non-dominant hand, but used the same keys for ongoing and prospective memory task as the baseline group.

Commission errors occurred significantly more often in the divided attention group compared to both other groups, while these did not differ in commission error occurrence. These results further support the modified dual mechanism account and indicate that commission errors are less dependent on failed suppression but are instead influenced by the cognitive resources available during the spontaneous retrieval of the intention.

Discussion

The study was conducted to allow a more direct comparison of the dual mechanism account to the modified dual mechanism account. Finding significantly more participants with commission errors when divided attention was added during the phase with the no longer relevant cue matched the predictions of both theories. The dual mechanism account predicted more commission errors, because the suppression process is considered resource dependent (Scullin et al., 2011). The modified dual mechanism account predicts more commission errors because the tagging process of the intention does not tag the no longer relevant intention as "not to be executed" if cognitive resources are low. When introducing the slip condition, in which a twitch of the thumb would result in a commission error, we could find no increase in commission errors, which contradicts the dual mechanism account. As the input could be given instantaneously participants should have executed the intention before the inhibition process could suppress it. The modified dual mechanism account predicted no increased commission error rate as the tagging of the intention occurs in combination with the spontaneous retrieval of the intention.

General Discussion

The present thesis used errors in prospective memory to infer on cognitive processes to remember intentions. In a series of five studies, omission errors in delay-execute prospective memory tasks and commission errors in the delay-execute as well as in the retrieve-execute paradigm were investigated. Each study, with the exception of Study 5, consists of at least two experiments aiming to replicate previous results as well as to extend the respective research question. By investigating the occurrence of both error types, as well as performance in the ongoing task in terms of reaction times and accuracy, established theories from the concurrent literature such as the active maintenance view (Einstein et al., 2003) and the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013) were empirically tested. Some effects from previous studies could be replicated across paradigms, such as the effect of more participants with commission errors after cancelled relative to finished instructions (Study 3 to 5), while other theories such as the active maintenance view were not supported (Study 1). The implications of the combined results of all conducted studies for the theory on prospective memory are presented in this section. Especially the newly proposed modification of the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013) established in Study 4, which can be considered the main contribution of this thesis to the field of prospective memory research, is discussed in more detail.

Theoretical implications for prospective memory and omission errors

Einstein et al. (2003) proposed the active maintenance view, which suggested that in a prospective memory task an intention is spontaneously recalled in response to a salient cue, but has to be actively maintained during a delay between cue and window of opportunity. The reaction times in Study 1 and Study 2 did not match this predicted pattern. Instead, a significant increase only for the ongoing task trial directly after the cue was found in both studies. There was no indication that active maintenance occurred in Study 1 and 2, which also holds true for Study 3 when observing commission errors.

However, across all three studies a significant increase in ongoing task reaction time was observed in the trial directly following the cue. Finding no indication for active maintenance is in line with the results reported by Ball et al. (2013), who also reported the pattern of slowing immediately after the cue but not for the rest of the delay. The pattern of increased reaction time can partly be explained by an orientation reaction (Walser et al., 2012) and resumption lag (Monk & Kidd, 2008) due to the salient cue which also very briefly interrupts the execution of the ongoing task, as observed in the conditions without prospective memory instructions in Study 1 and 3. However, the retrieval of the prospective memory task itself also affects the differences in this reaction time increase after the cue, as clearly indicated by the results of Study 3. We found that the increase in ongoing task reaction time was significantly lower when no prospective memory task was introduced compared to the increase when a prospective memory task was active. We consider this as an indication that the tagging of the intention, as proposed by the modified dual mechanism account, is responsible for the delay.

Finding no active maintenance but instead the increase in reaction time after the cue indicates that the intention is spontaneously retrieved, due to the salient cue, and appears to be reformulated to be implemented during the window of opportunity as suggested by Ball et al. (2013). This would explain why the increase is higher with an active prospective memory task relative to a manipulation, which never received prospective memory task instructions. Because the window of opportunity, which is indicated by a change in ongoing task type, can also be considered to be a salient cue and therefore requires no monitoring (McDaniel & Einstein, 2000), allows to retrieve the reformulated intention spontaneously. This distinction is highly relevant, because depending on the difference between tasks the window of opportunity might be less salient and might even require monitoring. This possible increase in ongoing task reaction times could be erroneously interpreted as active maintenance of the intention.

Considering the results of Study 1 to 3 as well as the results by Ball et al. (2013), the idea of active maintenance as suggested by Einstein et al. (2003) has to be reconsidered. When observing the data described in the experiments by Einstein et al. (2003) in more detail, it has to be noted that they only used one ongoing task trial between cue and window of opportunity in one condition and claimed active maintenance during this trial. This increase in reaction time for one trial can be considered essentially identical to the presented results, supporting spontaneous retrieval and reformulation. A similar case can be made for the second condition used within the study by Einstein et al. (2003). In this condition, there were only three ongoing task trials between cue and window of opportunity. Using the mean of only three trials could result in an overall increase in mean reaction time due to an increase in the trial following the cue, instead of active maintenance and increased reaction times for all three trials.

However, these conclusions are limited by the restrictions of the delay-execute paradigm which uses salient cues and window of opportunity. Instances in which monitoring for e.g., a nonfocal cue is necessary (Einstein et al., 2005; McDaniel & Einstein, 2000) might show a different pattern of reaction times. For this type of cue monitoring processes and overall increases in reaction times are established (Strickland, Heathcote, Remington, & Loft, 2017), but a similar reaction time analysis for the observed steep increase after the cue has, to our knowledge, not been conducted.

Other established findings were also reconsidered in relation to the conducted experiments. This is especially evident when considering the failed replication of lowered prospective memory performance in reaction to divided attention tasks in Study 1. The effect was reported by Einstein et al. (2003) and replicated in Study 2, while the effect was absent in both experiments of Study 1. The influence of a potential context change, which has been shown to be relevant for prospective memory performance in Study 2, has been discussed in more detail in the respective study. However, the same pattern and problem with added divided attention were also observed for interruptions during the delay. With the exception of Experiment 2 in Study 2 all presented studies showed, that an interruption during the delay reduced the probability of implementing the intention, either correctly as in Experiment 1 of Study 2 and Study 3, or incorrectly as a commission error as seen in both experiments of Study 3. Finding no indication for active maintenance while interruptions during the delay still affect the implementation of an intention, combined with the issues described for divided attention, clearly shows that several core aspects of prospective memory performance even in laboratory settings are not yet completely understood.

With the multiprocess view (McDaniel & Einstein, 2000) the detection of the cue itself in regard to spontaneous retrieval and monitoring processes appears to be well suited to predict experimental results. However, even though prospective memory performance is nearly perfect in retrieve-execute prospective memory experiments (Einstein et al., 2003), the main problem is to explain the influence of manipulations during the delay if the active maintenance view is not supported. Because the presented studies, as well as the cited literature, show a negative influence of different distraction types, but as no indication of active maintenance was found, this process could not have been impaired by the manipulations. Therefore it is necessary to further refine the previously presented idea that the intention is retrieved and reformulated following the cue and is to be spontaneously recalled during the window of opportunity.

The varying influence of different distraction types during the delay between cue and window of opportunity (Study 1), which appears to differ not only due to possibly different cognitive demands, but also to experimental manipulation of context change (Study 2), indicates that the intention can be influenced during the delay. Implementing a delay results in significantly lower prospective memory performance, but at the same time, there is no effect of the length of the delay as reported by Einstein et al. (2000) and in the first Experiment of Study 2. This decrease might be due to an error in retrieving and reformulating the intention. If the intention is correctly retrieved and reformulated, as indicated by the significant increase in ongoing task reaction time directly after the cue, as reported by Ball et al. (2013) and as observed in Study 1 and 2, this reformulated intention therefore appears to be stable over time, as long as no distractions occur.

The degree to which manipulations during the delay might influence this intention is inconsistent across the presented studies, which prevents a straightforward explanation of all results. First, there was no effect of an additional divided attention task on prospective memory performance, when the additional task was active during the entire prospective memory block, including cue presentation and until the window of opportunity (Study 1). As mentioned in the discussion of the respective study, it could be argued that the end of the divided attention task served as an additional cue to execute the intention. This proposition would be in line with the observation of lower prospective memory performance, if divided attention only occurred during a part of the delay and could not serve as a cue (e.g., Einstein et al., 2003). However, based on the idea that prospective memory performance in the delay-execute paradigm is generally dependent on cognitive resources (Kliegel & Jäger, 2006; McDaniel et al., 2003), an added divided attention task should also impair the suggested retrieval and reformulation. To explain the non-significant difference between performance with and without divided attention, the benefit of serving as an additional cue would have to be equal to the impairment caused by the added cognitive load. Additional testing for underlying mechanisms is therefore needed. A first simple step would be the replication of the experiment in Study 1 and changing the timing of the divided attention task, to compare a stop of the divided attention task before the window of opportunity occurs, a stop with the window of opportunity, and a stop after the window has passed.

Using interruptions only during the delay in Study 2 also showed inconsistent effects with a significant decrease in prospective memory performance in Experiment 1a and 1b, but no effect in Experiment 2. Even though context change was suggested and empirically supported as one mechanism to explain differences in prospective memory performance, no concurrent model or theory in prospective memory research can account for the presented results.

Overall, the presented studies empirically tested predictions of suggested mechanisms in prospective memory research and showed that the active maintenance account is not in line with the current results. The importance of the spontaneous retrieval and reformulation as suggested by Ball et al. (2013) is supported and matched by the results of Study 1 and 2, as well as the active prospective memory group in Study 3. If the active maintenance view is incorrect, a new mechanism is needed to explain the influence of distractions during the delay. The results of varying decrease in prospective memory performance due to different distraction types as well as the observed influence of context change in Study 2 might be a relevant step.

Theoretical implications for commission errors

The experiments of Study 3 were set up to test if the apparent retrieval and reformulation processes, as observed in Study 1 and 2, could also be observed for no longer relevant prospective memory tasks. To this end, the delay-execute paradigm was also used in Study 3 to investigate commission errors and was subsequently the first paper in commission error research to show that commission errors also occur in the delay-execute paradigm. The subsequent finding of commission errors despite the delay was a first indication that the dual mechanism account (Bugg et al., 2016) was not suited to explain commission error occurrence within this paradigm. The dual mechanism account was further tested in the subsequent Studies 4 and 5 and is discussed in more detail below.

The initial question of spontaneous retrieval and possible reformulation could also be addressed by the results of Study 3. Due to the occurrence of commission errors an even more detailed comparison than initially expected based on the predictions of the dual mechanism account was possible (Bugg et al., 2016). First, the initial increase in reaction time in the ongoing task, directly following the cue for an active prospective memory task, which was consistently observed in Study 1 and 2 was replicated. Second, the orientation or startle reaction following the salient cue as discussed in Study 1 was also replicated. Third, the effect of more commission errors after cancelled instructions relative to finished instructions from the retrieve-execute paradigm (Bugg & Scullin, 2013; Scullin & Bugg, 2013; Scullin et al., 2012) was also replicated. Fourth, by combining both previous results, the slowing after the cue was stronger for cancelled and active prospective memory tasks relative to finished or non-existing prospective memory task instructions, and therefore preceding commission error occurrence on group level. These results match studies demonstrating complete or partial deactivation for finished prospective memory tasks (Scullin et al., 2009; Walser et al., 2014).

Overall these results show that active maintenance, as suggested by Einstein et al. (2003), is also not supported in commission error research but that the idea of spontaneous retrieval and reformulation by Ball et al. (2013) also extends to no longer relevant intentions. A similar mechanism of retrieval and reformulation for active as well as for cancelled prospective memory tasks appears probable, while in contrast finished prospective memory tasks appear not to be recalled in response to the cue.

Consequently, the moment of spontaneous retrieval as well as the subsequent reformulation process also have to be considered in relation to the dual mechanism account (Bugg et al., 2016). The response lag manipulation in Study 4 showed no indication that more suppression occurred to prevent commission errors relative to a group without the response lag. Because spontaneous retrieval should have occurred in response to the salient cue

(McDaniel & Einstein, 2000), it appears that the response lag was used for reformulation and subsequent execution of the intention instead of for suppression.

Based on the results of Study 3 and 4 it can be argued that the reformulation is executed automatically following spontaneous retrieval after cancelled prospective memory instructions, while the intention appears not to be deactivated (Walser et al., 2014). This automated sequence might explain why the intention is executed even in the delay-execute paradigm. If the process is deliberate, the additional time should be long enough to integrate the fact that the prospective memory task is no longer active. The moment of spontaneous retrieval, therefore, appears to be primarily critical in active as well as in no longer active prospective memory tasks.

In Study 4, the added response lag did not result in fewer commission errors, and in Study 5, easier access to the key for the prospective memory task did not increase commission errors. As addressed in the discussion section of the respective studies it can be argued that suppression, which should have been affected by both manipulations (Scullin et al., 2012; Scullin et al., 2011), is not a good predictor for interindividual differences in commission error occurrence. This reasoning is in line with the previously discussed importance of the moment of retrieval, in comparison to possible subsequent processes such as suppression.

Therefore, other predictors for commission error occurrence should be considered which could be meaningfully tied to the moment of retrieval. These factors might be relevant to prospective memory performance as well as for commission error occurrence and might help to explain why the respective manipulations of laboratory experiments can explain only a part of the variance within prospective memory performance or commission error occurrence. There have only been a few studies, which attempted to relate prospective memory performance to other traits besides the ability to inhibit (Scullin et al., 2012). Working memory capacity has been previously linked to prospective memory performance (Ball et al., 2013; Kliegel, McDaniel, & Einstein, 2000), with higher working memory capacity being associated with better prospective memory performance. In turn, this trait might also be relevant for no longer relevant intentions.

Given that working memory capacity declines with age (Hedden & Gabrieli, 2004), this measure allows the same line of reasoning as given by Scullin et al. (2011) to classify inhibition ability as the predictor for commission errors. Considering the idea that working memory capacity is more likely to have an effect on the erroneous retrieval and reformulation instead of previously proposed suppression this trait appears to be suited to explain the reported effects in commission error occurrence in Studies 3 to 5, as well as results from other publications.

A second potentially relevant trait could be state orientation, which has also been previously linked to prospective memory performance (Kaschel, Kazen, & Kuhl, 2016). The increased aftereffects of completed intentions in participants with state orientation compared to action orientation participants (Walser et al., 2014) might also be relevant in commission error research. A first indication might be the differences in aftereffects between participants with cancelled and finished instructions in Study 3.

State and action orientation could also be of interest when trying to explain the established effect of more commission errors after cancelled, relative to finished instructions. Even though this effect is well established (Bugg et al., 2013; Bugg et al., 2016; Scullin et al., 2012), the paper by Bugg and Scullin (2013) differentiated this finding from the Zeigarnik effect (Zeigarnik, 1938), but could not distinctively identify the underlying process. However, because state-oriented individuals should recall the cancelled instruction more easily (Kuhl, 1992), commission errors would be more likely. Alternatively, both traits, working memory capacity as well as state or action orientation, might have to be considered simultaneously and it might require more cognitive resources for state-oriented individuals to correctly tag the intention as “not to be executed”, while action-orientated participants would tag the intention correctly with fewer resources available.

As described in more detail in Study 4, previous research has to be considered in light of the modified dual mechanism account. The difference in commission error occurrence between older and younger adults has already been addressed in terms of the modified dual mechanism account, but the differences in commission error occurrence within older adults based on an inhibition score (Bugg et al., 2013; Scullin et al., 2011) have to be discussed in more detail. Finding a low commission error rate in participants with higher inhibition score is directly in line with the dual mechanism account, but this result can also be considered congruent with the modified dual mechanism account. Because working memory capacity and the ability to suppress intention is correlated (e.g., Kane & Engle, 2003; Rosen & Engle, 1998) the described difference might be attributed to the difference in working memory capacity. Even if the ability to inhibit was different between the groups, it was not causal for the difference in commission errors. This reasoning would also account for the aforementioned failure to replicate a difference in commission error occurrence in older adults based on the inhibition ability (Bugg et al., 2013).

In the study by Pink and Dodson (2013) more commission errors were found in finished habitual prospective memory tasks when a digit-monitoring task taxed cognitive resources. This result is therefore in line with the modified dual mechanism account, but also with the dual mechanism account, which implies that the former might also apply to habitual prospective memory tasks.

However, it has to be noted that one result presented in Study 3 is incongruent to the predictions of the dual mechanism account as well as the modified dual mechanism account. The divided attention manipulation, which resulted in increased commission error rates in the retrieve-execute paradigm as presented in Study 5 showed an opposing effect in the delay-execute paradigm. This conflicting result can therefore not be accounted for by current theories and should be subject to further investigation. Potential experiments are outlined below.

Overall, the presented results stress the relevance of the moment of retrieval, which is represented in the suggested tagging mechanism in the modified dual mechanism account. The presented process can account for previous as well as the current results, except for the aforementioned inconsistency in Study 3. The view proposes that the amount of cognitive resources during spontaneous retrieval is critical for a tagging process, which either correctly tags the intention as “not to be executed” or sets it as “to be executed”. The account considers working memory capacity as the main dependent factor, but there might also be a dependency on state versus action orientation. As discussed throughout the text the modified dual mechanism account should be considered as a more suitable mechanism to explain the observed effects, which is better suited than the dual mechanism account but needs to be further refined and tested, especially in terms of the newly introduced traits working memory capacity and state orientation. Some potential studies are discussed in the next section.

Future Directions

There are several additional experiments, which should be conducted to continue this line of research, which would allow extending, replicating and further validating the results presented in this thesis. The selection presented here is mainly focussed on adequate follow-up studies, rather than on long-term speculation for this line of research.

Because the modified dual mechanism account is the central proposition of this thesis, further testing, especially in terms of predictive measures for interindividual differences in commission error occurrence would have to be the next necessary step. The study by Ball et al. (2013) used working memory capacity as a predictor for prospective memory performance, but to find an overall effect only the highest and lowest quarter in working memory capacity of the sample were used. A similar approach might be necessary for commission errors and could also be used to gather data on the influence of state and action orientation on commission errors, due to the connections of this trait to prospective memory tasks (Kaschel et al., 2016). The analysis of response time patterns used in the presented studies, analysing the trial directly following the no longer relevant prospective memory cue, could be used to see if state-oriented participants show higher increases replicating the results from Walser, Goschke, et al. (2014). A better understanding of relevant traits would help to develop a reliable theory to explain commission error occurrence and move beyond the description of effects and probable mechanisms.

As indicated by Scullin et al. (2012), post-experimental questionnaires in regard to commission errors are often inconsistent and might be due to post-hoc explanations, which is consistent with the results of the presented studies. To better differentiate whether participants are aware of the error during the experiment or whether they recall the instructions in the post-experimental questionnaire two approaches could be selected. First, it would be possible to use a structured interview instead of a questionnaire, which does not indicate if the reaction was correct or not and might therefore give a better indication of error awareness. Second, error negativity (Hester, Foxe, Molholm, Shpaner, & Garavan, 2005), an event related potential associated with an erroneous motor response, could be used to indicate whether participants realize their error. The problem with error negativity is that at least ten trials with errors would be required.

A more applied aspect of possible follow up experiments would be aimed at the reduction of commission errors. This idea is based on the ambiguous effect of divided attention manipulations on commission error occurrence, which lowered commission error occurrence in the delay-execute paradigm, while increasing them in the retrieve-execute paradigm. This effect should be investigated further, beginning with a replication of the results from Study 3, as the effect in the retrieve execute paradigm has been shown before by other researchers. Investigating this effect would also be a further test for the modified dual mechanism account. In addition, the use of forgetting practice has been shown to reduce commission errors, but only for finished prospective memory instructions (Bugg et al., 2016). Further investigation of this effect could allow to understand the process of commission error occurrence better. The investigation of aftereffects could be used to test if different manipulations on aftereffects result in similar results within one experiment. To this end, the observed partial deactivation of finished relative to cancelled conditions as presented in Study 3 could be compared with repeated exposure to the no longer relevant cue (Walser, et al., 2014) in addition to the forgetting practice (Bugg et al., 2016).

Conclusion

The presented studies extended research in prospective memory and on commission errors by applying and combining paradigms and manipulations previously not used within this field of research. Considering the overall impact of the experiments, the rigorous test of the active maintenance view and dual mechanism account could clearly show deficits in both theories. One main result was the consistent reaction time pattern following the cue indicating spontaneous retrieval and reformulation in prospective memory tasks but also in commission error experiments. This reaction time pattern, in combination with the newly proposed modified dual mechanism account of commission error occurrence, focussed on the moment of intention retrieval, can explain the results of Study 1 to 5 and appears to be in line with previous research in the field. The modified dual mechanism account has been shown to be more suited to predict commission error occurrence in experimental paradigms and to account for previously unexplained results in the literature. However, it was also evident that merely rejecting the active maintenance view as well as modifying the dual mechanism account may not account for all variance across empirical studies. The proposed experiments with a focus on interindividual differences based on cognitive traits can be considered as a sensible next step to understand intention retrieval better and therefore both prospective memory and commission error occurrence.

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Annexes

Annex A: Study 1 - Assessing the role of active maintenance in the delay-execute paradigm using different cognitive load manipulations

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Assessing the role of active maintenance in the delay-execute paradigm using different cognitive load manipulations

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Abstract

In two standard delay-execute prospective memory experiments we compared predictions of a retrieval-and-reformulation view with the active maintenance view. To this end, we increased cognitive load and examined the effect on prospective memory performance and ongoing task reaction times and accuracy. To increase cognitive load, we used an additional divided attention task (Experiment 1) or increased the pace of ongoing task trials (Experiment 2). In both experiments, we observed no significant differences in prospective memory performance between the manipulations and their respective baselines. The reaction times for the ongoing task showed a significant increase immediately after the cue, but not for the duration of the delay. There was also no significant decrease in ongoing task accuracy during the delay. Both results support the retrieval-and-reformulation view and contradict the active maintenance view, because the active maintenance view predicts costs on the ongoing task during the delay to keep the intention of the prospective memory task active. Overall, the retrieval-and-reformulation view is supported by both experiments. Despite a more sensitive measure and analysis compared to previous research, the present results do not support the active maintenance view.

Keywords: delay-execute paradigm; prospective memory; active maintenance

Assessing the role of active maintenance in the delay-execute paradigm using different cognitive load manipulations

To remember an intention and subsequently execute the intention in response to a specified cue is referred to as prospective memory task (PM, Einstein & McDaniel, 1990). In a retrieve-execute PM task, an intention can be executed instantaneously after encountering a specific cue in the environment, such as a nurse administering pre-operation medicine as soon as she/he encounters the patient (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). However, it is often necessary to postpone the relevant response due to ongoing task demands (Grundgeiger, Sanderson, MacDougall, & Venkatesh, 2010), which is often the case in applied settings (Dismukes, 2008, 2012; Dismukes & Nowinski, 2007; Grundgeiger, Sanderson, & Dismukes, 2014). For example, the nurse might remember to give the medication but needs to finish the task-at-hand first. Tasks with this feature are referred to as delay-execute PM tasks (Einstein et al., 2000; Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003).

In the laboratory, the delay-execute prospective memory paradigm is implemented by instructing participants to work on an ongoing task consisting of blocks of various question types of similar difficulty, with blocks typically lasting 60 seconds. For the PM task, the participant is instructed to press a certain key on the keyboard if a highly salient cue appears (i.e., screen turns red for 1 second) *but not until the present block of questions has finished and the next block with a different question type started.* This delay is usually set between 10 to 40 seconds (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). In general, PM performance is lowered in delay-execute tasks by delays as short as 10 seconds compared to retrieve-execute tasks (Einstein et al., 2000). In addition, if the delays are interrupted or contain an additional task, the PM performance declines even further and the PM performance also depends on the task demands during the delay (Einstein et al., 2003; Schaper & Grundgeiger, 2018).

To explain the effects of decreasing PM performance due to the delay and manipulations within the delay, Einstein et al. (2003) suggested the active maintenance view; the periodic activation of the intention during the delay to keep the intention active. Periodic activation is considered to be moderately demanding and should only occur in less-demanding phases of the ongoing task. Therefore, ongoing task reaction time during the delay should be increased, or the ongoing task accuracy should be lowered if an intention is maintained compared to no intention. Because it is assumed that participants are only able to devote additional rehearsal in phases of low ongoing task demand, the additional demands of periodic activation should be reflected in increased reaction times in the ongoing task (Einstein et al., 2003). If ongoing task demands are high, no additional rehearsal should occur and therefore lower prospective memory performance. Two mechanisms were proposed, which facilitate such periodic activation. First, an association between the intention and the ongoing task, based on the finding of better prospective memory performance if the context of encoding and retrieval is the same (Nowinski & Dismukes, 2005). Second, strategic retrieval of unfinished intentions from long-term memory (Ellis, 1996). Both processes are relevant to initiate strategic retrieval and therefore to keep the intention active (Einstein et al., 2003).

Several findings may be interpreted in favour of the active maintenance view. Prospective memory performance in the delay-execute paradigm is resource dependent (Ball, Knight, Dewitt, & Brewer, 2013; Einstein et al., 2003; Kliegel & Jäger, 2006; McDaniel, Einstein, Graham, & Rall, 2004; Rendell, Vella, Kliegel, & Terrett, 2009). For example, prospective memory performance decreased when a divided attention task was added during the delay between cue and window of opportunity (Einstein et al., 2003). Interruptions during the delay can lower prospective memory performance even further (Cook, Meeks, Clark-Foos, Merritt, & Marsh, 2013; McDaniel et al., 2004; Schaper & Grundgeiger, 2018). There is some indication that working memory capacity acts as a moderator for the effect of interruptions on prospective memory performance, with high working memory capacity predicting better performance on interrupted prospective memory trials than with low working memory capacity (Ball et al., 2013).

However, Ball et al. (2013) suggested an alternative mechanism of spontaneous retrieval and reformulation of the intention, which is also suited to explain the results of the previously stated studies. The reformulated intention aims to spontaneously retrieve the old intention once the window of opportunity occurs, based on a similar mechanism suggested by McDaniel, Einstein, Stout, and Morgan (2003) in older adults. This mechanism predicts increased reaction times only directly after the cue, but not across the entire delay.

The mechanism of retrieval and reformulation by Ball et al. (2013) was based on finding increased reaction times in the ongoing task directly following the cue, but not across the rest of the delay. In light of this finding of Ball et al. (2013), the experiments by Einstein et al. (2003), as an example of support for the active maintenance view, have to be reconsidered more detail. In their second experiment, the delay between cue and the window of opportunity was manipulated (5 seconds, 15, seconds, 40 seconds), and the increase in the ongoing task during the delay was compared between prospective memory blocks and control blocks. Einstein et al. (2003) only reported a significant effect when the delay was one ongoing task trial long (5 seconds), which was proposed to support active maintenance but would also be in line with the mechanism of Ball et al. (2013) because of a retrieval and reformulation of the intention after encountering the cue. The results of Einstein et al. (2003) do not show consistent slowing in the ongoing task trials or consistently reduced accuracy.

Overall, we suggest that the results of Einstein et al. (2003) and other previous research, which could be interpreted in support of the active maintenance view, can also be explained by the mechanism of retrieval and reformulation (Ball et al., 2013; McDaniel et al., 2003). To test this prediction we reassessed the results by Einstein et al. and used a more sensitive measure for reaction time analysis (i.e., reaction times deviations from the participants mean) as well as use a more fine-grained analysis for the reaction times (i.e., using trial by trial measures instead of only mean across several trials). We consider this more sensitive measure especially important because the predicted slowing of the active maintenance view during the whole length of the delay was not demonstrated in the paper of its origin.

Present Experiments

The aims of the experiments were twofold. As the first aim, we planned to compare the predictions of reaction time changes in the ongoing task directly after cue presentation, based on the mechanism of retrieval and reformulation (Ball et al., 2013; Schaper & Grundgeiger, 2017) and in relation to the active maintenance view (Einstein et al., 2003). To allow a better comparison between both views, we implemented several more trials after the cue and window of opportunity. Therefore, a more detailed analysis of reaction times on trial by trial basis is possible. In addition, we used z-scores of reaction times, standardized within each participant and ongoing task type, resulting in a more sensitive measure for reaction time changes.

As a second aim, we planned to test the effect of an adapted approach to the manipulation of cognitive load in the delay-execute paradigm. In addition to manipulating cognitive load by adding a divided attention task, we implemented a group with reduced time available for each ongoing task trial. Reducing time for all ongoing task trials can be more adequately compared to the divided attention manipulation during the entire prospective memory block. The cognitive load manipulation did, therefore, affect not only the delay but also the proposed retrieval and reformulation process.

The active maintenance view (Einstein et al., 2003) would make the following general predictions. First, due to the moderate costs of the active maintenance, the active maintenance view predicts increases in the ongoing task reaction times during the delay, for situations without additional cognitive load. Second, the active maintenance view also predicts lower prospective memory performance in the group with divided attention as well as in the group with decreased time for each ongoing task trial relative to a control group, because there is no phase of low cognitive load during the delay. Alternatively, participants might be able to use strategic rehearsal actively to improve their prospective memory performance outside of phases of low cognitive load. This trade-off would result in no decrease in prospective memory performance, but in significantly reduced performance in the ongoing task during the delay. Active rehearsal of an intention should also be more likely to occur if the delay after the cue increases, which should result in longer mean ongoing task reaction times in the later part of the delay compared to the earlier part.

If prospective memory performance is instead dependent on the mechanism of retrieval and reformulation (Ball et al., 2013; Schaper & Grundgeiger, 2017), initially prospective memory performance should be expected to decline, because cognitive resources are low in the moment of retrieval, due to either one of the cognitive load manipulations. However, by taking additional time in the ongoing task directly after the cue, producing the reaction time pattern reported by Schaper and Grundgeiger (2018), the intention can be reformulated, and high prospective memory performance can be expected. Therefore, prospective memory performance should not be significantly lowered, but the trial following the prospective memory cue should show increased reaction time due to the reformulation process (Ball et al., 2013; Schaper & Grundgeiger, 2017). There is no predicted cost on the ongoing task for the remainder of the delay after the initial reformulation.

Overall, we expected no difference in prospective memory performance between the different cognitive load manipulations based on the retrieve-and-reformulate view (Ball et al., 2013). Our analysis of the ongoing task should show a significant increase in reaction time in the trial directly following the cue (Ball et al., 2013; Schaper & Grundgeiger, 2017). Contrary to the active maintenance view (Einstein et al., 2003), there should be no increased reaction times during the delay, with the exception of the aforementioned trial, regardless if an intention had to be executed after the delay. It might be argued, that periodic activation might be more likely during an early part of the delay, due to the similarity of the experiments by (Einstein et al., 2003) or in a later part of the delay due to the length of the delay. Therefore, the trials of the delay should be separated into two parts, to rule out that active maintenance occurs in both or either part of the delay.

We conducted two experiments in which we used a baseline group with five seconds for each ongoing task trial. We implemented increased cognitive load in the first manipulation with an additional task during prospective memory blocks while keeping the ongoing task at five seconds per trial. For the second manipulation, the time available for all ongoing task trials was reduced to three seconds.

To better separate the predicted response time pattern from an expected startle effect (Monk & Kidd, 2008) or orientation reaction (Walser, Fischer, & Goschke, 2012) due to the salient cue, we realised a second control group with five seconds for each ongoing task trial. Participants received no prospective memory instructions but were told that red screens (which served as prospective memory cue for the other groups) could occur during the experiment, which should be ignored (Schaper & Grundgeiger, 2017).

Experiment 1

In Experiment 1, we tested the effect of increased cognitive load on prospective memory performance twofold by reducing the time available for each ongoing task trial from five to three seconds and by adding a digit-counting task to the five seconds ongoing task.

The active maintenance view (Einstein et al., 2003) predicts better prospective memory performance in the baseline group with five seconds for each ongoing task trial and no divided attention during the prospective memory blocks compared to both groups with increased cognitive load. If prospective memory performance is not lower, the ongoing task mean reaction times and accuracy during the delay have to be compared to control trials, to test if participants actively engaged in active maintenance and traded ongoing task performance for prospective memory performance.

The retrieval-and-reformulation view (Ball et al., 2013; Schaper & Grundgeiger, 2017) does not predict a difference in prospective memory performance across groups. But instead, an increase in the ongoing task reaction time in the trial directly after the cue compared to the trial before the cue in all groups, to reflect the reformulation of the intention. The retrieval-and-reformulation view also predicts that the ongoing task reaction times for the remainder of the delay should not be significantly higher compared to the reaction times before the cue in all three groups.

In contrast, the active maintenance view (Einstein et al., 2003) predicts higher ongoing task reaction times during the remainder of the delay, especially in the baseline group, because participants are expected to actively maintain the intention due to the low demands. In both other groups, the demands of the ongoing task or the additional divided attention task should prevent active maintenance, which should be reflected in lower prospective memory performance in both groups compared to the baseline.

Method

Participants. A total of 63 students of the Julius-Maximilians-Universität Würzburg took part in the experiment, in exchange for partial course credit or 10€. Nine participants were excluded from the analysis because they could not correctly recall the prospective memory task at the end of the experiment (two participants), or because they deviated from the instructions such as pressing “q” immediately upon seeing the red screen (three participants), or used their non-dominant hand as external reminder (four participants). The final sample of 54 ($N_{5seconds\ prospective\ memory} = 12$, $N_{3seconds\ prospective\ memory} = 15$, $N_{5seconds\ prospective\ memory+div} = 14$, $N_{5seconds\ No\text{-}prospective\ memory+div} = 13$), participants had a mean age of 22 years (range 18-32 years) and 72% of the participants were female.

Design. We compared the groups (1) five seconds for each ongoing task trial & full attention (5 seconds prospective memory), which served as a baseline, (2) three seconds for each ongoing task trial & full attention (3 seconds prospective memory), (3) five seconds for each ongoing task trial & divided attention (5 seconds prospective memory + div), and (4) five seconds for each ongoing task trial & divided attention, but without prospective memory task (5 seconds No-prospective memory + div). Time available for each ongoing task trial was kept constant within each group, but phases with divided attention were rearranged depending on group allocation, to be present during prospective memory blocks. The overall length of each ongoing task block was kept constant across all groups. Main dependent variables were prospective memory performance and ongoing task reaction times and accuracy.

Procedure and materials. The instructions were given in four steps, interleaved with practice trials. Before each practice session, the participants were given the opportunity to ask questions, or the experimenter would comment on their actions if necessary.

First, participants were instructed about the ongoing task. Participants had to answer questions within five or three seconds, depending on their allocated group, and indicate their answer by pressing either the left or right arrow key on a keyboard. The next question was shown automatically after the time window had elapsed. Participants were instructed to use index and middle fingers of their dominant hand to press the keys and to keep the fingers on the keys throughout the experiment. The key configuration was counterbalanced within each group. We used six different question types for the ongoing task: (1) deciding if a word contains a specific letter, (2) deciding if a word belongs to a specific category, (3) indicating if a third number (not shown) in a sequence is odd or even based on the preceding numbers, (4) deciding if a word describes a living or non-living object, (5) deciding if the number of letters of a word is odd or even, or (6) deciding if the first and last letters in a word are in alphabetical order. All participants conducted a short training that included two questions of each question type.

Second, the participants were instructed about the divided attention task they had to perform throughout the experiment. For this task, participants heard a string of random numbers from 1 to 9 and had the instruction to press a clicker with their non-dominant hand when an odd number occurred while the ongoing task continued.

Third, the participants were instructed about an additional interrupting task they had to perform throughout the experiment. If the ongoing task monitor showed the text “Please work on the other screen”, the participants had to switch to a second monitor to their right. On the second screen, they had to work on a LDT in which a new question was presented immediately after answering, using the “N” and “M” key to indicate if a string of letters is a word or non-word. After 15 seconds, the ongoing task restarted on the ongoing task screen. Participants conducted a short training including one interruption.

Fourth, the groups, with the exception of the group without prospective memory task, received instructions about the standard delay-execute prospective memory task – pressing “q” after a red screen was presented *but delaying the execution until the type of ongoing task had changed*. Participants conducted a short training, including one prospective memory cue (i.e., red screen). The experimenter gave feedback on prospective memory performance and explained the prospective memory task again if a participant failed to respond correctly.

All groups worked on 36 blocks of the ongoing task, lasting one minute each. Baseline blocks contained either 12 (for groups with five seconds for each ongoing task trial) or 20 (for the group with three seconds for each ongoing task trial) trials, depending on the allocated group. Blocks 5, 10, 14, 20, 26 and 31 contained only a 15-second interruption after 30 seconds into the block. The blocks 3, 12, 17, 22, 28 and 34 contained a prospective memory cue (i.e., red screen) after 15 seconds into the block, the prospective memory cue and window of opportunity were therefore always separated by 45 seconds.

For the 5 seconds prospective memory + div group and the 5 seconds No-prospective memory + div group, these blocks additionally contained the divided attention task for the duration of the whole block. Both previously mentioned groups also worked on the divided attention task during the blocks 6, 9, 15, 19, 30 and 36.

For both other groups the blocks 2, 6, 8, 9, 15, 16, 21, 24, 25, 30 and 33 contained the divided attention task. For all groups, the blocks 5, 10, 14, 20, 26 and 31 contained the interrupting task. The question types were evenly spread across the 38 blocks with the additional constraint not to have the same two question types in succession. This order was equivalent for all participants, but each ongoing task trial was randomly chosen without replacement for each participant.

Finally, participants completed a demographic questionnaire and had to explain the initial prospective memory task (i.e., what they had to do in response to the prospective memory cue and when they had to execute this action). The final question asked the degree, according to a 5-point scale, to which participants tried to rehearse the intention during the delay vs. relying on the intention to just “pop into mind”. In the questionnaire for the group without prospective memory task, the participants were asked if they reacted to the red screen in any way. Participants were tested individually or in pairs (paired tests only within the same group). The total experiment lasted approximately 60 minutes.

Results

For all analyses in Experiment 1 and Experiment 2, a correct prospective memory response was defined as pressing “q” within the first two questions of a new question type after the prospective memory cue. The statistical analysis was conducted with SPSS 23 (Chicago, IL). For all tests, alpha was set at .05.

Prospective memory hits. We calculated the percentage of correct prospective memory responses out of six prospective memory events and used it as the dependent variable in a one-way ANOVA with the factor group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). There was no significant main effect $F(2, 38) = .09$, $p = .912$, $\eta_p^2 = .01$. The mean prospective memory hit rate in the 5 seconds prospective memory group was 88.89% ($SD = 23.92$), the mean prospective memory hit rate for the 3 seconds prospective memory group was 90.00% ($SD = 13.80$), and the mean prospective memory hit rate in the 5 seconds prospective memory + div group was 91.67% ($SD = 10.84$).

Reaction times. Before analysing reaction times, we excluded the first question of each block, the first question after each interruption, and all incorrect responses. Also, we z-standardized all included data points within each participant and question type to be able to compare reaction times for different question types meaningfully. Due to six different question types, we used an adapted trimming procedure of Ball et al. (2013; see also Brewer, 2011) and did not only consider each participant's overall mean but each mean relative to the question type. Subsequently, we only analysed responses within 2.5 standard deviations of the participants mean response time within each question type (removing 1.87% of the data).

We conducted RM-ANOVAs for each group with the calculated z-scores of the reaction times as the dependent variable for the blocks containing red screens (Figure 1). As the repeating factor, we used the question position relative to the red screen i.e., the trial prior to the red screen (pre), the trial following the red screen (post), as well as the subsequent trial (post-post).

For the 5 seconds prospective memory group we found a significant effect of question position $F(2, 22) = 10.69$, $p = .001$, $\eta_p^2 = .49$. Bonferroni-corrected post hoc tests showed significantly faster reactions in the prior compared to the post trial ($p = .004$) as well as significantly slower reactions in the post compared to the post-post trial ($p = .009$). The prior and post-post trials did not differ significantly ($p = 1$).

For the 3 seconds prospective memory group we found a significant effect of question position $F(2, 28) = 25.43$, $p < .001$, $\eta_p^2 = .65$. Bonferroni-corrected post hoc tests showed significantly faster reactions in the prior compared to the post trial ($p < .001$) as well as significantly slower reactions in the post compared to the post-post trial ($p < .001$). The prior and post-post trials did not differ significantly ($p = .335$).

For the 5 seconds prospective memory + div group we found a significant effect of question position $F(2, 26) = 3.94$, $p = .032$, $\eta_p^2 = .23$. Bonferroni-corrected post hoc tests did not show faster reactions in the prior compared to the post trial ($p = .093$) but significantly slower reactions in the post compared to the post-post trial ($p = .046$). The prior and post-post trials did not differ significantly ($p = 1$).

For the 5 seconds No-prospective memory + div group we found a significant effect of question position $F(2, 24) = 10.43$, $p = .001$, $\eta_p^2 = .47$. Bonferroni-corrected post hoc tests showed significantly faster reactions in the prior compared to the post trial ($p = .022$) as well as significantly slower reactions in the post compared to the post-post trial ($p = .005$). The prior and post-post trials did not differ significantly ($p = 1$).

To test for increased reaction times due to active maintenance during the delay after the prospective memory cue (Einstein et al., 2003), we conducted a 2 × 2 × 3 mixed ANOVA with the first within-factor block type (baseline block, prospective memory block), the second within-factor time after cue (early, late) and the between-factor group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). For the factor block type, we used reaction times from blocks without additional task for the 5 seconds prospective memory group and the 3 seconds prospective memory group as baseline. For 5 seconds prospective memory + div group we used blocks containing only the added divided attention task as baselines. The factor time after cue describes the differentiation between the mean reaction times for the first half of all reaction times after the cue (excluding the trial directly following the cue), or the second half of all reaction times during the delay. Therefore, for the 5 seconds prospective memory group and 5 seconds prospective memory + div group the mean of four ongoing task trials from 5 to 8 were used for the first half and the mean of ongoing task trials 9 to 12 for the second half. In the 3 seconds prospective memory group the mean of 7 ongoing task trials from 7 to 13 were used for the first half and the mean of ongoing task trials 14 to 20 for the second half.

The analysis showed a significant main effect of group, $F(2, 38) = 45.49$, $p < .001$, $\eta_p^2 = .71$. Bonferroni-corrected post-hoc tests showed longer reaction times in the 5 seconds prospective memory + div group ($M = .13$, $SD = .03$), compared to the 5 seconds prospective memory group ($M = -.26$, $SD = .04$; $p < .001$) and the 3 seconds prospective memory group ($M = -.27$, $SD = .03$; $p < .001$). There was also a significant effect of time after cue $F(1, 38) = 4.31$, $p = .045$, $\eta_p^2 = .10$. There was no significant effect of block type $F(1, 50) = 0.24$, $p = .628$, $\eta_p^2 = .01$. The interaction between group and time after cue was also significant $F(2, 38) = 3.81$, $p = .031$, $\eta_p^2 = .17$, with a decrease in reaction times in the later part of the delay in the 5 seconds prospective memory group and the 3 seconds prospective memory group, but an increase in the later part of the delay in the 5 seconds prospective memory + div group. There were no further significant interactions.

Ongoing task accuracy. To assess accuracy in the ongoing task, we calculated the mean percentage of correctly solved ongoing task trials for each participant after excluding the first question of each block and the first question after each interruption. A one-way ANOVA with the factor group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div, 5 seconds No-prospective memory + div) showed a significant effect $F(3, 50) = 7.68$, $p < .001$, $\eta_p^2 = .32$. Bonferroni-corrected post hoc tests showed a significant lower accuracy in the 3 seconds prospective memory group ($M = .84$, $SD = .06$) compared to 5 seconds prospective memory group ($M = .90$, $SD = .04$, $p = .020$, $d = 1.09$), the 5 seconds prospective memory + div group ($M = .91$, $SD = .04$, $p = .001$, $d = 1.47$) and the 5 seconds No-prospective memory + div group ($M = .91$, $SD = .05$, $p = .002$, $d = 1.26$). There were no other significant differences between the groups.

We repeated the 2 × 2 × 3 mixed ANOVA, used for the ongoing task reaction times, using mean accuracy, to test for lowered accuracy due to active maintenance during the delay after the prospective memory cue (Einstein et al., 2003). The first within-factor was block type (baseline block, prospective memory block), the second within-factor was time after cue (early, late) and the between-factor was group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). The analysis showed a significant main effect of group, $F(2, 38) = 3.57$, $p = .038$, $\eta_p^2 = .16$, however there was no significant effect of block type $F(1, 38) = 0.59$, $p = .446$, $\eta_p^2 = .02$ or of time after cue $F(1, 38) = 0.75$, $p = .393$, $\eta_p^2 = .02$. There were no significant interactions.

Discussion

Active maintenance view (Einstein et al., 2003) and the mechanism of retrieval and reformulation (Ball et al., 2013; Schaper & Grundgeiger, 2017) predicted lower prospective memory performance in both groups with increased cognitive load, compared to the baseline group. The data did not match this prediction, showing no significant differences between any of the three groups with a prospective memory task. Considering the results in more detail, we observed a mean prospective memory performance of roughly 90% in each group; this appears to be a ceiling effect, which resulted in no significant differences between the groups. In comparison to the study by Einstein et al. (2003) where prospective memory performance was reported at 76% for a divided attention group, the performance in the present experiment is surprisingly high (92%).

In all groups with a prospective memory task, we found a significant increase in ongoing task reaction times immediately following the cue, except for the 5 seconds prospective memory + div group where the pattern occurred descriptively. Directly after this increase, we observed that the reaction times sped up again to the same level as before the cue. The speeding up was present in all groups with PM task, indicating that no active maintenance occurred almost immediately after cue presentation. The same pattern was also found in the group without prospective memory task (5 seconds No-prospective memory + div), in which case this slowing in the post-trial has to be considered as a resumption lag (Monk & Kidd, 2008) or orientation reaction (Walser et al., 2012), as retrieval of the intention could not occur without a prospective memory task.

To specifically test the active maintenance view (Einstein et al., 2003), we compared the reaction times in the ongoing task during the delay to equivalent trials during blocks with no prospective memory task. Finding no difference in reaction times between ongoing task trials within a prospective memory delay and the equivalent trials indicates that no costs occurred due to active maintenance processes. Given that the PM performance is near ceiling, this result contradicts the active maintenance view because this view predicts that the intention is periodically activated during the delay to keep it active, which should have resulted in increased ongoing task reaction times during the delay.

As an additional measure, we assessed ongoing task accuracy because ongoing task accuracy might also be lowered by active maintenance (Einstein et al., 2003). Given the present results on prospective memory performance and ongoing task reaction times, the active maintenance view could still account for the results if participants actively used strategic rehearsal of the prospective memory task, and as a trade-off neglected the ongoing task during the delay in terms of accuracy, but not in terms of increased reaction times.

We considered ongoing task accuracy as an overall measure and explicitly tested the predictions of the active maintenance view by repeating the analysis used for the reaction times during the delay with reaction time as the dependent variable. First, with overall accuracy we found that the ongoing task accuracy in the 3 seconds prospective memory group was significantly lower than in all other groups, while there were no further differences between the other three groups. The lower accuracy can be considered as a manipulation check of the reduced time for each trial, indicating that the time available was short enough to decrease performance. Second, when comparing the accuracy in the ongoing task during the delay in prospective memory blocks with control blocks, there was no significant main effect, demonstrating no lower ongoing task accuracy during the prospective memory delay compared to equivalent trials. Finding an effect in this analysis would have been an indication for the resource dependent active maintenance proposed by the active maintenance view (Einstein et al., 2003).

The predicted reaction time pattern for the ongoing task, caused by a combination of retrieval and reformulation (Ball et al., 2013), as well as a startle effect (Monk & Kidd, 2008) or orientation reaction (Walser et al., 2012), as described by (Schaper & Grundgeiger, 2017), was replicated. Finding no differences in prospective memory performance influences the predicted patterns of ongoing task reaction times based on the active maintenance view (Einstein et al., 2003). As stated above, finding good prospective memory performance would mean that participants should have actively used strategic retrieval, which should result in overall worse performance in the ongoing task during the delay. The presented data did not match this prediction.

However, there were some other significant effects, in the ongoing task analysis, which have to be addressed. In the reaction time analysis for the delay, we found a significant effect of group, due to the overall increased reaction times in the 5 seconds prospective memory + div group. The main effect is likely to be the result of the divided attention manipulation and not relevant for the distinction between retrieval and reformulation and active maintenance view. The effect of time after cue was also significant with faster mean reaction times in the later part of the delay. This result can be interpreted as a learning process over time. Similarly, there was a significant interaction between group and time after cue, due to fast reaction times later during the delay in the 5 seconds prospective memory group and the 3 seconds prospective memory group, while an increase was found in the 3 seconds prospective memory group. This effect is mainly driven by the main effect of time after cue, which does not occur in the 5 seconds prospective memory + div group. The 5 seconds prospective memory + div group is most likely not showing this effect due to the divided attention task.

There was also a significant a significant effect of group in the analysis of ongoing task accuracy during the delay, due to the overall increased reaction times in the 5 seconds prospective memory + div group, due to the divided attention task. This main effect is a direct result of the divided attention manipulation and not relevant for the distinction between retrieval-and-reformulation view and active maintenance view.

Overall, both manipulations used to increase cognitive load, the 3 seconds prospective memory group and the 5 seconds prospective memory + div group, did not result in significantly lower prospective memory performance compared to the baseline. This is in line with the predictions of the retrieval-and-reformulation view, but not with the active maintenance view. It could be argued that the lower overall ongoing task accuracy in the 3 seconds prospective memory group is an indication for a trade-off between ongoing task accuracy and prospective memory performance occurred in the 3 seconds prospective memory group. However, this is not supported by the analysis of accuracy during the delay, which showed no indication for lower accuracy in prospective memory blocks.

The divided attention manipulation used did not significantly lower prospective memory performance, compared to a more difficult divided attention task (count if two consecutive odd digits occur), which lowered prospective memory performance in the study of Einstein et al. (2003). The other difference in the manipulation is the timing of the divided attention task, while in this experiment the divided attention task was active during the whole prospective memory block the divided attention task was active only during a part of the delay in the study by Einstein et al. (2003). Therefore, we decided to repeat the experiment using the divided attention task by Einstein et al. to investigate a possible effect on prospective memory performance.

Experiment 2

The first aim of Experiment 2 was to replicate the results in support for the retrieval-and-reformulation view (Ball et al., 2013; Schaper & Grundgeiger, 2017) in contrast to the active maintenance view (Einstein et al., 2003). Therefore, the 5 seconds prospective memory group, the 3 seconds prospective memory group and the 5 seconds prospective memory + div group were once again realized. The second aim was to test if the difficulty of the divided attention task or the different timing can account for the difference in prospective memory performance between the 5 seconds + div group in Experiment 1 and the significantly lower performance in the experiment of Einstein et al. (2003). Therefore, the 5 seconds + div group used within Experiment 2 had a divided attention task manipulation, which was matched to the task of Einstein et al. (2003); participants had to count if two consecutive odd digits occurred in succession. This task is not only more difficult but also dependent on memory in addition to attention, because the last number has to be memorized to comply with the task demands.

Method

The method of Experiments 2 followed the method of Experiment 1. Therefore, only deviations from Experiment 1 methods are described.

Participants. A total of 56 students participated and were paid 10€. Nine participants were excluded from the analysis because they could not correctly recall the prospective memory task at the end of the experiment (1 participant), due to deviations from the instructions such as pressing “q” immediately upon seeing the red screen (5 participants), or because they used their non-preferred hand as memory-aid (3 participants). The final sample of 47 participants ($N_{5\text{seconds prospective memory}}$ = 16, $N_{3\text{seconds prospective memory}}$ = 15, $N_{5\text{seconds prospective memory+div}}$ = 16) had a mean age of 23 years (range 19-29 years) and 70% of the participants were female.

Design. In Experiment 2, all groups from Experiment 1 were once again realized except for the 5 seconds No-prospective memory + div group. The time available for each ongoing task trial was also identical to Experiment 1 for each respective group. The difficulty of the divided attention task was increased across all groups, by asking participants to react to two consecutive odd digits instead of every odd digit.

Materials and procedure. The procedure was identical to Experiment 1 and used the same combination of instructions interleaved with practice trials. The material for the ongoing task as well as the timing of blocks was also identical.

Results

The same criteria as in Experiment 1 for prospective memory hits and reaction times were realized. We used the same reaction time procedure as described in Experiment 1 (removing 1.36% of the data).

Prospective memory hits. As in Experiment 1, we calculated the percentage of correct prospective memory responses out of six prospective memory events and used it as the dependent variable in a one-way ANOVA with the factor group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). There was no significant main effect of group $F(2, 44) = .69$, $p = .506$, $\eta_p^2 = .03$. The mean prospective memory hit rate in the 5 seconds prospective memory group was 78.13% (*SD* = 32.04), the mean prospective memory hit rate for the 3 seconds prospective memory group was 88.89% (*SD* = 25.72), and the mean prospective memory hit rate in the 5 seconds prospective memory + div group was 87.50% (*SD* = 25.46).

Reaction times. As in Experiment 1, we conducted RM-ANOVAs for each group with the calculated z-scores of the reaction times as the dependent variable for the blocks containing red screens (Figure 2). As the repeating factor, we used the question position relative to the red screen i.e., the trial prior to the red screen (pre), the trial following the red screen (post), as well as the subsequent trial (post-post).

For the 5 seconds prospective memory group we found a significant effect of question position $F(2, 30) = 24.44$, $p < .001$, $\eta_p^2 = .62$. Bonferroni-corrected post hoc test showed significantly faster reactions in the prior compared to the post trial ($p < .001$) as well as significantly slower reactions in the post compared to the post-post trial ($p < .001$). The prior and post-post trials did not differ significantly ($p = 1$).

For the 3 seconds prospective memory group we found a significant effect of question position $F(2, 28) = 19.00$, $p < .001$, $\eta_p^2 = .58$. Bonferroni-corrected post hoc test showed significantly faster reactions in the prior compared to the post trial ($p < .001$) as well as significantly slower reactions in the post compared to the post-post trial ($p = .002$). The prior and post-post trials did not differ significantly ($p = .335$).

For the 5 seconds prospective memory + div group we found a significant effect of question position $F(2, 30) = 4.74$, $p = .016$, $\eta_p^2 = .24$. Bonferroni-corrected post hoc test showed significantly faster reactions in the prior compared to the post trial ($p = .034$) but not significantly slower reactions in the post compared to the post-post trial ($p = .073$). The prior and post-post trials did not differ significantly ($p = 1$).

To test for increased reaction time in the ongoing task due to strategic rehearsal during the delay after the prospective memory cue (Einstein et al., 2003), we repeated the 2 × 2 × 3 mixed ANOVA from Experiment 1. The first within-factor was block type (baseline block, prospective memory block), the second within-factor was time after cue (early, late) and the between-factor was group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). The analysis showed a significant main effect of group, $F(2, 44) = 445.91$, $p < .001$, $\eta_p^2 = .95$. Post-hoc tests with Bonferroni correction showed significantly longer reaction times the 5 seconds prospective memory + div group ($M = .63$, $SD = .03$) compared to the 5 seconds prospective memory group ($M = -.39$, $SD = .03$; $p < .001$) and the 3 seconds prospective memory group ($M = -.31$, $SD = .03$; $p < .001$). There was also a significant effect of block type $F(1, 44) = 4.31$, $p = .044$, $\eta_p^2 = .09$ with increased reaction times in the prospective memory blocks. There was no significant effect of time after cue $F(1, 44) = 0.47$, $p = .496$, $\eta_p^2 = .01$ and no significant interactions.

Ongoing task accuracy. As in Experiment 1, we calculated the mean percentage of correctly solved questions for each participant after excluding the first question of each block and the first question after each interruption to assess accuracy in the ongoing task. A one-way ANOVA with the factor group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div, 5 seconds No-prospective memory + div) showed a significant effect $F(2, 44) = 9.46$, $p < .001$, $\eta_p^2 = .30$. Bonferroni-corrected post hoc tests showed a significant difference between the 3 seconds prospective memory group ($M = .84$, $SD = .07$) and the 5 seconds prospective memory group ($M = .92$, $SD = .04$, $p < .001$, $d = 1.54$) and the 5 seconds prospective memory + div group ($M = .90$, $SD = .06$, $p = .008$, $d = 1.02$). There was no significant difference between the 5 seconds prospective memory and the 5 seconds prospective memory + div group ($p = .934$).

To test for lowered accuracy due to active maintenance during the delay after the prospective memory cue (Einstein et al., 2003), we repeated the 2 × 2 × 3 mixed ANOVA used for the ongoing task using mean accuracy. The first within-factor was block type (baseline block, prospective memory block), the second within-factor was time after cue (early, late) and the between-factor was group (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). The analysis showed a significant main effect of group, $F(2, 44) = 4.88$, $p = .012$, $\eta_p^2 = .18$, however there was no significant effect of block type $F(1, 44) = 2.78$, $p = .103$, $\eta_p^2 = .06$ or of time after cue $F(1, 44) = 0.47$, $p = .496$, $\eta_p^2 = .01$. There were no significant interactions.

Discussion

The first aim of Experiment 2 was to replicate the results of Experiment 1 in relation to the response time pattern in the ongoing task, which support the mechanism of retrieval and reformulation (Ball et al., 2013; Schaper & Grundgeiger, 2017). The predicted pattern was replicated in the 5 seconds prospective memory group and the 3 seconds prospective memory group. In the 5 seconds prospective memory +div group the overall pattern was replicated with a significant increase in ongoing task reaction time directly following the cue, but the difference to the subsequent trial did not reach significance. Altogether, the reaction time patterns after the prospective memory cue match the theoretical predictions and the results of Experiment 1.

The second aim was to test if the divided attention manipulation to increase cognitive load would show a significant effect on prospective memory performance if the difficulty of the task was increased to match the manipulation by Einstein et al. (2003). As in Experiment 1, there was no significant difference in the prospective memory performance between the three groups, once again supporting the mechanism of retrieval and reformulation. Contrary to the study of Einstein et al. (2003) there was no significant decrease in prospective memory performance in the 5 seconds prospective memory + div group even though the divided attention task was identical. This result is considered in more detail in the general discussion.

The overall prospective memory performance was descriptively lower in Experiment 2, but there was no significant difference in the performance in the nearly identical 5 seconds prospective memory group and 3 seconds prospective memory group across experiments.

As an additional analysis, we repeated the comparison of ongoing task reaction times during the delay to test for an increase in reaction time or decrease in accuracy as predicted by the active maintenance view (Einstein et al., 2003). The results showed no decrease in accuracy during the delay of a prospective memory task compared to equivalent trials, which replicated the results of Experiment 1. However, there was a significant increase in reaction times in the ongoing task during the delay during prospective memory blocks, compared to equivalent trials, which would match the active maintenance view. This conflicting result is considered in relation to the results of both experiments in the general discussion.

General Discussion

In the present experiments, we had two main aims. The first aim was to investigate if increased cognitive load caused by faster pacing of the ongoing task or an additional task reduces delay-execute prospective memory performance. The second aim was to investigate the relative change in ongoing task reaction times following the prospective memory cue as either a single increase in reaction times (Ball et al., 2013; Schaper & Grundgeiger, 2017) or as an indication of active maintenance (Einstein et al., 2003) with increased reaction times across the delay between cue and window of opportunity.

In terms of prospective memory performance there was no significant decrease of either reducing the time for each ongoing task and therefore increasing the frequency of ongoing task trials (3 seconds prospective memory group), or of adding a simple (count odd numbers – Experiment 1) or difficult (count consecutive odd numbers – Experiment 2) divided attention task (5 seconds prospective memory + div group). No differences to the baseline group were found in each respective experiment and neither when combining the data of the 5 seconds prospective memory and 3 seconds prospective memory groups across both experiments. This result does not match initially the idea that delay-execute prospective memory performance is resource dependent (Kliegel & Jäger, 2006; McDaniel et al., 2003) as well as the results and predictions by (Einstein et al., 2003).

The manipulations should first be considered separately to better understand this surprising result. In the 5 seconds prospective memory + div condition, previous research predicted a significant decrease in prospective memory performance due to increased cognitive load during the delay (Einstein et al., 2003). For Experiment 1 and 2 very similar ongoing tasks and divided attention tasks were used, but there were significant differences in the timing of the divided attention task. Not only was it already active before and when the prospective memory cue occurred, but it also remained active during the entire delay. Therefore, the increased cognitive load could be taken into account during reformulation, but also the end of the divided attention task could have served as an additional cue to execute the intention. Finally, the reaction time analysis indicated that the mechanism of retrieval and reformulation was used, which did not predict a decrease in prospective memory performance.

For the 3 seconds prospective memory group we found an overall decrease in ongoing task accuracy, which was not more pronounced during the delay in prospective memory blocks. This result is in line with the mechanism of retrieval and reformulation (Ball et al., 2013), but does not match the prediction of the active maintenance view, because the active maintenance view predicts costs on the ongoing task during the delay, which predicts lower accuracy, if reaction time was not negatively affected.

The analysis of the reaction times in ongoing tasks showed a significant increase from the trial prior to the cue compared to the subsequent trial in all groups without divided attention. This was followed by a significant decline in the next trial, down to a level, which did not differ significantly from the trial prior to the cue. This pattern was also found for the No-prospective memory + div group in Experiment 1, which received no prospective memory task and was told, that red screens could be ignored. This result suggests that an orientation reaction to a salient stimulus (Walser et al., 2012) or resumption lag (Monk & Kidd, 2008) occurs in reaction to the salient cue, which has been previously demonstrated in the delay-execute paradigm (Schaper & Grundgeiger, 2017). However, the effect was not significant for the 5 seconds prospective memory + div group in Experiment 1, even though it was observed descriptively. This result is surprising, as the effect was, in general, found in all other groups across both experiments, even in the same group in Experiment 2 using a more difficult divided attention task. We suggest that the increase in reaction times after the cue in the 5 seconds No-prospective memory + div group was stronger in Experiment 1, as the participants were aware that red screens would occur but did not see one compared to the 5 seconds prospective memory + div group, which received a practice prospective memory trial.

Overall, the described patterns match the mechanism of retrieval and reformulation after the cue (Ball et al., 2013; Schaper & Grundgeiger, 2017).

To test the predictions of the active maintenance view (Einstein et al., 2003), we compared the ongoing task reaction times and accuracy during the delay between prospective memory cue and window of opportunity and equivalent trials in ongoing task blocks without prospective memory tasks. Across both experiments, there was no effect of lower accuracy during the delay. However, in the reaction times of Experiment 2, there was a significant increase in ongoing task reaction times during the delay between cue and window of opportunity for the prospective memory task, relative to equivalent trials without prospective memory tasks. This increase was not present in Experiment 1. This possible indication of active maintenance has to be considered relative to the prospective memory performance and reaction times across both experiments as well as the methods used.

First, mean prospective memory performance was descriptively better in Experiment 1 compared to Experiment 2; this is not in line with the active maintenance view, because the increase in reaction time should also have been present in Experiment 1 and should have even been more pronounced given the better prospective memory performance. Second, the observed increase in reaction times during the delay might have only been observed due to the z-standardizing procedure due to different ongoing task types, as well as the comparison to equivalent trials. When repeating the analysis using standardized reaction times (Ball et al., 2013), the main effect of an intention during the delay was not observed. Overall, the idea of active maintenance is not consistently supported by our data, there is only an indication for its occurrence in one of the experiments and where it is observed, the overall prospective memory performance is descriptively worse instead of better. Furthermore, the apparent active maintenance is described as the difference between the reaction times is not correlated with prospective memory performance.

Theoretical Implications

As described, there was no indication across both experiments that delayed execute prospective memory performance was reduced by either reducing the time for each ongoing task or by adding a divided attention task. We propose that the better prospective memory performance in Experiment 1 and 2 in the divided attention groups relative to the study by Einstein et al. (2003) was caused by the different timing of the additional divided attention task. In our experiments, the divided attention task was only active during retrieval and delay of the prospective memory task, which served as an additional cue to the window of opportunity as the change of question type and the end of the divided attention task coincided. In contrast to the study of Einstein et al. (2003) in which the divided attention task was active throughout the delay and window of opportunity. It is also possible that the reformulation of the prospective memory task after the cue was facilitated by the knowledge about the ongoing divided attention task, relative to experiments where the task starts during the delay. This result shows that manipulations in prospective memory task also have to be considered relative to their timing and not only to their type or difficulty. For the 3 seconds + prospective memory group there was some indication of possible active maintenance during Experiment 2, which did not result in better prospective memory performance and was not observed in Experiment 1.

The mechanism of retrieval and reformulation as suggested by Ball et al. (2013) matched the predictions of no differences in prospective memory performance between groups in both experiments. The observed reaction time patterns, including an orientation reaction to a salient stimulus (Walser et al., 2012) or resumption lag (Monk & Kidd, 2008), replicated previous results (Schaper & Grundgeiger, 2017) supporting the mechanism.

The active maintenance view (Einstein et al., 2003) was not supported by the results in terms of prospective memory performance as well as ongoing task performance. However, the significant difference in reaction time between prospective memory block and baseline blocks has to be considered in more detail. We used a very sensitive measure by using the z-scores instead of mean reaction times and by comparing the z-scores to trials from other blocks, the possible masking of active maintenance by increasing speed due to adaption to the ongoing task question type was ruled out. If active maintenance consistently occurs this analysis should have been sensitive enough to find the effect in both experiments. Furthermore, the increase in the z-scores during the delay was not correlated with the prospective memory performance of the participants in either of the experiments. We propose that the participants might sometimes think about the prospective memory task after the cue causing a slight delay in the ongoing task, but this does not appear to be a consistent mechanism necessary for prospective memory performance.

Conclusion

The delay-execute paradigm is considered to be resource dependent (Ball, Knight, Dewitt, & Brewer, 2013; Einstein et al., 2003; Kliegel & Jäger, 2006; McDaniel, Einstein, Graham, & Rall, 2004; Rendell, Vella, Kliegel, & Terrett, 2009). Multitasking during the delay between prospective memory cue and window of opportunity has been shown to result in lower prospective memory performance (Einstein et al., 2003; Schaper & Grundgeiger, 2018). Interruptions during the delay especially lowered prospective memory performance (Cook et al., 2013; McDaniel et al., 2004), especially if a change of context is involved (Schaper & Grundgeiger, 2018). In the present experiments, this effect of increased cognitive load could not be replicated in terms of prospective memory performance. In the groups with the additional divided attention task, we also found no negative effect on prospective memory performance, which might have been caused by the divided attention task serving as an additional cue for the window of opportunity. Manipulations of cognitive load therefore also have to consider the importance of their onset and end within experiments. In addition, the knowledge about the divided attention task, which is already present during the cue might allow for a more suited reformulation, similar to the effect of context effects or knowledge about the own ability to complete the prospective memory task (Cook, Marsh, & Hicks, 2005; Einstein & McDaniel, 2007). Overall, especially based on the unchanged prospective memory performance in the 3 seconds prospective memory group, the results support the idea that the prospective memory task can be correctly implemented without phases of low cognitive load and there is no indication that cost during the delay occur with or without high cognitive load.

The analysis of reaction times of the No-prospective memory group in Experiment 1 indicated that the slowing in reaction times following a salient prospective memory cue is an indication of retrieval and reformulation of the intention (Ball et al., 2013; Schaper & Grundgeiger, 2017), in addition an orientation reaction (Walser et al., 2012) or resumption lag (Monk & Kidd, 2008) is also taking place. The decrease in reaction times following the significant increase in reaction times did not show an indication that active maintenance, as suggested by Einstein et al. (2003), occurred, as the ongoing task reaction times returned to the same level as before the cue. The detailed analysis of the delay between prospective memory cue and window of opportunity showed a possible effect of active maintenance in Experiment 2, which was not considered conclusive support for this view. We proposed that such an increase had to be related to the performance in the prospective memory task, to support the active maintenance view.

In summary, our experiments showed that increased cognitive load do not always result in reduced prospective memory performance. This finding appears to be consistent across manipulations with reduced time for ongoing task trials and for divided attention tasks of different difficulty. In addition, all these groups indicate retrieval and reformulation directly after the cue, but no indication of resource-demanding active maintenance of the intention during the delay.

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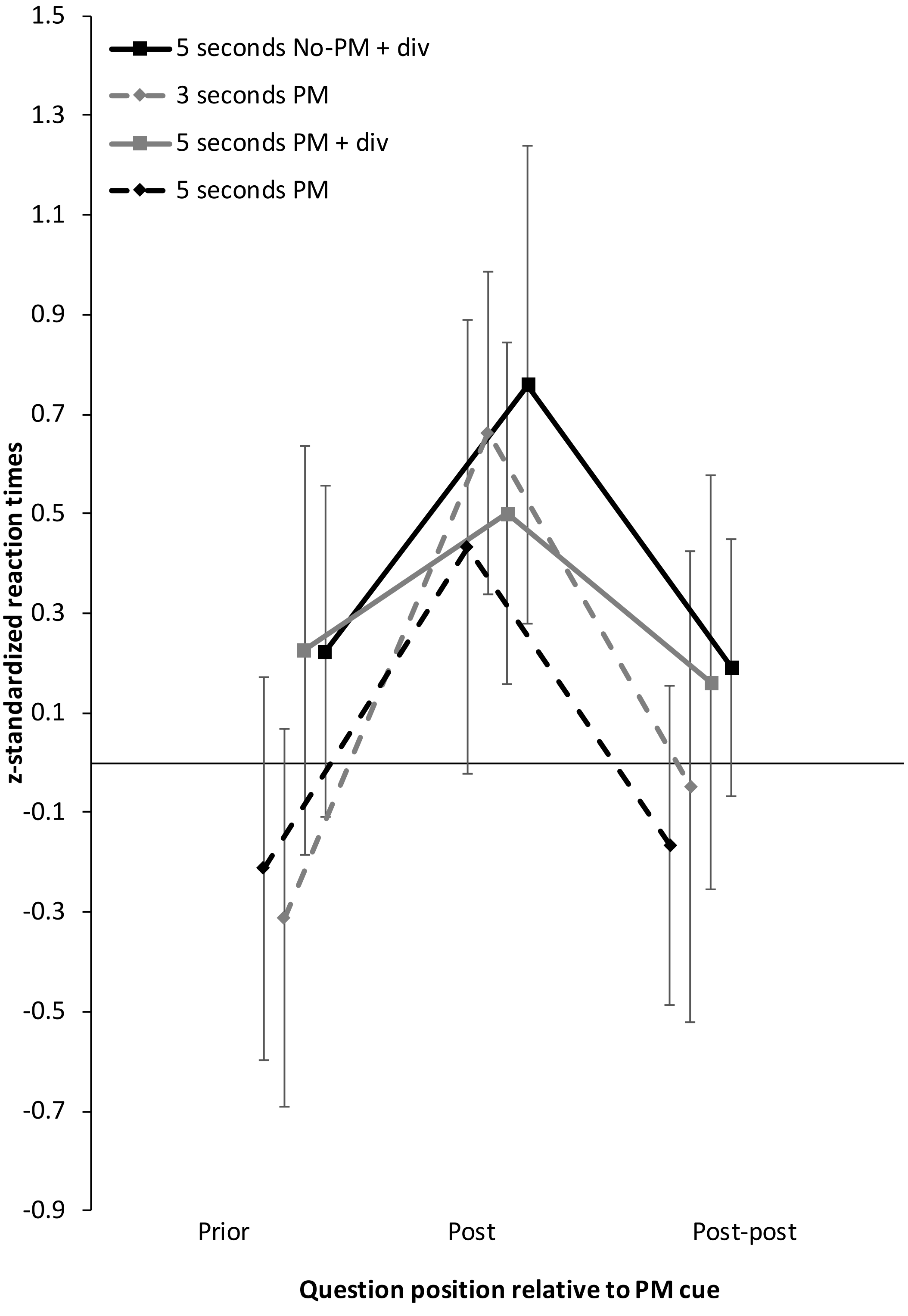

Figure 1. Z-standardized reaction times of Experiment 1 separated by question position relative to the prospective memory cue (prior, post, post-post) and group allocation (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div, 5 seconds No-prospective memory + div). Error bars represent SD.

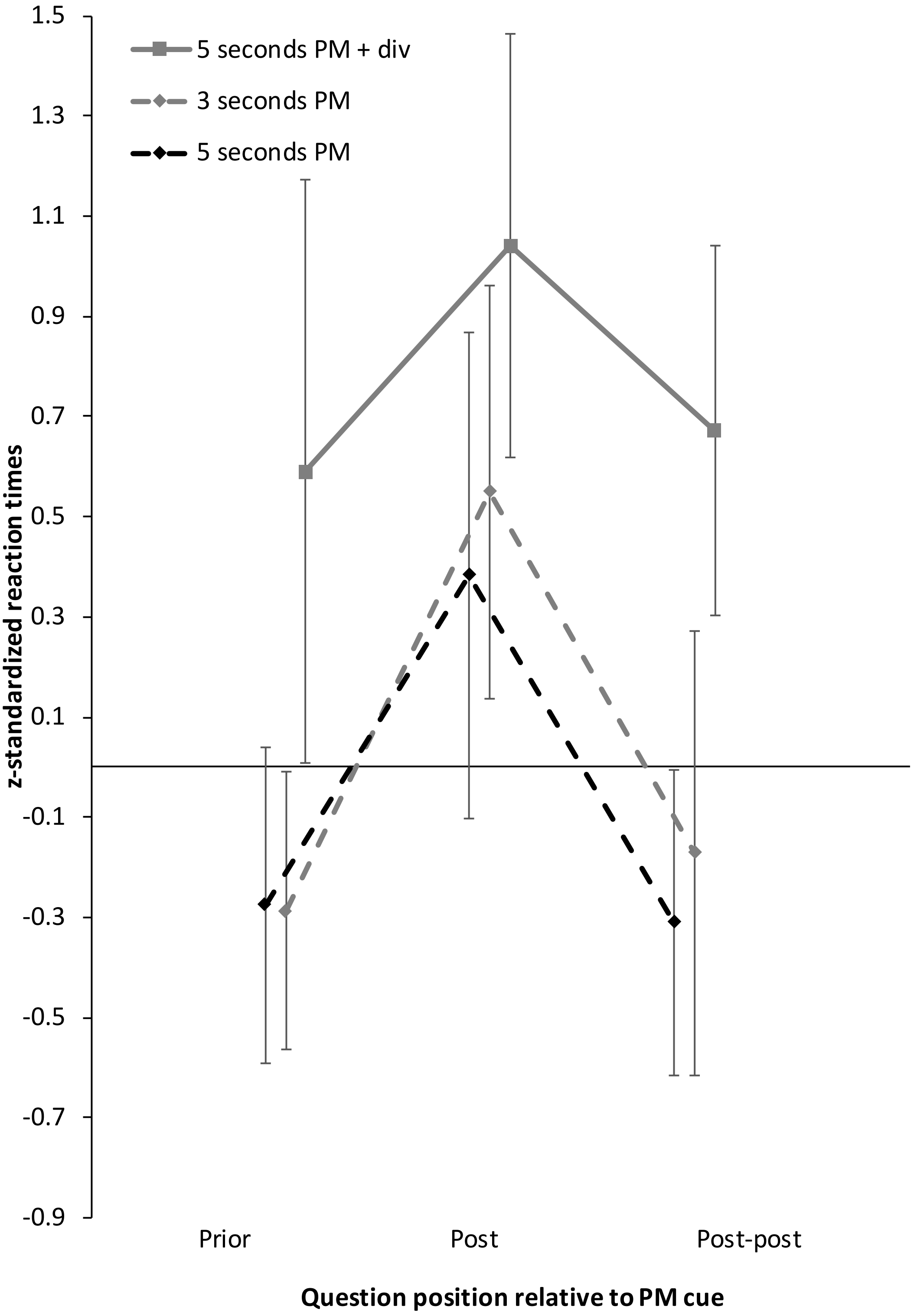

Figure 2. Z-standardized reaction times of Experiment 2 separated by question position relative to the prospective memory cue (prior, post, post-post) and group allocation (5 seconds prospective memory, 3 seconds prospective memory, 5 seconds prospective memory + div). Error bars represent SD.

***Annex B:* Study 2 - The effects of different distractions on remembering delayed intentions**

Schaper, P., & Grundgeiger, T. (2018). The effect of different distractions on remembering delayed intentions. *Memory*, *26*(2), 154-170.

Author	Contribution
Schaper, P.	Literature review, experimental design (Exp. 2), data collection (Exp. 2), data analysis (Exp. 1 & 2), manuscript preparation and revision
Grundgeiger, T.	Experimental design (Exp. 1), data collection (Exp. 1), data analysis (Exp. 1), contributed to experimental design (Exp. 2), manuscript revision

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The effect of different distractions on remembering delayed intentions

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ABSTRACT
In safety-critical domains, frequently intentions need to be delayed until an ongoing task is completed. Research using the delay-execute paradigm showed that interruptions during the delay cause forgetting. However, staff members often handle an initial distraction not by interrupting the ongoing task but by acknowledging the distraction or multitasking. In Experiments 1a and 1b, we observed that, compared to a no distraction condition, multitasking significantly decreased remembering of intentions and interrupting decreased remembering even further. In Experiment 2, interruptions with context change reduced remembering of intentions compared to uninterrupted delays, and at the same time, interruptions without context change improved memory performance compared to uninterrupted delays. However, improved memory performance resulted in decreased interrupting task performance. Theoretically, the results support the contextual cueing mechanism of delay-execute tasks. Considering safety-critical domains, multitasking, interruptions and context changes can contribute to forgetting of tasks.

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Delay-execute paradigm; prospective memory; interruptions

Forming an intention at one point and remembering to execute the intention at a later point in time – a phenomenon known as prospective memory (PM) – is a common and important task in daily living and at work (Kliegel, McDaniel, & Einstein, 2008; Marsh, Cook, & Hicks, 2006a; McDaniel & Einstein, 2007). Forgetting an intention in our daily life is annoying or even costly; however, forgetting an intention in safety-critical domains, such as the cockpit of an aircraft (Dismukes, Young, Sumwalt, & Null, 1998) or critical care (Grundgeiger, Sanderson, MacDougall, & Venkatesh, 2010), might jeopardise human lives.

The present research focuses on *delay-execute* PM tasks. In these tasks, the intention may be retrieved from memory due to a certain event, but the execution needs to be delayed for at least 5 s, whereas in *retrieve-execute* tasks, the intention can be executed immediately (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). Nurses, for example, frequently face situations where they need to remember such delayed intentions (Ebright, Patterson, Chalko, & Render, 2003; Grundgeiger et al., 2010; Tucker & Spear, 2006). A doctor might tell a nurse to change the rate of an infusion, while the nurse is currently checking vital sign alarm limits on the patient monitor. The nurse needs to delay the new intention until the alarm limit check is finished. Research has shown that delay-execute PM tasks are particularly vulnerable to interruption during the delay phase (e.g., Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). However, in safety-critical domains interruptions are not the only form of distractions (e.g., Colligan & Bass, 2012; Grundgeiger et al., 2010). In the present paper, we investigated the influence of different types of distractions during the delay phase on delay-execute PM task performance (Experiments 1a and 1b) and demonstrated the negative effects of task context changes as part of an interruption (Experiment 2).

Distraction types in safety-critical domains

Safety-critical domains, such as healthcare, are cognitively challenging environments because of multiple tasks and time pressure (DeLucia, Ott, & Palmieri, 2009) and in particular due to frequent distractions and interruptions (Biron, Lavoie-Tremblay, & Loiselle, 2009; Grundgeiger & Sanderson, 2009). The negative influence of interruptions on PM performance has been extensively investigated in the laboratory (for a review see Trafton & Monk, 2007). However, in field settings such as healthcare (Colligan & Bass, 2012; Grundgeiger et al., 2010) or office environments (Zijlstra, Roe, Leonora, & Krediet, 1999), humans do not necessarily interrupt an activity because of an initial distraction. For example, Grundgeiger et al. (2010) investigated how nurses manage distractions. Nurses acted on distractions using any of three different strategies. First, nurses might *acknowledge* the distraction. For example, a second nurse would ask the participating nurse to check the expiry date of a medication. This check requires only a brief look at the medication and does not require a break in the task at hand, which is a critical component

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in research on interruptions (Brixey et al., 2007; Trafton, Altmann, Brock, & Mintz, 2003). Second, nurses might *multitask*. A doctor, for example, might ask the participating nurse a question about the patient while the nurse is setting up an infusion pump. For multitasking, the nurse would continue the set-up and answer the question concurrently. Third, nurses might *interrupt* the task at hand. For example, a second nurse might ask whether the participating nurse could hold a breathing tube in place while turning a patient. In contrast to acknowledging and multitasking, an interruption always involves breaking with the task at hand.

Research on distractions and interruptions in safety-critical domains is frequently motivated by research from cognitive psychology that has shown interruptions can lead to forgetting tasks (e.g., Dodhia & Dismukes, 2009; Einstein et al., 2003; McDaniel, Einstein, Graham, & Rall, 2004). In regards to delay-execute PM tasks, there is good evidence that interruptions during the delay cause forgetting (e.g., Ball, Knight, Dewitt, & Brewer, 2013; Cook, Meeks, Clark-Foos, Merritt, & Marsh, 2013; Einstein et al., 2003; McDaniel et al., 2004). However, to our knowledge, there are no empirical studies on whether other distraction types have similar detrimental effects on delay-execute PM task performance. To this end, we compare the influence of different distraction types observed in the healthcare domain on delay-execute PM task performance in Experiments 1a and 1b.

Different distraction types and delay-execute PM

PM researchers have investigated the effects of various manipulations on the execution of delayed intentions (Einstein et al., 2000; Kliegel & Jäger, 2006; McDaniel, Einstein, Stout, & Morgan, 2003; Rendell, Vella, Kliegel, & Terrett, 2009) and the effect of interruptions has raised particular interest (Ball et al., 2013; Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004; Schaper & Grundgeiger, 2017). In the experimental set-up, participants were involved in working on task sets that lasted 1 min each. Participants were required to press a certain key on the keyboard whenever the screen briefly flashed red *but not until the current task set had finished and a new task set had started*. The participants, therefore, had to delay the intention to press the key until the appropriate point in time. Delaying the response for 5 s lowered PM performance (Einstein et al., 2003; McDaniel et al., 2004). Interestingly, longer delays of 15 or 40 s did not further decrease performance. However, an additional interruption by a pattern-comparison test (Salthouse & Babcock, 1991) during delay periods of 10, 15, or 20 s decreased PM performance dramatically (Einstein et al., 2003; McDaniel et al., 2004). The length of the interruption (10 vs. 20 s) did not affect performance (McDaniel et al., 2004).

Theoretically, the *active maintenance view* has been supported as an explanation for how people remember delayed intentions (Einstein et al., 2003; McDaniel et al., 2004). The active maintenance view of delayed PM suggests that remembering depends upon periodic activation of the intention. Such a periodic activation is assumed to be supported by two mechanisms: *contextual cueing* and *strategic rehearsal*.

Contextual cueing is based on the idea that when the participant sees the PM cue an association is formed automatically between the intention to execute the associated action and the ongoing task (Cook et al., 2013; Einstein, McDaniel, Smith, & Shaw, 1998; Marsh, Cook, & Hicks, 2006b; McDaniel, Robinson-Riegler, & Einstein, 1998; Nowinski & Dismukes, 2005). Working on the ongoing task seems to keep the intention activated by serving as a constant cue. Contextual cueing is supported by studies that manipulated the task context during which a PM task had to be executed. If the context of the PM cue task is the same during the window of opportunity, then performance is enhanced compared to cues during an interruption (Cook et al., 2013) or a different ongoing task context (Nowinski & Dismukes, 2005). Additionally, PM performance is higher if the context of the window of opportunity is known to the participants compared to an unknown or to a deliberately presented wrong context (Cook et al., 2013).

Strategic rehearsal refers to periodic checking of memory for incomplete intentions (Ellis, 1996; Kvavilashvili, 1987). The checks are assumedly resource demanding (Einstein et al., 2003). Strategic rehearsal has been supported by findings that showed decrements in remembering when participants had to do an additional, resource requiring task during the delay and retrieval phase, such as an additional digit monitoring task (Einstein et al., 2003). Participants with high working memory capacity showed better delay-execute PM performance compared to low working memory capacity (Ball et al., 2013). Furthermore, individuals with declined working memory capacity due to age (Kliegel & Jäger, 2006) or not yet fully developed attentional capacity (Rendell et al., 2009) showed impaired delay-execute PM performance.

The negative influence of interruptions on PM performance during the delay has been explained in various ways. The most prominent explanation is disrupted strategic rehearsal. Strategic rehearsal is impeded by additional cognitive demand (Einstein et al., 2003) and if the demands of the interrupting task are too high to allow rehearsals, the intention might be forgotten. Available resources during ongoing tasks as well as during interruptions seem to facilitate the rehearsal of the intention and therefore result in better PM performance.

Furthermore, interruptions might disrupt contextual cueing by the ongoing task (Einstein et al., 2003). When participants turn to the interruption they suspend processing of the ongoing task demands and the PM task. On returning to the ongoing task, the ongoing task demands are reactivated but not the PM task. Although the effect of task context has been shown (Cook, 2005; Hicks, Marsh, & Cook, 2005; Kominsky & Reese-Melancon, 2017;

McDaniel et al., 1998; Nowinski & Dismukes, 2005), the above suggested contextual cueing mechanism has not been empirically addressed. Experiments 1a and 1b indicate that task context might be relevant for PM performance in the delay-execute paradigm, and we specifically addressed this mechanism in Experiment 2.

The main aim of Experiments 1a and 1b was to investigate whether different distraction types observed in the field (acknowledging, multitasking, and interrupting) during the delay phase affect performance in delay-execute PM tasks. In Experiment 2, we used the insights from Experiments 1a and 1b to specifically address the effect of context change as part of an interruption. We investigated whether the degree of context change as part of an interruption affects delay-execute PM performance.

Experiments 1a and 1b

The experimental design and procedure were based on Einstein et al. (2003). Participants were required to answer sets of multiple-choice questions as an ongoing task. At some points, a red screen would flash and participants were told to press the slash key ("/") *but only after the current set of questions had finished and the next set of questions on a different topic had started*. The delay between cue and the window of opportunity (i.e., the change of question type) was set at 40 s for both experiments. Participants had to work on three additional tasks during the delay phase that resembled different strategies observed in the field (Grundgeiger et al., 2010): For *acknowledging*, participants were required to briefly judge which of three lines matched the length of a given line while still working on the ongoing task; for *multitasking*, participants had to tally the number of odd digits presented via a speaker for 15 s while still working on the ongoing task; for *interrupting*, the ongoing task stopped and participants had to turn away from the screen and do a symbol substitution task for 15 s located to their right. Finally, a condition with *no distraction* during the delay was used as a control. The distraction manipulation is shown graphically in Figure 1.

Theoretically, acknowledging may be considered as a short period of divided attention. Based on the idea that participants use strategic rehearsal to keep the intention active and the finding that divided attention during the whole set reduced PM performance (Einstein et al., 2003), acknowledging may reduce PM performance compared to the no distraction condition. But as the context is not changed contextual cueing should not be affected by acknowledging. Multitasking may be considered as a long period of divided attention. Therefore strategic rehearsal should be negatively affected, because additional cognitive resources are required for the distracting task. However, because the context is not changed contextual cueing should not be affected by multitasking. Based on this reasoning, we also predict lower PM performance for PM sets that include multitasking during the delay phase compared to the no distraction condition. Interrupting may affect strategic rehearsal because a different task with different task demands has to be started as well as context change because the ongoing task is discontinued and the ongoing task-PM task association does no longer keep the PM task activated. Based on this reasoning and on the findings summarised above (e.g., Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004), we expect to replicate the negative effect of interruptions during the delay phase on PM performance compared to the no distraction condition. Finally, because interrupting includes a context change and acknowledging and multitasking do not, PM performance may be even more compromised for interrupting compared to acknowledging and multitasking.

In safety-critical settings, such as intensive care or aviation, a task at hand is often crucial and high levels of accuracy are important (DeLucia et al., 2009). To mimic these conditions, we introduced task priority as a between-subjects factor in Experiment 1a. In one group, all tasks were assigned the same priority. In the second group, the

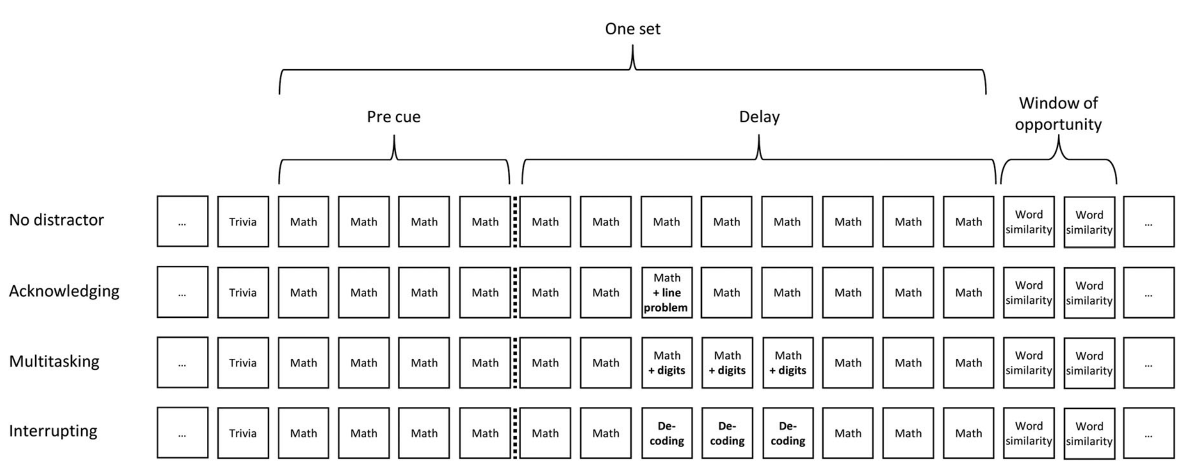

Figure 1. Graphic representation of distraction conditions (no distractor, acknowledging, multitasking and interrupting) in Experiment 1a. Each square represents one question which was presented for 5 s each. The bold dotted lines represent the prospective memory cue (i.e., red screen).

ongoing task was assigned the highest priority. If the ongoing task is assigned a higher priority in attention-demanding (i.e., non-focal) retrieve-execute PM tasks compared to less or non-attention-demanding (i.e., focal) PM tasks, participants appear to devote more attentional resources to the ongoing task (Kliegel, Martin, McDaniel, & Einstein, 2004). If this finding translates to the delay-execute paradigm, PM performance in the acknowledging and multitasking condition should be worse in the ongoing task high priority condition compared to the same priority condition. For the interruption manipulation, PM performance may increase in the ongoing task high priority condition compared to the same priority condition, because a higher priority of the ongoing task may allow better reactivation of the ongoing task context after the interruption and subsequently of the PM task compared to the same priority condition.

The aim of Experiment 1b was to replicate the effects of the different distraction types on PM performance. In particular, the operationalisation of multitasking and interruption might have resulted in different cognitively demanding tasks (counting the odd digits for multitasking vs. symbol substitution task for interrupting) in Experiment 1a. In Experiment 1b, the interrupting task was changed to resemble the demands of the multitasking task.

Finally, as the timing of distractions can seldom be influenced by the affected person and distractions could occur at any time during the delay, we introduced the between-subject factor distraction onset (early and late) to investigate the effect of distraction onset on PM performance. We expected that PM performance should be better for early interruptions compared to late interruptions, because participants spend more time on the ongoing task before the window of opportunity to reactivate the PM task (Cook et al., 2013). For acknowledging and multitasking, we expected no effect of the onset manipulation as the PM task should not have been discarded due to these manipulations.

Method

Participants

In each experiment 40 first year psychology students of The University of Queensland, Australia, participated for course credit (Experiment 1a: 5 males, average age 19 years; Experiment 1b: 6 males, average age 20 years). Based on the answer to a questionnaire at the end of the experiments, two participants were replaced in Experiment 1a and one participant was replaced in Experiment 1b. These participants failed to correctly recall the PM task and it was therefore not possible to tell whether they forgot to execute the PM task or did not understand the PM task at all (cf. Einstein et al., 2003).

Design

Experiments 1a and 1b had a 2 × 4 mixed factorial design. In Experiment 1a, the factor task priority was manipulated between subjects. The participants were told that answering the ongoing questions had the highest priority of all tasks (ongoing task priority), or they were told that all three tasks had the same priority (same priority). In Experiment 1b, the factor distraction onset (early vs. late) was manipulated between subjects. In both experiments, the within-subject factor was distraction type during the delay period (no distraction, acknowledging, multitasking, and interrupting). The main dependent variable was PM performance. In addition, we collected data on interrupting task performance and subjective rehearsal ratings. Data on ongoing task performance was not recorded.

Procedure and materials

To reduce complexity, the instructions were given in four steps, interleaved with practice on the computer. After each practice session, the participants could ask questions or the experimenter would comment on their actions if necessary.

First, the ongoing task was introduced. The participants were told that they would be presented with sets of questions. Each set would have several questions of the same question type. Each question had four possible answers (the four answer keys h, j, k, and l, were marked with labels A, B, C, and D). Participants were instructed to enter an answer by pressing the corresponding key on the keyboard with their preferred hand. Furthermore, the programme would not move on as soon as the participant entered the answer, but would move on automatically after 5 s. For each ongoing task question, the question type, the current question and the answer choices were displayed. The first practice included two question of each question type. Participants were told that the programme recorded accuracy and response times but in reality, these data were not collected.

Second, the PM task was introduced. The participants were informed that at certain points during a question set, a red screen would briefly flash for 1 s. If the participants saw a red screen, they would need to press the slash key ("/") on the keyboard, *but only after the current task set had finished and the next set with a different question type had started*. The response key was the "v" key for left-handed participants. In Experiments 1a and 1b, a standard QWERTY keyboard was used and the slash key and "v" key were, therefore, in similar positions relative to the input keys for the ongoing task, depending on the participant's dominant hand. The participant then did a practice set which included a PM task and required a response at the beginning of the next set.

Third, the distracter tasks were introduced. The participants were told that at random points they would be asked via speakers to work on an additional task. If the participants heard "Please judge the next line!" they were instructed to solve the first line problem by comparing the given line with the three possible answers and marking the line with the same length (acknowledging). Four line-length judgment problems were printed on a single sheet of paper that was placed on the left side of the keyboard (right side for left-handed participants). In addition, participants would still need to work on the questions on the screen. Therefore, the line would need to be marked with the non-preferred hand.

If the participants heard "Please make a tally of the odd digits!" they were told to tally up the number of odd digits on the sheet provided (multitasking). Two audio files were prepared with seven digits and two files with eight digits. In all four audio files, a digit was presented approximately every 1.5 s. A sheet of paper with four boxes was placed on the left side of the keyboard below the sheet with the line problems for tallying the digits (right side for left-handed participants). Again, participants were instructed to continue to work on the questions on the screen and use the non-preferred hand for tallying.

Finally, if participants heard "Please decode the next page!" they were told that the questions would stop and they needed to turn to the right and decode the first page of the booklet by matching the symbols with the according numbers (interrupting). The task materials were taken from the Digit Symbol Substitution task in the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). A four-page booklet, each page containing the digits one to nine with according symbols and a random array of 25 symbols, was placed on a side table located to the right of the participant. The participants had to write the matching numbers under the symbol of the random array. The participants were further instructed to keep an eye on the screen and return to the ongoing task immediately once the questions resumed. The participants were instructed to hold the pen in their non-preferred hand throughout the experiment, but could change hands for the decoding task. This way, the participants could not use their non-preferred hand as external memory aid. The participants then did three sets of questions to practice the three distracter tasks.

Fourth, the experimenter tested whether the participant understood the different tasks by asking what they would need to do if they saw a red screen or heard any of the three audio alerts. In addition, the participants were told that the additional tasks (distracter tasks) were not considered a change of questions. Only a change of questions type on the screen would indicate pressing the "/" key. Finally, in the same priority condition, participants were told that the three tasks (answering questions, pressing slash, and the additional tasks) had the same priority and they should try to do them equally well. In the question highest priority condition, participants were told that answering the questions had the highest priority. Participants should work on all tasks, but answer the questions as correctly as possible.

The instructions in Experiment 1b were the same as for Experiment 1a, except for the following changes: First, to match the multitasking distraction task and the interrupting task, participants were told that if they hear "Please mark the numbers!" the questions on the screen would stop and they should turn to the right and mark the numbers read out in the boxes provided. This instruction replaced the interrupting instructions from Experiment 1a. Each 4×10 box each containing the digits 1–9 in a random fashion were printed on a sheet of paper and placed on a table to the right of the participant. We created four audio files with the alert "Please mark the numbers!" followed by seven or eight digits presented approximately every 1.5 s. The participants were further instructed to keep an eye on the screen and return to the question task immediately when the questions resumed. Second, all participants were told that the three parts (answering questions, pressing slash, and the additional tasks) had the same priority and they should try to do them equally well.

The ongoing task consisted of 35 sets, each containing 12 questions, resulting in 420 individual questions. Seven different question types were used which appeared equally often, (1) judging the similarity of two words, (2) judging how well a word fitted in a category, (3) judging how pleasant a word is, (4) trivia questions, (5) calculating simple math problems, (6) finding the letter that is not in a shown word, and (7) indicating the synonym of a given word. Each question type occurred once in a block of 7 sets. The order within a block was determined randomly with the additional constraint of no repetition of question types in succession at a block border.

In Experiment 1a, the red screen occurred 8 times (sets 4, 6, 13, 18, 21, 25, 30, and 34). The red screen occurred once during each question type, except for "finding the letter that is not in the word", where it was used twice. Each of the four distraction types (no distraction, acknowledging, multitasking, and interrupting) appeared once in the first 18 sets and once in the remaining 17. To balance the design, four counterbalanced conditions were created. Over the four conditions, each distraction happened equally often at each of the eight positions.

The red screen always appeared after the fourth question of a task set. Therefore, the intention to press the slash key always needed to be delayed for 40 s. The red screen was always followed by two further questions. In the no distraction sets, the remaining 30 s were filled with six additional questions. In the acknowledging sets, the audio alert to do the next line problem was played with the seventh question and five further questions followed. In the multitasking sets, the audio alert to count the odd digits was played with the seventh question and the digits were played back. The digits started during the seventh question and were present for two further questions. The multitasking period (including the audio alert) lasted 15 s in total and was followed by three further questions. In the interrupting sets, the audio alert to decode the next page was played after the sixth question and the screen showed "Please go to decoding task!" for 15 s. After the 15 s, 3 additional questions followed.

To avoid an association between the distractions and pressing the slash key at the end of every distracted set, further distractions were implemented in sets with no PM task (sets 2, 7, 11, 15, 19, 23, 26, and 32). Again, the distractions (including no distraction) were counterbalanced and happened equally often in the eight positions. Furthermore, the additional distractions occurred at different positions within a question set (acknowledging at the fifth and the ninth question, multitasking at the third and sixth question, and interrupting at the second and eighth question).

For Experiment 1b a new set order was constructed with the same questions and constraints as in Experiment 1a. For each participant, the red screen occurred 8 times (sets 3, 9, 13, 17, 21, 24, 30, and 34). Each question type was used once and rating word pleasantness was used twice. Counterbalancing was done as in Experiment 1a.

The red screen always appeared after the second question of a task set and therefore needed to be delayed for 50 s. Again, the red screen was always followed by two further questions. In the no distraction sets, the remaining 40 s were filled with eight additional questions. In the acknowledging sets, the audio alert to do the next line problem was played with the fifth question in the early condition and the 10th question in the late condition. In the multitasking sets, the audio alert to count the odd digits was played with the fifth question in the early condition and the eighth question in the late condition. In both conditions, the digits were present for two further questions (total length, including alert, 15 s). In the interrupting sets, the audio alert to mark the numbers was played after the fifth question in the early condition and the eighth question in the late condition. The screen showed "Please go to marking task!" for 15 s. After the three possible distractions, ongoing task questions were added to produce sets lasting 1 min each. As in Experiment 1a (Figure 1), all sets lasted 1 min and all delays were 50 s, independent of possible distraction. The early and late levels were chosen to maximise the time working on the ongoing task after the distraction for the early level, and to minimise this duration for the late level.

Further distractions were implemented in question sets with no PM task (sets 2, 6, 11, 15, 18, 23, 27, and 32). In all conditions in Experiment 1b, sets 15 and 23 included no additional distractions, sets 11 (11th question) and 27 (fifth question) included an acknowledgement, sets 2 (third question) and 32 (sixth question) included multitasking, and sets 6 (fourth question) and 18 (eighth question) included interrupting.

At the end of Experiments 1a and 1b, the participants filled in a questionnaire asking about demographics, what they had to do when the red screen occurred, and when they were meant to execute this action. These questions were used to retrospectively ensure that participants understood the PM task instructions correctly and could still correctly recall the instructions. The final question asked how participants tried to remember the intention (cf. Einstein et al., 2003). In both experiments, participants could indicate their answer on a 5-point scale (1 = "tried to rehearse the intention", 5 = "let it pop into mind"). All participants were individually tested and the session lasted approximately 50 min.

Results

For all experiments, a correct PM response was defined as pressing the target key within the first two questions of a new question type after the PM cue. All analyses were conducted with SPSS 22 (Chicago, IL) and alpha was set at .05. We report Cohen's *d* or partial eta squared (η_p^2) for effect sizes.

PM performance

We calculated the proportions of correct PM answers out of two answers per condition as measure for PM performance (Table 1). In both experiments, all participants showed at least three PM responses, which indicated that failure for other sets were probably due to PM failures and not retrospective memory failures.

For Experiments 1a, we conducted a 2 × 4 mixed ANOVA for PM performance with the within-factor distraction type (no distraction, acknowledging, multitasking, and interrupting) and the between-factor task priority (same priority and ongoing task high priority). The analysis showed a significant main effect of distraction type, $F(3, 114) = 18.45$, $p < .001$, $\eta_p^2 = .33$ but no significant effect of priority, $F(1, 38) = 0.05$, $p = .826$, $\eta_p^2 = .00$. The interaction was also not significant, $F(1, 114) = 0.58$, $p = .632$, $\eta_p^2 = .02$.

To follow up the main effect of distraction type, we conducted Bonferroni-corrected *post hoc* tests. The analysis showed no difference between the no distraction baseline and acknowledging ($p = .264$, $d = 0.50$), but better performance in the no distraction baseline compared to multitasking ($p = .006$, $d = 0.87$) and interrupting ($p < .001$, $d = 1.35$).

Table 1. Proportion of remembered intentions in Experiments 1a and 1b depending on distraction condition and priority condition (Experiment 1a) or distraction onset (Experiment 1b).

		Distraction condition			
		No distraction	Acknowledging	Multitasking	Interrupting
Experiment 1a	Same priority	0.98 (0.11)	0.85 (0.24)	0.80 (0.25)	0.48 (0.41)
	Ongoing task high priority	0.95 (0.15)	0.88 (0.28)	0.75 (0.30)	0.58 (0.47)
	Average	0.96 (0.13)	0.86 (0.25)	0.78 (0.28)	0.53 (0.44)
Experiment 1b	Early distraction	0.90 (0.21)	0.85 (0.24)	0.83 (0.24)	0.58 (0.44)
	Late distraction	0.98 (0.11)	0.85 (0.24)	0.78 (0.34)	0.50 (0.32)
	Average	0.94 (0.17)	0.85 (0.23)	0.80 (0.30)	0.54 (0.38)

Note: Standard deviations are in parentheses.

PM performance in the acknowledging condition was significantly better compared to interrupting ($p < .001$, $d = 0.94$) but not compared to multitasking ($p = .421$, $d = 0.33$). Finally, PM performance in the multitasking condition was significantly better compared to the interrupting condition ($p = .007$, $d = 0.68$).

For Experiment 1b, we conducted a 2 × 4 mixed ANOVA for PM performance with the within-factor distraction type (no distraction, acknowledging, multitasking, and interrupting) and the between-factor distraction onset (early and late). The analysis showed a significant main effect of distraction type $F(3, 114) = 20.21$, $p < .001$, $\eta^2_p = .35$, but no significant effect of distraction onset $F(1, 38) = 0.04$, $p = .836$, $\eta^2_p = .00$. The interaction was also not significant $F(3, 114) = 0.75$, $p = .527$, $\eta^2_p = .02$.

Bonferroni-corrected *post hoc* tests showed no difference between the no distraction baseline and acknowledging ($p = .198$, $d = 0.43$) and multitasking ($p = .086$, $d = 0.57$), but better performance in the no distraction baseline compared to interrupting ($p < .001$, $d = 1.36$). PM performance in the acknowledging condition was significantly higher than for interrupting ($p < .001$, $d = 0.99$) but not for multitasking ($p = 1$, $d = 0.19$). Finally, PM performance in the multitasking condition was significantly better compared to the interrupting condition ($p = .001$, $d = 0.77$).

Distraction tasks performance

For Experiment 1a, performance on the three additional tasks was compared between the priority conditions (same priority and ongoing task high priority) by calculating *t*-tests for independent samples. The means for the number of correctly answered line problems (out of four) for acknowledging did not differ significantly across priority conditions (same priority: $M = 3.20$, $SD = 0.95$; ongoing task high priority: $M = 3.10$, $SD = 0.79$), $t(38) = 0.36$, $p = .719$, $d = 0.12$. There was no difference between the means for the number of errors made when counting odd numbers while multitasking (same priority: $M = 0.85$, $SD = 1.6$; ongoing task high priority: $M = 0.75$, $SD = 1.21$; $t(38) = 0.22$, $p = .825$, $d = 0.07$). Finally, the number of correctly solved symbols during the interruption between the same priority condition ($M = 31.75$, $SD = 8.23$) and the ongoing task high priority conditions ($M = 27.65$, $SD = 6.06$) did not differ significantly $t(38) = 1.79$, $p = .081$, $d = 0.57$.

For Experiment 1b, performance on the three additional tasks was compared between the distraction onset conditions (early and late) by calculating *t*-tests for independent samples. The means for the number of correctly answered line problems (out of four) for acknowledging did not differ significantly (early: $M = 3.20$, $SD = 0.70$; late: $M = 3.10$, $SD = 0.85$), $t(38) = 0.41$, $p = .687$, $d = 0.13$. The means for the number of errors made when counting odd numbers while multitasking did not differ significantly (early: $M = 0.55$, $SD = 1.15$; late: $M = 0.60$, $SD = 0.82$), $t(38) = -0.16$, $p = .875$, $d = 0.05$. The interrupting task performance in both groups was perfect, but one participant committed a single mistake.

Other measures

In Experiment 1a a simple *t*-test for independent samples was calculated to analyse whether there were differences in the amount of rehearsal of the intention to press the slash key between the same priority condition ($M = 2.95$, $SD = 1.00$) and the ongoing task high priority condition ($M = 3.15$, $SD = 1.09$). The conditions did not differ significantly $t(38) = -0.61$, $p = .549$, $d = 0.19$. Similarly in Experiment 1b, there was no difference in the reported amount of rehearsal of the intention to press the slash key between early ($M = 3.10$, $SD = 1.25$) and late condition ($M = 3.10$, $SD = 1.25$), $t(38) = 0.0$, $p = 1$, $d = 0.00$.

Discussion

The results of Experiment 1a indicated that multitasking and interrupting but not acknowledging caused forgetting of delayed intentions when compared to an uninterrupted baseline, but only the significant difference between the baseline (no distraction) condition and interrupting could be replicated in Experiment 1b. The negative influence of interruptions on PM performance replicated existing research (Ball et al., 2013; Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004; Schaper & Grundgeiger, 2017). In both experiments, PM performance in the interrupting condition was significantly lower than in the baseline, acknowledging and multitasking conditions. In particular, even when task characteristics of multitasking and interrupting were more similar in Experiment 1b, interrupting caused significantly more forgetting than multitasking.

Contrary to our hypothesis, we did not observe any negative effects of acknowledging (a very brief period of divided attention in the ongoing task context). This result may indicate that strategic rehearsal was not negatively affected by short distractions. As expected, in the multitasking condition (15 s of divided attention in the ongoing task context), strategic rehearsal appeared to be negatively influenced by the additional task, resulting in significantly lower PM performance compared to the no distraction condition in Experiment 1a. This difference was not significant in Experiment 1b, even though the performance was similar on the descriptive level, while the effect size as Cohen's *d* is smaller (Experiment 1a: .19 difference, $d = 0.883$; Experiment 1b: .14 difference, $d = 0.573$).

As hypothesised and consistent across both experiments, PM performance in the interrupting condition was significantly lower compared to the multitasking condition. This difference may be explained by the additional context change in the interrupting condition compared to the multitasking condition. In Experiment 1a, the cognitive demand of the interrupting task (symbol decoding task) might also have been higher compared to the cognitive demand of multitasking (ongoing task and marking odd digits). This may have caused less strategic rehearsal in the interrupting condition, as available cognitive resources were low, resulting in lower PM performance compared to the multitasking condition. However, after adapting the interrupting task to match the demands of multitasking and interrupting in Experiment 1b, an almost identical PM performance as in Experiment 1a was found.[1] Performance was still significantly lower in the interrupting condition relative to the multitasking condition, indicating the difference was caused by contextual cueing rather than strategic rehearsal. Finally, in Experiments 1a and 1b, we found no significant differences in subjective rehearsal ratings between the experimental groups.

The priority manipulation in Experiment 1a did not meaningfully affect PM performance ($\eta_p^2 = .00$) which might indicate that priority does not affect PM performance in the delay-execute paradigm. Such an interpretation would be consistent with results from retrieve-execute PM studies in which no effect of importance was found (Kliegel, Martin, McDaniel, & Einstein, 2001). It has been suggested that importance can influence PM performance if strategic allocation of resources is necessary for successful PM performance (Kliegel et al., 2004). In Experiment 1a, the PM event (i.e., red screen) can be considered a salient event which may have captured attention regardless of task emphasis (Smith, Hunt, McVay, & McConnell, 2007). Alternatively, the present priority manipulation may have not been internalised by the participants. Possible manipulation checks, such as performance in the distraction task (which should be worse in the ongoing task high priority) and rehearsal ratings (which should be higher in the ongoing task high priority) did not differ significantly. However, with sufficient statistical power ($1-\beta = 0.80$), we were only able to detect medium to large priority or distraction onset effects ($\eta_p^2 = .11$). In summary, based on the present data, the effect of priority instructions in the delay-execute PM task remains inconclusive.

The distraction onset manipulation in Experiment 1b indicated that the distraction timing did not meaningfully influence delay-execute PM performance ($\eta_p^2 = .00$). The results in relation to interruptions are in line with a study by McDaniel et al. (2004) in which a 10-s interruption and additional 20 s of ongoing task caused similar forgetting compared to a 20-s interruption and an additional 10 s of ongoing task. However, in the study by McDaniel et al. (2004) the different times were confounded with interruption duration. In Experiment 1b, this discrepancy was not present, but early distractions (25 s of ongoing task after distraction) and late distractions (10 s of ongoing task after distraction) resulted in similar delay-execute PM performances. Overall, it seems plausible to conclude that distraction onset does not affect PM. However, as mentioned above, with sufficient statistical power we were only able to detect medium to large distraction onset effects.

Overall, the results of Experiments 1a and 1b suggest that contextual cueing seems to affect PM performance. As Einstein et al. (2003) suggested, the intention might be discarded at the beginning of the interruption, but not reinstated when the ongoing task is resumed. We explicitly investigated the effect of context change in Experiment 2.

Experiment 2

In Experiment 2, we decided to follow up on the negative influences of the different distraction types in Experiments 1a and 1b. We focused on interruptions due to the strong negative effect on PM performance. Therefore, we used only interruptions as distractions and tested whether different degrees of context change would influence PM performance. To this end, we used a lexical decision task (LDT) as the interrupting task. One group of participants conducted the LDT on a computer (no context change) and the other group conducted the LDT with paper and pencil (context change). Both tasks were set to be as similar as possible in all aspects besides the medium to convey the LDT and, therefore, elicit context change or no context change, respectively. As in Experiments 1a and 1b, the interrupting task was set up in a right angle to the participant (for the no context change group, we used an additional monitor and keyboard); it was self-paced, and participants had to monitor whether the ongoing task on the first screen had restarted. To imitate unfinished tasks on paper, the screen with the LDT still displayed questions, even though the ongoing task had restarted. This manipulation enabled us to test the influence of contextual cueing without simultaneously affecting cognitive resources. Furthermore, we included a non-interrupted delay condition as baseline.

As in previous research (e.g., Ball et al., 2013; Einstein et al., 2003), we expected a main effect of interruption with better PM performance for PM tasks without interruption during the delay compared to PM tasks with interruption. The results of Experiments 1a and 1b also indicated that the degree of context change affects delay-execute PM performance (e.g., Einstein et al., 2003; Hicks et al., 2005; Kominsky & Reese-Melancon, 2017). Therefore, we expected a significant context × interruption interaction. PM performance in both groups should be similar if no interruption occurs, but with an interruption during the delay, PM performance should be better in the no context change group compared to the context change group.

In Experiment 2, we also measured ongoing task performance. Based on the studies by Ball et al. (2013), we expected to find slowed reaction times in the ongoing task trial immediately following the PM cue (red screen). For PM research, this is an indication that the PM task is retrieved (Ball et al., 2013; Einstein et al., 2005). In addition, we analysed the ongoing task performance during the delay phase. Based on the results of Ball et al. (2013) and Schaper and Grundgeiger (2017), we did not expect slowed ongoing task response times for sets with active PM tasks compared to set with no PM tasks.

Method

Participants

A total of 76 students participated in exchange for partial course credit (students at the Institute of Human-Computer-Media, 59% of sample) or were paid 10€ (other students at the Julius-Maximilians-Universität Würzburg). Twelve participants were excluded from the analysis either because they could not correctly recall the PM task at the end of the experiment (four participants) or because they deviated from the instructions such as pressing "q" immediately upon seeing the red screen (eight participants). The final sample consisted of 64 participants (14 males, average age 21.5 years).

Design

The design included the factor context (no context change vs. context change) as between-factor and interruption (no interruption vs. interruption) as within-factor. The main dependent variable was PM performance. In addition, we collected data on ongoing task performance, interrupting task performance, and subjective rehearsal ratings.

Procedure and materials

As in Experiments 1a and 1b, the instructions were given in three steps, interleaved with practice on the computer or on paper, depending on the allocated group. Before each practice session, the participants were given the opportunity to ask questions or the experimenter would comment on their actions if necessary.

First, participants were instructed about the ongoing task. Participants had to answer questions within 3 s and indicate their answer by pressing either the left or right arrow key on a keyboard. The next question was shown automatically after 3 s had elapsed. Participants were instructed to use their index fingers for pressing the keys and to keep the fingers on the keys throughout the experiment. The key configuration was counterbalanced within each group. We used six different question types: (1) deciding if a word contains a specific letter, (2) deciding if a word belongs to a specific category, (3) indicating if a third number (not shown) in a sequence is odd or even based on the preceding numbers, (4) deciding if a word describes a living or non-living object, (5) deciding if the number of letters of a word is odd or even, or (6) deciding if the first and last letters in a word are in alphabetical order. For each ongoing task question the question type, the current question and the answer choices were displayed. All participants conducted a training that included four questions of each question type.

Second, the participants were instructed about an additional task they had to perform throughout the experiment. In the context change group, if the ongoing task monitor showed the text "Please work on the task on the paper", the participants had to work on the LDT in a paper booklet to their right. On each sheet of paper, 20 LDT tasks were printed and participants had to check if the string of letters was a word or non-word. Participants were instructed to always use a new page for each additional task. In the no context change group, if the ongoing task screen showed the text "Please work on the other screen", the participants had to work on an additional screen. On the second screen they had to work on the LDT in which a new question was presented immediately after answering. The LDT questions continued even after the message on the first screen disappeared to resemble the LDT task in the paper condition as much as possible. After 15 s, the ongoing task restarted on the ongoing task screen and participants were instructed to keep an eye on the ongoing task screen so not to miss the restart. Participants conducted a short training that included the respective interruption version.

Third, both groups received identical instructions about the delay-execute PM task – pressing "q" after a red screen was presented *but delaying the execution until the type of ongoing task had changed*. Participants conducted a short training, including one PM cue (i.e., red screen). Participants were told that a change to the LDT was not considered a change in the ongoing task. The experimenter gave feedback on PM performance and explained the PM task again if a participant failed to respond correctly.

Both groups worked on 38 sets of the ongoing task with baseline sets containing 20 questions each and all lasting 1 min. Sets 4, 8, 10, 15, 16, 19, 24, 26, 29, 31, 35, and 38 contained only a 15-s interruption after the 10th question in the set. The sets 2, 17, 22, and 32 contained a PM cue (i.e., red screen) after the fifth question within the set, while the sets 7, 12, 27, and 36 contained a PM cue after the fifth question as well as a 15-s interruption after the tenth question. The PM cue and window of opportunity were therefore always separated by 45 s. The order of sets containing only PM cues and sets with PM cues and an interruption was counterbalanced within groups. The question types were evenly spread across the 38 sets with the additional constraint not to have the same two question types in succession. This order was equivalent for all participants, but each individual question was randomly chosen without replacement for each participant.

Finally, participants completed a demographic questionnaire and had to explain the initial PM task (i.e., what they had to do in response to the PM cue and when they had to execute this action). Again, the final question asked the degree of intention rehearsal vs. relying on the intention to just "pop into mind". However, this time we used a 7-point scale. Participants were tested individually or in pairs (paired tests only within the same group). The total experiment lasted approximately 60 min.

Results

PM performance

The proportions of correct PM answers out of the four answers per condition were calculated. We conducted a 2×2 mixed ANOVA with the factors context (no context change and context change) and interruption (no interruption and interruption).

We observed no main effect of interruption, $F(1, 62) = 0.36$, $p = .553$, $\eta_p^2 = .01$, and no main effect of context, $F(1, 62) = 0.01$, $p = .912$, $\eta_p^2 = .00$, on PM performance. The context × interruption interaction was significant, $F(1, 62) = 4.57$, $p = .036$, $\eta_p^2 = .07$ (Figure 2). To analyse the interaction, we conducted Bonferroni-corrected *post hoc* tests for the interruption effect in both conditions. For the context change group, PM performance in non-interrupted delays ($M = 0.84$, $SD = 0.18$) was not significantly higher compared to interrupted delays ($M = 0.77$, $SD = 0.28$, $p = .286$, $d = 0.31$). In the no context change group performance was not significantly higher in interrupted delays ($M = 0.87$, $SD = 0.27$) compared to non-interrupted delays ($M = 0.74$, $SD = 0.25$, $p = .061$, $d = 0.50$).

Ongoing task performance

We analysed reaction times by excluding the first question of each set, the first question after each interruption, and all incorrect responses. Subsequently, we *z*-standardised all remaining data points within each participant and question type to be able to meaningfully analyse the different question types. For all analyses, we only used *z*-values between 2.5 and −2.5 (removing 2.16% of the data). This procedure is based on the procedure by Ball et al. (2013; see also Brewer, 2011). Note, however, that we observed the same pattern when using reaction times instead of *z*-scores.

We calculated the proportion of correctly answered ongoing tasks for each participant after excluding the first question of each set and the first question after each interruption. The mean ongoing task accuracy did not significantly differ between the no context change group ($M = 0.90$, $SD = 0.04$) and the context change group ($M = 0.90$, $SD = 0.04$), $t(62) = 0.15$, $p = .880$, $d = 0.04$.

To assess possible differences in intention recall when seeing the PM cue (i.e., red screen), we conducted a 2 × 3 mixed ANOVA with the factors context (no context change and context change) and question position relative to the PM cue (prior, post and post–post). We found a significant effect of question position, $F(2, 124) = 105.52$, $p < .001$, $\eta_p^2 = .63$, but no significant effect of context, $F(1, 62) = 0.31$, $p = .577$, $\eta_p^2 = .01$, and no significant interaction, $F(2, 124) = 0.45$, $p = .636$, $\eta_p^2 = .01$. Bonferroni-corrected *post hoc* tests showed significantly faster reaction times for the trial prior to the PM cue compared to the post cue trial ($p < .001$, $d = 2.42$) and the post–post trial ($p < .001$, $d = 0.78$). The post cue trial also showed significantly slower reaction times compared to the post–post trial ($p < .001$, $d = 1.63$, Figure 3). Slowed response after PM cue presentation is usually interpreted as intention recall or active maintenance of the intention (Ball et al., 2013). Therefore, the analysis showed that the intention was initially recalled in both groups.

To test if rehearsal occurred after the intention had been recalled (i.e., in the delay phase), we conducted a 2 × 2 × 2 mixed ANOVA with the factors context (no context change and context change), PM task (active PM

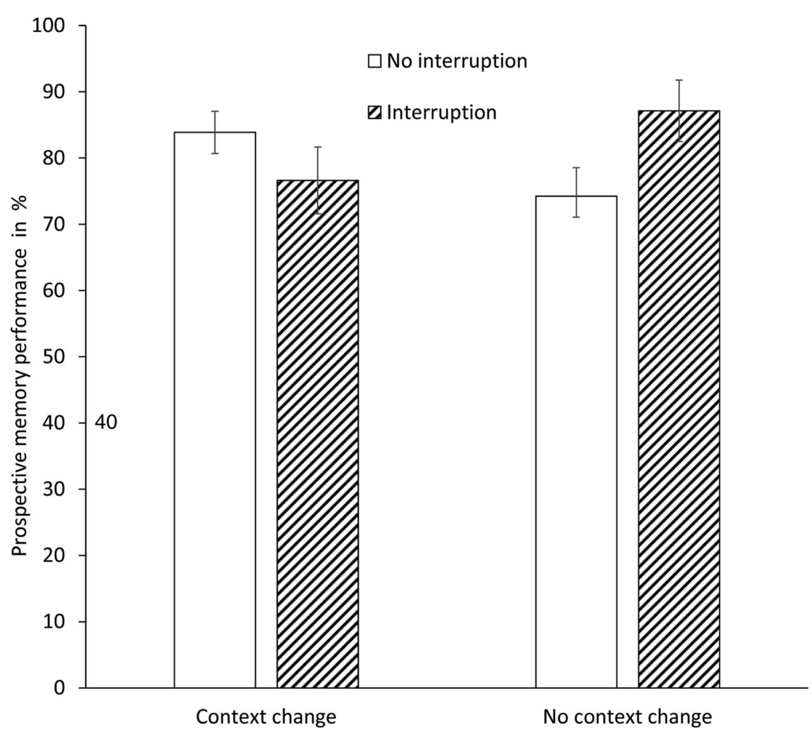

Figure 2. Prospective memory performance in Experiment 2 depending on context (context change vs. no context change) and interruption (no interruption vs. interruption). Error bars represent SE.

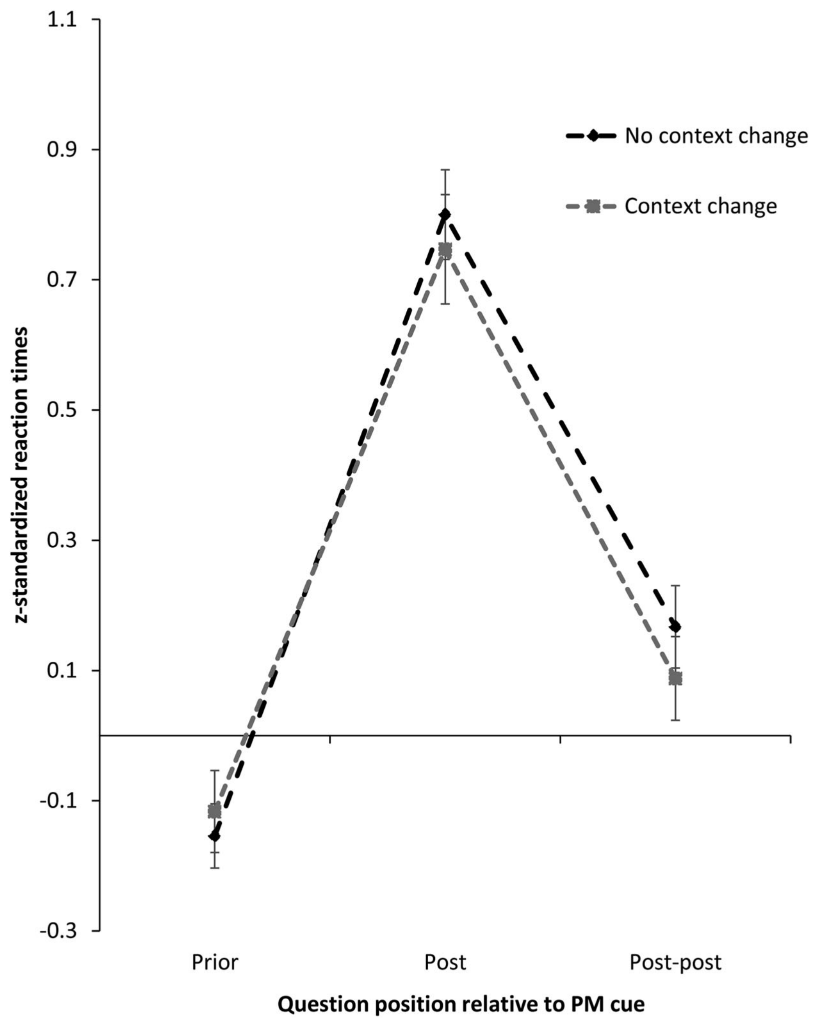

Figure 3. *Z*-standardised reaction times for the ongoing task of Experiment 2 separated by question position relative to the PM cue (prior, post and post–post) and context (no context change and context change). Error bars represent SE.

task without interruption, no PM task), and phase after PM cue (questions 7–10, questions 17–20). For the analysis, we removed the trial immediately after the PM cue (red screen) because slower reactions on this trial indicate intention retrieval. We used an average of the four questions after the sixth trial (questions 7–10) and the four questions after the interruption but without the question immediately after the interruption (questions 17–20) because the question immediately after the interruption includes the time it took to get back to the main monitor The *z*-standardised reaction time data, including the additional average for the phase (questions 2–5) before the PM cue, is shown in Figure 4.

We found no significant main effect of context $F(1, 62) = 3.21$, $p = .078$, $\eta_p^2 = .05$, PM task $F(1, 62) = 0.58$, $p = .450$, $\eta_p^2 = .01$, or phase $F(1, 62) = 3.39$, $p = .071$, $\eta_p^2 = .05$. No interaction was significant (context × PM task: $F(1, 62) = 1.39$, $p = .243$, $\eta_p^2 = .02$; context × phase: $F(1, 62) = 0.07$, $p = .791$, $\eta_p^2 = .00$; PM task × phase: $F(1, 62) = 0.58$, $p = .446$, $\eta_p^2 = .01$; three-way interaction: $F(1, 62) = 0.44$, $p = .509$, $\eta_p^2 = .01$). Based on this analysis, we observed no strategic rehearsal in any phase of a set.

Finally, to test whether rehearsal of the intention occurred after resuming the ongoing task at the end of the interruption (questions 17–20), we calculated a 2 × 2 mixed ANOVA with the factors context (no context change and context change) and interruption (PM set without interruption; PM set with interruption). The analysis showed a significant effect of interruption, $F(1, 62) = 15.46$, $p < .001$, $\eta_p^2 = .20$, but no significant effect of context, $F(1, 62) = 0.72$, $p = .398$, $\eta_p^2 = .01$, and no significant interaction, $F(1, 62) = 0.05$, $p = .819$, $\eta_p^2 = .00$. This analysis indicates that no group showed strategic rehearsal after the interruption despite differences in PM performance.

Interrupting task performance

We assessed performance in the LDT by calculating the percentage of correctly solved questions and, in addition, analysed reaction times for the no context change group

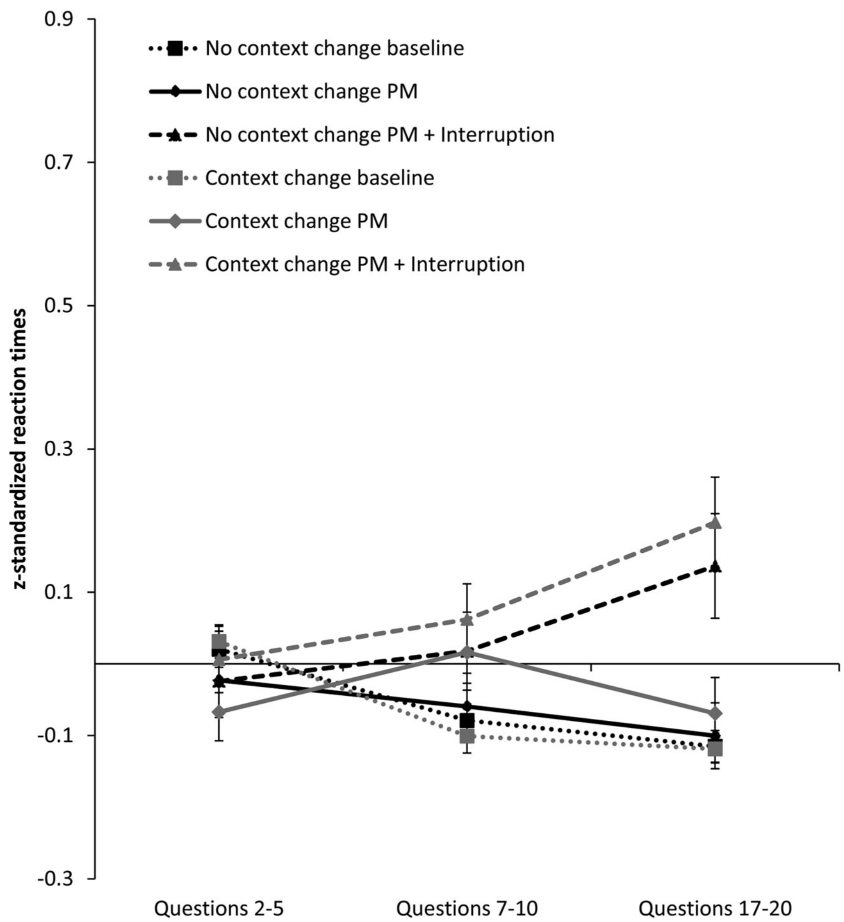

Figure 4. *Z*-standardised reaction times for the ongoing task from Experiment 2 separated by phase (phase 1: trials 2–5, phase 2: trials 7–10, phase 3: trials 17–20), set (baseline, PM), context (no context change and context change) and interruption (no interruption and interruption). Error bars represent SE.

working on the computer. One participant in the context change group was removed from this analysis because no new sheet of paper was used for each interruption as instructed. Furthermore, because turning to the interrupting tasks takes time, the first LDT trial of each interruption in the no context change group was removed for the analysis. The LDT accuracy was significantly higher in the context change group ($M = 0.96$, $SD = 0.02$) compared to the no context change group ($M = 0.93$, $SD = 0.03$), $t(62) = 6.99$, $p < .001$, $d = 1.20$.

To investigate a possible influence of an active intention on LDT accuracy, we conducted a 2 × 2 mixed ANOVA with the factors context (no context change and context change) and PM task (no PM task and active PM task). The effect of context was significant, $F(1, 61) = 20.62$, $p < .001$ $\eta_p^2 = .25$, as well as the effect of PM task, $F(1, 61) = 6.81$, $p = .011$ $\eta_p^2 = .10$. The context × PM task interaction, $F(1, 61) = 0.85$, $p = .361$ $\eta_p^2 = .01$, was not significant (Table 2). In the context change group, Bonferroni-corrected *post hoc* tests revealed no difference between no PM task and an active PM task ($p = .538$, $d = 0.27$). In the no context change group, LDT task performance was significantly higher with no PM task compared to an active PM task ($p = .026$, $d = 0.39$).

Table 2. Mean accuracy in the interrupting LDT task in Experiment 2.

		PM task status	
		Active PM task	No PM task
Condition	Context change	0.96 (0.04)	0.97 (0.03)
	No context change	0.92 (0.05)	0.94 (0.03)

Note: Standard deviations are in parentheses.

Finally, for the no context change group, we compared reaction times of the LDT task for interruptions with no PM task and an active PM task. We used the same selection criteria as for the ongoing task analysis (excluding incorrect trials, the first questions of each interruption, and reaction times more than 2.5 standard deviations from a participant's mean). A *t*-test for dependent groups showed significantly faster reaction times for interruptions with no PM task ($M = 901$ ms, $SD = 169$) compared to interruptions with an active PM task ($M = 936$ ms, $SD = 178$), $t(32) = -3.51$, $p = .001$, $d = 0.20$.

Additional measures

In Experiment 2, a simple *t*-test for independent samples was calculated to analyse whether there were differences in the amount of rehearsal of the intention to press the "q" key between the context change and no context change group based on the questionnaire data. The conditions did not differ significantly between no context change ($M = 3.03$, $SD = 1.94$) and context change groups ($M = 3.16$, $SD = 2.00$), $t(62) = -0.27$, $p = .791$, $d = 0.07$.

Discussion

As expected, we observed a significant context × interruption interaction in PM performance; however no main effect of interruption on PM was observed. This result appeared to be caused by the magnitude in which contextual cueing influenced PM performance. In the context change group, we observed a decrease in PM performance in interrupted delays compared to non-interruption delays, whereas, at the same time in the no context change group the effect reversed. Contrary to the predictions of Einstein et al. (2003), the interruption during the delay did not lower PM performance for the no context change group, but resulted in descriptively better performance. We will return to this finding in the general discussion. Finally, we did not observe a simple effect of interruption in the context change group. This might be a result of the higher similarity of the ongoing and interrupting tasks in Experiment 2. Both tasks involved very simple two choice questions. Contrary, in Experiments 1a and 1b, the ongoing task consisted of four choice questions and the interrupting task consisted of a decoding task in Experiment 1a and a number marking task in Experiment 1b. The interruptions in Experiment 2 may have been less disruptive, due to a less pronounced context change.

The analysis of interrupting LDT task accuracy showed a significant decrease in the no context change group if an intention had to be kept active during an interruption. Although the context × PM task interaction was not significant, this difference was less pronounced in the context change group. In addition, the no context change group showed significantly slower responses in the LDT when a PM task was active compared to no active PM task. In the retrieve-execute paradigm (Einstein et al., 2005; Smith, 2003) slowed reaction times during PM task delays are interpreted as an indicator that the participants spend resources on maintaining the PM task active.

The active maintenance view (Einstein et al., 2003) and empirical results (Cook et al., 2013), suggest that the intention is linked to the ongoing task context. The significant interaction between context and interruption for PM performance suggests that an intention was less likely to be discarded if the ongoing task context was not changed due to an interruption (i.e., still working on a computer) compared to a context change (i.e., paper and pencil task). Considering PM and interrupting task performance of Experiment 2, we suggest that PM performance was influenced by degree of context change caused by the interruption. If the context was not changed, the PM task was not discarded but strategically rehearsed during the interruption, which lowered performance in the interrupting task and subsequently resulted in better PM performance. If the context was changed, the PM task was discarded, which caused better performance in the interrupting task compared to the interruptions with no context change, but resulted in lower PM performance because the discarded intention might not be reinstated at the end of the interruption.

In the analysis of the ongoing task performances, we found no differences between the context change and no context change groups in ongoing task accuracy. Furthermore, there were no differences between the groups in participants' reaction time increases immediately following the PM cue, which can be interpreted as retrieval and reformulation of the intention (Ball et al., 2013; Einstein et al., 2005). We found no indication that rehearsal occurred after the PM cue had been retrieved, either shortly after the PM cue or before the window of opportunity, and also not after interruptions occurred. To find a small to intermediate effect ($d = 0.4$) with sufficient statistical power ($1-\beta = 0.80$), a sample of 52 participants would already have been sufficient.

In summary, the results indicate that in both groups, the PM intention is retrieved and reformulated to be executed during the window of opportunity, but successful PM performance is influenced differently by interruption during the delay, depending on the degree of context change.

General discussion

We conducted three experiments to investigate the effect of different distraction types during an ongoing task on delay-execute PM performance. In Experiments 1a and 1b we observed that the different distraction types, acknowledging, multitasking, and interruption differently affected PM performance. Performance was significantly lower for interrupted trials compared to the uninterrupted baseline in both experiments, while the other distractions also impaired PM performance, but less severely. In Experiment 2, we further investigated the effect of context change within interruptions and could show that the negative effect of interruptions can be explained by the context change within an interruption.

The results of Experiments 1a and 1b indicated that periods of multitasking and interruptions during the delay phase of a delay-execute PM task made remembering the intention less likely. In addition, both experiments showed more forgetting due to interrupting compared to multitasking. The result of Experiment 2 showed the influence of context changes as part of interrupting in terms of possible trade-offs between PM performance and interrupting task performance.

Considering the literature on delay-execute PM (Ball et al., 2013; Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004; Schaper & Grundgeiger, 2017), we replicated the negative effects of interruptions on PM performance in Experiments 1a and 1b. Furthermore, the difference between multitasking and interrupting seemed to contradict previous findings on dividing attention during different parts of a set. Einstein et al. (2003, Experiment 1) found a strong effect of interrupted vs. uninterrupted sets, but did not find this effect when attention was divided by a digital monitoring task (counting the number of two consecutive odd digits with a hand held clicker) during the delay and the retrieval phase. Einstein et al. argued that under the assumption that interruptions are resource demanding, the rehearsal processes of the participants were already disrupted by dividing attention and a further interruption would, therefore, have no additional effect. However, Einstein et al. also acknowledged that the additional digital monitoring task might have decreased the degree of context change during the delay phase (possibly by associating the intention with the digital monitoring task) compared to the undivided condition. The current study supports the latter explanation by showing that if the context was not changed (multitasking in Experiments 1a and 1b and Experiment 2) PM performance was better compared to context change (interruption in Experiments 1a and 1b and Experiment 2). Paradoxically, introducing the resource demanding digital monitoring task in Einstein et al.'s experiment might have increased remembering rates by keeping the context change of the interruption moderate compared to a stronger context change in the condition without the monitoring task.

Interestingly, in our no context change group, PM performance was descriptively (but not significantly) better in the interruption compared to the no interruption condition. At first, this result seems to contradict Einstein et al. (2003), who reported descriptively worse performance in the interruption compared to the no interruption condition. However, in Einstein et al.'s experiment, participants had to work on the interrupting task and the divided attention task concurrently. In our Experiment 2, participants only worked on the interrupting task. In Einstein et al.'s experiment, context change and attentional demands were confounded. The reduced demands in our Experiment 2 may have enabled participants to engage in active maintenance of the intention (which is indicated by the increased reaction times when a PM task is active compared to no PM task) and therefore increase PM performance.

Theoretical implications

The active maintenance view (Einstein et al., 2003) suggests that moderate resources are needed to maintain an intention over a brief delay. In this view, strategic rehearsal and contextual cueing have been suggested as two possible mechanisms to support the periodic activation of delayed intentions.

The negative effect of increased cognitive load during periods of multitasking on strategic rehearsal and therefore PM performance was observed in Experiments 1a and 1b, while both experiments also showed a further decrease in PM performance when the context was changed by an interruption in addition to the increased cognitive load. This may indicate a combined effect of both factors on periodic activation.

Alternatively, one may also consider multitasking as a form of context change as a different task is started. From this point of view, multitasking reduces PM performance because of a partly changed context and interrupting reduces PM performance because of a fully changed context. Such a view would assume that strategic rehearsal is not necessary for successful delay-execute performance (see also Einstein et al., 2003, Experiment 2). Furthermore, ongoing task reaction times during the delay phase were also not affected by an active PM task (see also Ball et al., 2013; Schaper & Grundgeiger, 2017).[2]

The interpretation of the context × interruption interaction in Experiment 2 indicates that contextual cueing of an unchanged context eliminated the negative effect of the interruptions on PM performance compared to a change of context, which resulted in lower PM performance when interrupted. In combination with the performance in the interrupting LDT task, the results suggest that performance in the interrupting task is traded off against PM performance but only in the group without context change. It appeared that if the task context was not changed, the intention stayed active and participants engaged in more strategic rehearsal during the interruption, which in turn, resulted in worse interrupting task performance. If the task context was changed, the intention was discarded and did not affect interrupting task performance. This explanation matches recent research on the effects of contextual associations in delay-execute PM tasks (Cook et al., 2013) and the idea by Einstein et al. (2003) that intentions are discarded at the beginning of an interruption if the context is changed. The similar changes in the context change and the no context change groups in reaction times in response to the PM cue, which we interpret as intention retrieval, and the similar increase in reaction times after an interruption are further indicators that the critical phase for the differences in PM performance between the groups was during the interruption and was, therefore, influenced by the degree of context change.

Practical implications

Safety-critical workplaces such as critical care nursing or aviation have many PM demanding situations in which intentions need to be delayed (e.g., Dismukes, 2008, 2012; Ebright et al., 2003) and distractions are frequent (Dismukes & Nowinski, 2007; Grundgeiger & Sanderson, 2009). But the literature also indicates staff members use different distraction management strategies such as acknowledging, multitasking, or interrupting. The current results showed that multitasking and interruptions during the delay period decreased PM performance whereas acknowledging did not. Our results have direct implications for the nurse from the introductory example. In the example, the nurse was checking the vital sign alarm limits of the patient monitor when a doctor asks to change the settings of a running infusion. In this case, the nurse needs to delay changing the infusion setting. During the delay, answering further questions of other staff (multitasking) or having to deal with an interruption might affect remembering to change the infusion settings and therefore compromise patient safety. In contrast, briefly double checking a drugs name and its expiration date for another nurse (acknowledging) seems not to disrupt PM performance.

The results showed that interruptions have a stronger effect on delayed intentions compared to multitasking. If there is a delayed intention, this finding suggests that, for example, nurses might benefit from handling an initial distraction by acknowledging or multitasking, rather than interrupting the current task. The results of Experiment 2 further suggested that this is especially relevant if the context of ongoing tasks and interrupting tasks are dissimilar. Additionally, a study on resuming interrupted critical care tasks indicated that keeping the task context during the interruption made task resumption easier (Grundgeiger et al., 2010).

The literature (Ball et al., 2013; Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004) and the current results showed how fragile cognition can be when one relies only on individual cognition to remember delayed intentions. This highlights the need for environmental support when remembering delayed intentions. Research showed, for example, that a blue dot during the delay phase improved PM performance to ceiling level (McDaniel et al., 2004) and breaks and reminders at the end of an interruption could improve task resumption (Dodhia & Dismukes, 2009). In the context of sociotechnical systems, researchers have suggested a *distributed PM* system, which specifically considers the interaction between the environment and the individual for successful PM performance (Grundgeiger, Sanderson, & Dismukes, 2014).

Conclusions

Acknowledging, multitasking, and interruptions are common in many safety-critical work places and these work places hold many PM demanding situations (Dismukes, 2008, 2012; Ebright et al., 2003). Previous research showed that brief interruptions of 10 s during the delay compromise remembering delayed intentions (Einstein et al., 2003; McDaniel et al., 2004). We extended this finding to periods of multitasking and have replicated the results on interruptions with complete changes in context. When comparing interruptions with and without context exchange, interruptions with no context change had no negative effect on delayed intentions, but, at the same time, reduced interrupting tasks performance. Theoretically, the results emphasise the contribution of task context changes as part of a distraction during the delay period and support the active maintenance view for remembering delayed intentions. From an applied perspective, the results highlight the effect of different distraction management, while holding a delayed intention in mind.

Notes

1. Using the same task for multitasking and interrupting would be the best way to ensure equally difficult tasks. However, interrupting and multitasking are, by definition, different forms of distractions. To investigate which distraction phase was more demanding, we conducted a short study in which 23 participants received the first (ongoing task) and the third (distraction tasks) steps of the instructions (see Procedure and materials of Experiments 1a and 1b) and worked on two consecutive sets of each distraction (set order counterbalanced across all participants). After both sets, they rated demands on the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) and finally judged which distraction phase was most difficult. We conducted an ANOVA for the mean scores of the NASA-TLX. The results showed a significant effect of distraction type $F(2, 44) = 8.20$, $p = .001$, $\eta_p^2 = .27$. Bonferroni-corrected *post hoc* tests showed significantly higher scores (on a scale from 1 to 10) for multitasking ($M = 6.14$, $SD = 1.14$) compared to acknowledging ($M = 5.36$, $SD = 1.22$, $p = .017$, $d = 0.66$) and interrupting ($M = 5.33$, $SD = 1.36$, $p = .003$, $d = 0.64$). Acknowledging and interrupting did not differ significantly ($p = 1.00$, $d = 0.02$). The results of the final judgment showed that most of the participants considered the sets with multitasking distraction as the most difficult ones (73.9%), while the acknowledging (21.7%) and interruption sets (4.3%) were selected infrequently. Critically, it therefore seems reasonable to assume that lower PM performance for the interrupting condition compared to the multitasking condition was not caused by a more demanding distraction phase.
2. Einstein et al. (2003) reported worse ongoing task reaction times during the delay when an intention is active compared to no intention. However, this result is limited to a 5-s delay and was not present in 15-s or 40-s delays. The effect in the 5-s delay is likely to be because of intention recall on account of the PM cue (i.e., red screen) which we observed in Experiment 2 in the post question (see also Ball et al., 2013; Schaper & Grundgeiger, 2017).

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Disclosure statement

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***Annex C:* Study 3 - Commission errors in delay-execute prospective memory tasks**

Schaper, P., & Grundgeiger, T. (2017). Commission errors in delay-execute prospective memory tasks. Quarterly Journal of Experimental Psychology, 70(8), 1423-1438.

Author	Contribution
Schaper, P.	Literature review, experimental design, data collection, data analysis, manuscript preparation and revision
Grundgeiger, T.	Contributed to experimental design, manuscript revision

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Commission errors in delay–execute prospective memory tasks

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ABSTRACT
Individuals frequently retrieve an intention, but the execution of the task needs to be delayed due to ongoing task demands - so-called delay-execute prospective memory (PM) tasks. We investigated commission errors in the delay-execute paradigm. Participants were told that a PM task is finished (PM task has been executed and is now finished for a final phase) or cancelled (PM task has been cancelled immediately after introduction). We observed commission errors and ongoing task performance in the final phase which included several irrelevant PM cues. In two experiments, we observed significantly more commission errors for cancelled compared to the finished intentions. In Experiment 2, commission errors were eliminated if the final phase required divided attention, regardless of PM task status. In addition, we observed significantly more PM cue interference on the ongoing task in the cancelled compared to the finished group, indicating that the PM task was retrieved in the cancelled group but not in the finished group. As retrieval and execution of the PM task were separated by a delay, the results indicate that commission errors are not always the result of a quick, spontaneous retrieval-execution sequence and may also occur when retrieval and execution are temporally separated.

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Remembering intentions and executing them when a certain cue appears is referred to as prospective memory (PM, Einstein & McDaniel, 1990). Successful PM performance is important in everyday life as well as in safety-critical domains (Dismukes, 2008; Grundgeiger, Sanderson, & Dismukes, 2014). Recent research indicated that not only may forgetting to execute PM tasks (omission errors) be problematic, but also the erroneous execution of PM tasks (commission errors) is cause for concern (Scullin, Bugg, & McDaniel, 2012; Walser, Fischer, & Goschke, 2012). Previous research on commission errors has been conducted exclusively using the retrieve–execute PM paradigm (e.g., Bugg & Scullin, 2013; Pink & Dodson, 2013; Scullin & Bugg, 2013; Scullin et al., 2012). In the present experiments, we investigated commission errors using the delay–execute PM paradigm.

Delay–execute prospective memory tasks

In the frequently studied retrieve–execute PM paradigm an intention is retrieved and can be executed immediately (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). In many situations, however, an intention may be successfully retrieved when encountering a PM cue but execution of the relevant response has to be postponed due to ongoing task demands. Tasks with these features are referred to as delay–execute PM tasks (Einstein et al., 2000; Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003).

Delay–execute PM has been studied in the laboratory by instructing participants to work on an ongoing task consisting of blocks of various types of questions such as arithmetic problems or category verification, with blocks typically lasting 60 s. Participants are instructed to remember to press a certain key on a keyboard if the computer screen turns red for 1 s

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but not until the present block of questions was finished, and a new block of different questions began. This additional delay may last 5 to 40 s. Research has shown that successful performance in delay–execute PM tasks requires attentional resources (Ball, Knight, Dewitt, & Brewer, 2013; Einstein et al., 2003; Kliegel & Jäger, 2006; McDaniel, Einstein, Graham, & Rall, 2004; Rendell, Vella, Kliegel, & Terrett, 2009). For example, Einstein et al. (2003) observed that PM performance decreased when participants were required to perform a digit-counting task concurrently with the PM task. Furthermore, interrupting participants during the delay for 10, 15, or 20 s decreased PM performance compared to non-interrupted trials (Cook, Meeks, Clark-Foos, Merritt, & Marsh, 2013; Einstein et al., 2003; McDaniel et al., 2004). Ball et al. (2013) further showed that the effect of interruptions was moderated by working memory capacity. Participants with a high working memory capacity showed better performance on interrupted PM trials than participants with low working memory capacity.

There are two critical differences between the delay–execute paradigm and the retrieve–execute paradigm. First, only in the delay–execute PM it is possible to make a temporal distinction between intention retrieval, which occurs when the PM cue is encountered, and execution of an intention, when the window of opportunity arises. Second, in the delay–execute paradigm, the PM cue is always very salient, thus ensuring that participants will initially retrieve the PM task, whereas in the retrieve–execute paradigm PM cues may be missed. Einstein et al. (2000) tested whether participants retrieve the intention when they encounter the PM cue and observed that 97% of younger adults do remember the PM task in the delay–execute paradigm. Furthermore, increases in ongoing task reaction time following presentation of a PM cue have been interpreted as an indication of PM task retrieval (Ball et al., 2013).

Commission errors

An omission error occurs when the participant fails to respond to a PM cue (Kliegel, Martin, McDaniel, & Einstein, 2004). In contrast, a commission error occurs when an intention is executed even though it should not have been executed (McDaniel, Bugg, Ramuschkat, Kliegel, & Einstein, 2009). Commission errors can be investigated if a PM task is cancelled or declared complete but previously relevant PM cues still appear during the ongoing task (Bugg & Scullin, 2013).

To study commission errors in the laboratory, participants encode a PM task such as pressing the "q" key when a specific word appears during an ongoing task. In a following intermediate phase, participants in the finished condition perform a short PM task including several PM targets; at the end of this phase they are told that the PM task is now finished, and they should not execute the PM response again. Participants in the cancelled group immediately receive the instruction that the PM task has been cancelled after the PM task encoding, and they should not perform the PM response. In the final phase, all participants are presented with multiple PM cues—which are no longer relevant—during the ongoing task.

To investigate the effect of finished or cancelled instructions, researchers compare reaction times to PM targets and matched control words. Longer reaction times for PM targets are interpreted as a failure to deactivate the related intention (Cohen, Dixon, & Lindsay, 2005; Scullin, Bugg, McDaniel, & Einstein, 2011; Walser et al., 2012; Walser, Goschke, & Fischer, 2014; Walser, Plessow, Goschke, & Fischer, 2014). A further dependent variable is actual commission errors (Bugg & Scullin, 2013; Bugg, Scullin, & McDaniel, 2013; Pink & Dodson, 2013; Scullin & Bugg, 2013; Scullin et al., 2012).

Discussing why commission errors occur, Scullin et al. (2012) suggested that "commission errors occur when a completed intention is spontaneously retrieved and individuals fail to suppress executing the intention" (p. 52). Recent research on commission errors, which we summarize below, further supports this explanation.

First, commission errors are more likely if PM cues are salient and occur in the same ongoing task context as that used during the intermediate phase than if PM cues are non-salient and a mismatch in task context (Scullin et al., 2012). Furthermore, implementation intention encoding results in more commission errors than standard encoding (Bugg et al., 2013). Second, diminished executive control also increases the commission error rate; cognitive ageing, which is associated with decreased executive control, increases commission error rates (Scullin et al., 2012). Similarly, Pink and Dodson (2013) showed that divided attention during the final phase increased the commission error rate compared to full attention in a habitual retrieve–execute PM task.

Third, Scullin and Bugg (2013) observed that participant fatigue resulted in more commission errors.

Although the difference between finished and cancelled intentions seems to be a fine nuance, it affects the frequency of commission errors. Bugg and Scullin (2013) showed that the commission error rate in retrieve–execute PM tasks was lower if the PM task was executed then declared complete rather than being cancelled without being executed. Because we compared finished and cancelled intentions in the present experiments, we summarize three possible explanations for this intriguing effect (cf. Bugg & Scullin, 2013).

The notion that unfulfilled tasks are more accessible and produce some kind of tension in comparison to completed intentions and are therefore more easily recalled is known as the Zeigarnik effect (Zeigarnik, 1938). Bugg and Scullin (2013) measured commission errors in a task involving two PM target words of which only one was used in the intermediate PM phase. One might argue that the tension relating to an unexecuted intention should have been satisfied during this intermediate PM block and hence that there should have been few commission errors during the final phase; however, Bugg and Scullin (2013) observed that in the final phase there were more commission errors related to the non-presented target word than to the presented target word.

A further explanation is the deactivation view, which states that an intention can be deactivated after it has been executed (Scullin, Einstein, & McDaniel, 2009). This view is based on the idea that reactivated memories become unstable after activation and are either strengthened or prepared for forgetting (Diekelmann, Wilhelm, Wagner, & Born, 2013; Nader & Hardt, 2009). Because the finished condition includes activation and execution of the intention before the PM task is declared finished, the intention can be deactivated more efficiently than in the cancelled condition. In case of the cancelled instruction, the intention has not been executed, is therefore not in the transient destabilized state, and hence is not prepared for an effective forgetting instruction. Therefore, the finished instruction leads to no commission errors.

Finally, the episodic trace view suggests that the influence of episodic traces and their relative strength affect the occurrence of commission errors. Stronger episodic traces based on repetition (i.e., executing the PM task) make it easier to build up a "no-go" memory—an association between the intention and a memory that it should not be executed (Hommel, Müsseler, Aschersleben, & Prinz, 2001). In the finished condition, performing the PM task in the intermediate PM phase facilitates inhibition of the PM action after the PM task is completed, which is reflected in a lower commission error rate in the final phase than in the cancelled condition.

Present experiments

In the present experiments, we investigated the effect of PM status on commission errors and reaction time changes in a delay–execute PM paradigm. To this end, we conducted two experiments in which we adapted the finished and cancelled conditions of Bugg and Scullin (2013) to the delay–execute PM paradigm. In short, we first introduced the ongoing task and the PM task to the participants. In the intermediate phase, participants in the finished group performed a short PM block including two PM events and were then told that the PM task was finished. Participants in the cancelled group were told that the PM task was cancelled immediately after the instructions had been given. In the final phase, both groups answered ongoing task questions and encountered six PM cues to which they should no longer react (Figure 1).

The delay–execute PM paradigm enables several new insights into commission errors because there is a delay between intention retrieval and intention execution. First, it is possible to observe changes in reaction time on the ongoing task trial, which follows presentation of the PM cue without "losing a data point" due to commission errors; this is in contrast to the retrieve–execute PM paradigm, where no meaningful reaction times can be measured for this event (Scullin et al., 2012).

Second, we can investigate whether commission errors are the result of failures to suppress an immediate reaction to the PM cue. As indicated above, current explanations of commission errors emphasize failure to suppress the PM response (Scullin & Bugg, 2013; Scullin et al., 2012).

Third, we can study the effect of additional manipulations, such as interruptions during the delay, on the occurrence of commission errors. Interruptions during the delay phase have a strong negative effect on PM performance (Einstein et al., 2003; McDaniel et al., 2004). In Experiment 2, we specifically address interruptions and divided attention.

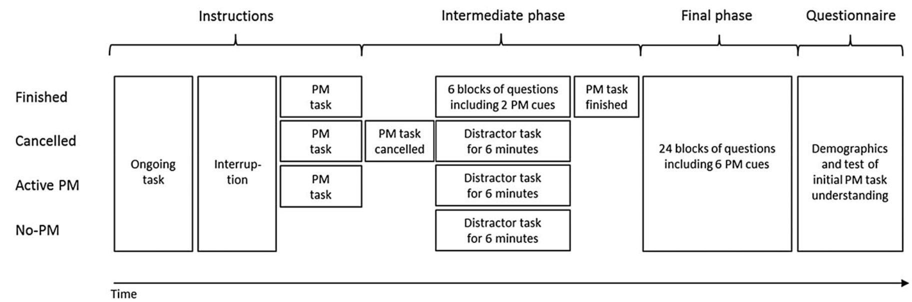

Figure 1. Design and procedure of Experiment 1. PM = prospective memory.

Experiment 1

In Experiment 1, we first aimed to test whether commission errors occur in the delay–execute PM paradigm. We predicted that, as in the retrieve–execute PM paradigm (Bugg & Scullin, 2013), fewer participants in the finished group would make commission errors than in the cancelled group. This hypothesis is supported by all current theoretical explanations of commission errors. In case of the Zeigarnik effect, one could argue that for the cancelled group, presentation of the PM cue triggers the tension associated with an unfinished task and hence induces commission errors. In the finished group, this tension should not arise as participants executed the PM task during the intermediate phase. The deactivation view suggests that, after experiencing PM execution in the finished condition, the unstable memories can be successfully deactivated. Finally, the episodic trace view suggests that the finished group are better placed to build up a no-go memory than the cancelled group. However, although supported by theory, the above prediction is not given. As mentioned above, commission errors are thought of as a spontaneous retrieval of the PM task plus failure to suppress the PM response (Pink & Dodson, 2013; Scullin & Bugg, 2013; Scullin et al., 2012). In the delay–execute PM paradigm, the initial retrieval of the intention and the execution are separated by a delay, which may prevent commission errors.

Second, we aimed to analyse the reaction times of the ongoing task trials after the PM cue presentation as an indicator of PM task retrieval processes (Ball et al., 2013). In the retrieve–execute paradigm, longer reaction times in the final phase on trials following former PM cues have been interpreted as indications of retrieval of the PM task (Scullin et al., 2011; Walser et al., 2012). In addition to the finished and cancelled groups, we included an active PM group and a no-PM group (Figure 1). The active PM group performed the standard delay–execute PM task. The no-PM group were never given instructions for the PM task, but they were told that red screens would appear and that they should be ignored. The active PM and no-PM groups were control groups to provide valid reaction times for PM task retrieval and no PM task retrieval, respectively.

Considering ongoing task reaction times on the question following the PM cue, as in previous research (Ball et al., 2013), we expected longer reaction times in the active PM group than in the no-PM group. Since we predicted commission errors in the cancelled group, we expected that participants in the cancelled group would retrieve the PM task upon seeing the PM cue and therefore show similar slowing to the active PM group. Reaction times after the PM cue in the cancelled group should therefore also be longer than those in the no-PM group.

As stated above, we expected that the finished group would make fewer commission errors than the cancelled group. One possibility is that observing fewer commission errors in the finished group is the result of no PM task retrieval for most participants when encountering the PM cue. In this case, reaction times in the finished group should be similar to those in the no-PM group and shorter than those in the active PM group. The Zeigarnik effect predicts that the PM task will not be retrieved, since there should be no tension due to incomplete intentions. Similarly, the deactivation view predicts no retrieval of the PM task because the intention should have been deactivated. Such a complete deactivation of the intention has been reported before (Scullin et al., 2009).

Another possibility is that the PM task is retrieved but not executed after the delay. This is consistent with the episodic trace account, according to which a stimulus–response link between PM cue and PM response is established during the intermediate PM block. This link enables participants to build a no–go memory (Hommel et al., 2001). In the final phase, this link results in automatic retrieval of the associated PM response, which is reflected in longer reaction times on the critical trials. However, the automatic retrieval does not result in commission errors because the PM action is inhibited by the no-go memory (cf. Walser et al., 2012). In this case, on critical trials the reaction times of the finished group should be similar to those of the active PM group and longer than those of the no-PM group.

Method

Participants

Because we did not have an assumption about possible effect sizes, we aimed for a group size of $N = 20$ per group based on previous delay–execute PM research (Einstein et al., 2003; McDaniel et al., 2004). Our initial sample consisted of 80 students who took part in the experiment in exchange for partial course credit (students at the Institute of Human-Computer-Media, 80% of sample) or were paid 8€ (other students at the Julius-Maximilians-Universität Würzburg). Three of the participants were excluded from the analysis because they could not correctly recall the PM task at the end of the experiment. This resulted in an overall N of 77 ($N_{finished} = 19$, $N_{cancelled} = 20$, $N_{active\ PM} = 18$, $N_{no\text{-}PM} = 20$) with a mean age of 21 years (range 18–38 years) and with 83% of the participants being female.

Design

The experiment had four groups, which differed in terms of their PM status. The groups finished, cancelled, and active PM first received the standard delay–execute PM task instructions. In the finished group, participants conducted an intermediate phase including two PM events and were told that the PM task was now finished and that they did not need to perform the task in the final phase. In the cancelled group, participants were told immediately after PM task encoding that the PM task was cancelled and that they did not need to perform the task in the final phase. In the active PM group, participants received no further instructions. Finally, participants in the no-PM group received no PM instruction but were informed that red screens would appear during their ongoing task and that these screens should be ignored (Figure 1).

Materials and procedure

The present experiment had four main phases: (a) instructions, (b) intermediate phase, (c) final phase, and (d) questionnaire.

First, participants were informed about the ongoing task. Participants needed to answer questions within 3 s and indicate their answer by pressing either "v" or "n" on a keyboard in correspondence to two answers displayed on a monitor. The next question was shown automatically after the 3 s elapsed. Participants were instructed to use their index finger of their left and right hand and to keep these fingers on the keys throughout the experiment. The key configuration was counterbalanced within each group. We used six types of questions: (a) indicating whether a word contains a certain letter, (b) indicating whether a word belongs to a certain category, (c) predicting whether the third number, which is not shown, in a sequence is odd or even based on the preceding numbers, (d) indicating whether a word describes a living or non-living object, (e) indicating whether the number of letters of a word is odd or even, or (f) indicating whether the first and last letter in a word are in alphabetical order. Participants conducted a short training including four questions of each question type.

Next, participants were informed that at some points throughout the experiment they had to perform an additional task (i.e., interrupting the ongoing task). If the screen showed the text "Please work on the decoding task", the participants had to work on a paper and pencil task on a side-desk to their right as long as the message remained on screen (15 s). In the decoding task, numbers had to be matched to different symbols, and participants had to autonomously monitor when the ongoing task on the screen continued. The task materials were taken from the Digit Symbol Substitution task of the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981). Participants conducted a short training that included such an interruption.

Next, the finished, cancelled, and active PM groups received the standard delay–execute PM task—pressing "q" after a red screen was presented *but delaying the execution until the type of ongoing task changed*. The three groups conducted a short training including one PM cue (i.e., red screen). The experimenter gave feedback on PM performance and explained the PM task again if necessary.

Second, in the intermediate phase, participants in the finished group conducted a short PM experiment with six blocks of questions. Each block included 20 questions of the same question type. Since a question was always presented for 3 s, each block lasted 60 s. The second block included a PM event. In this case, a red screen appeared after five questions (15 s) for 1 s. The participants had to delay the execution of the task (i.e., press "q") for 15 questions (45 s) until the next block with a different question type started. The 4th block included an interruption. Participants had to change tasks after 10 questions (30 s) and work on the decoding task for 15 s. After returning to the ongoing task, participants completed a further five questions (15 s). The 5th block included a PM event and an interruption. After completing these six blocks, participants were informed that the PM task was finished, and subsequent red screens should be ignored, even though they still occurred due to the experimental set-up.

Participants in the cancelled group were told that the PM task was cancelled, and the following red screens should be ignored, because they were selected for an experimental group that did not have to react to the red screen. The exact wording of the instructions in German (or an English translation) can be requested from the authors. They solved simple mathematical equations for six minutes to match the duration of the finished groups' intermediate PM block. Participants in the active PM group received no further instructions and likewise solved equations for six minutes. Finally, participants in the no-PM group were informed that red screens would appear during their ongoing task and should be ignored; this group also solved equations for six minutes.

Third, in the final phase, all groups worked on 24 blocks of the ongoing task. Blocks 5, 14, and 21 included an interruption only after the 10th question. Blocks 2, 12, and 19 included a PM cue after the fifth question. Blocks 7, 16, and 23 included a PM cue after the fifth question as well as an interruption after the 10th question. The length and timing for each type of block were identical to those in the intermediate phase.

To ensure that the six question types were evenly spread across the 24 blocks, we separated the 24 blocks in four units of six blocks. Within a unit, each question type occurred once; the order was randomized in each unit with the additional constraint to not have the same two question types in succession at a unit border. This order was equivalent for all participants, but each individual question was randomly chosen without replacement for each participant.

Fourth, participants completed a short demographic questionnaire. In addition, they had to answer several questions regarding the PM task depending on their allocated group. Participants in the finished group and active PM group had to explain the initial PM task including what they had to do in response to the PM cue and when they had to execute this action. Participants in the finished group were asked whether they still reacted to the red screen in the second part of the experiment. Participants in the cancelled group were asked what they should have done in reaction to the PM cue and when this action should have been carried out. In addition, they were asked whether they still reacted to the red screen. The questionnaires were used to ensure a correct understanding of the instructions and manipulations.

Participants were tested individually or in pairs (same group). The total experiment lasted approximately 60 minutes.

Results

For all analyses in Experiment 1 and Experiment 2, a correct PM response or a commission error was defined as pressing "q" within the first two questions of a new question type after the PM cue. The parametric statistical analysis was conducted with SPSS 22 (Chicago, IL), and non-parametric statistical analysis was conducted with StatXacte 8 (Cambridge, MA). For all tests, alpha was set at .05.

Prospective memory hits

For the intermediate PM block of the finished group, we calculated the percentage of correct PM responses out of two PM events. The mean PM hit rate was 76.32% ($SD = 25.65$), and each participant showed at least one PM hit. For the participants in the active PM group, we calculated the percentage of correct PM responses out of six PM events. The mean PM hit rate was 66.67% ($SD = 30.78$).

Commission errors

As in previous research (Bugg & Scullin, 2013), a participant was considered to commit commission errors if she or he committed at least one error during the experiment. A Barnard's exact test showed that significantly more participants in the cancelled group committed commission errors (5 of 20, 25%) than in the finished group (0 of 19, 0%; $p = .024$, two-tailed).

Reaction times

To analyse reaction times, we excluded the first question of each block, the first question after each interruption, and all incorrect responses. In addition we z-standardized all included data points within each participant and question type to be able to meaningfully compare reaction times for different question types. Subsequently, we only analysed responses within 2.5 standard deviations of the participants' mean response time within each question type (removing 2.46% of the data). Due to six different question types, we used an adapted trimming procedure of Ball et al. (2013; see also Brewer, 2011) and considered not only each participant's overall mean but each mean in regard to the question type. Note, however, that we observed the same result pattern when using reaction times instead of z-scores.

Figure 2 gives an overview of the z-standardized reaction times depending on PM status (finished, cancelled, active PM, or no-PM) for the question prior to the PM cue (prior), immediately after the red screen (post), and the second question after the PM cue (post-post). To test the hypothesis that PM status affects PM task retrieval, we conducted a one-way analysis of variance (ANOVA) including the factor PM status (finished, cancelled, active PM, no-PM) on the post-trial. The analysis showed a significant effect of PM status, $F(3, 73) = 10.89$, $MSE = 0.29$, $p < .001$, $\eta_p^2 = .31$. Using planned contrasts to test our specific hypotheses, we found significantly slower responses in the active PM group than in the no-PM group, $F(1, 36) = 14.93$, $MSE = 0.31$, $p < .001$, $\eta_p^2 = .29$. We observed no statistical difference between the cancelled group and the active group, $F(1, 36) = 2.90$, $MSE = 0.33$, $p = .097$, $\eta_p^2 = .07$, but a difference between the cancelled and the no-PM group, $F(1, 38) = 4.68$, $MSE = 0.32$, $p = .037$, $\eta_p^2 = .11$. The finished group showed significantly faster reactions than the active group, $F(1, 35) = 30.94$, $MSE = 0.25$, $p < .001$, $\eta_p^2 = .47$, and no difference compared to the no-PM group, $F(1, 37) = 1.92$, $MSE = 0.25$, $p = .174$, $\eta_p^2 = .05$. Finally, we observed significantly slower reactions in the cancelled group than in the finished group, $F(1, 37) = 13.66$, $MSE = 0.26$, $p = .001$, $\eta_p^2 = .27$.

To exclude the possibility that "no" or "yes" answers for the critical trials biased our reaction times, we calculated the mean percentage of questions that required a "yes"-response for the post-trials that were included in the analysis. Because only three question types used this answer format, we restricted this analysis to these types. The overall average was 52.6%, and a one-way ANOVA showed no significant effect of group, $F(3, 71) = .86$, $MSE = 0.14$, $p = .468$. Furthermore, because single questions were drawn randomly, the distribution of easy and hard tasks in the post-trials should be similar to the "no" or "yes" answers.

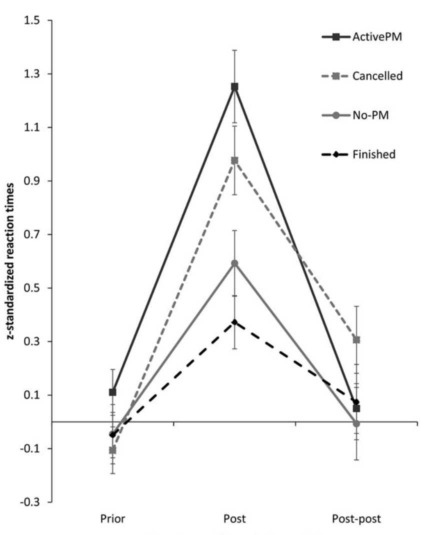

Figure 2. Z-standardized reaction times of Experiment 1 separated by question position relative to the prospective memory (PM) cue (prior, post, post-post) and PM task status (finished, cancelled, active PM, no-PM). Error bars represent standard errors.

Ongoing task accuracy

To assess accuracy in the ongoing task, we calculated the mean percentage of correctly solved questions for each participant after excluding the first question of each block and the first question after each interruption. A one-way ANOVA with the factor PM status (finished, cancelled, active PM, no-PM) showed a significant effect, $F(3, 73) = 3.76$, $MSE = 0.00$, $p = .014$, $\eta_p^2 = .13$. Bonferroni-corrected post hoc tests showed a significant difference between the finished group ($M = 0.85$, $SD = 0.05$) and the active PM group ($M = 0.78$, $SD = 0.08$, $p = .017$) only. Accuracy was

$M = 0.79$ ($SD = 0.04$) for the cancelled group and $M = 0.81$ ($SD = 0.06$) for the no-PM group.

Additional analysis

Somewhat surprisingly, we observed that even participants in the no-PM group showed slower responses to the question after the red screen (post). A repeated measures ANOVA with the question position relative to the PM cue (prior, post, post-post) as a factor for the no-PM group showed a main effect of question position, $F(2, 38) = 8.06$, $MSE = 0.32$, $p = .001$, $\eta_p^2 = .30$, and Bonferroni-corrected post hoc tests showed a significant difference between prior and post ($p < .001$), post and post-post ($p = .034$), but no difference between prior and post-post ($p = 1$). Again we tested whether "no" or "yes" answers for the critical trials biased our reaction times, using the same procedure as that described above. The overall mean of "yes"-response was 50.8%, and the ANOVA showed no significant effect of relative position to PM cue, $F(2, 36) = 1.37$, $MSE = 0.15$, $p = .268$.

Finally, we conducted a post hoc analysis on the effect of interruptions (no interruption vs. interruption) during the delay on PM hits (active PM group) and commission errors (cancelled group). For the analysis, we only included participants who made at least one PM hit or one commission error ($N_{cancelled} = 5$, $N_{activePM} = 17$) and used the Wilcoxon signed-ranks test. In the active PM group, PM hits were more frequent descriptively if no interruption was present ($M = 80.39\%$, $SD = 20.61$) compared to trials with an interruption ($M = 60.78\%$, $SD = 42.87$); however this was a non-significant difference, $z = -1.90$, $p = .054$. In the cancelled group, commission errors were significantly more frequent if no interruption was present ($M = 93.33\%$, $SD = 14.91$) than for trials with interruptions ($M = 33.33\%$, $SD = 33.33$), $z = -2.07$, $p = .038$.

Discussion

Our first aim was to test whether commission errors occur in the delay–execute PM paradigm. We observed significantly more commission errors in the cancelled group than in the finished group. We were able to replicate the findings of previous research using the retrieve–execute PM paradigm (Bugg & Scullin, 2013) in the delay–execute PM paradigm. Furthermore, the commission error rate appears to be lower if the PM task is performed and declared finished than if it is cancelled without being performed.

Our second aim was to analyse changes in ongoing task response times following presentation of the PM cue. Replicating previous research (Ball et al., 2013), we observed that being required to perform the PM response in the final phase (active PM group) resulted in significantly stronger task interference after the PM cue than in the no-PM group. More interestingly, the cancelled instruction does not seem to deactivate the intention: The cancelled group showed a similar response pattern to that of the active PM group. Finally, participants in the finished group appeared to have deactivated the PM task, as their responses on the trial following the PM cue were similar to those of the no-PM group. Theoretically, the results from the finished group support the deactivation view and the Zeigarnik effect, which both predicted that the PM intention will not be retrieved; however the result is inconsistent with the episodic trace account, which predicts retrieval of the PM intention followed by successful suppression of the PM response.

Surprisingly, the no-PM group showed significant slowing on the trial immediately after the red screen relative to the previous trial and the second trial after the red screen. This result is inconsistent with previous research (Ball et al., 2013). It should be noted, however, that Ball et al. (2013) averaged reaction times across the two questions following the PM cue, potentially removing the effect. In addition, one may consider the red screen as a 1-s task interruption; interruptions as short as 1 s can result in longer ongoing task resumption times (Monk & Kidd, 2008). Alternatively, the increase could also be attributed to an orientation reaction to a highly salient stimulus (Walser et al., 2012).

Finally, we noted that interruptions during the delay affect PM hits and commission errors. Although the former effect was not statistically significant, this is likely to be an issue of statistical power as it is an effect reported consistently in the literature (Cook et al., 2013; Einstein et al., 2003; McDaniel et al., 2004). The decline in PM hits in the standard delay–execute PM paradigm may be attributed to the reduction of cognitive resources resulting from the requirements to switch between the interrupting and ongoing tasks (e.g., Ball et al., 2013; Einstein et al., 2003). Similarly, commission errors in the cancelled group may be due to retrieval of the PM task in response to the PM cue, whilst participants fail to maintain the erroneous intention if they are interrupted during the delay.

In summary, these results indicate that commission errors are not necessarily the result of spontaneous retrieval combined with the failure to suppress a PM response to the PM cue. In the present experiment, 25% of participants in the cancelled group made a commission error after a delay of 45 s between the PM cue and the window of opportunity. The reaction time suggests that participants in the cancelled group retrieved the intention when encountering the PM cue and reformulated the plan to execute the related response at the next question type change; however, if an interruption occurs during the delay between PM cue and response opportunity this plan tended to be compromised. Taken together these data suggest that commission errors seem to reflect a conscious decision to execute an inappropriate PM response rather than execution of the PM response "by accident".

Experiment 2

The first aim of Experiment 2 was to replicate the results of Experiment 1 in relation to commission errors. We calculated the achieved power of the finished versus cancelled comparison in commission errors based on Fisher's exact test. This test was chosen as it produces a more conservative estimate due to its lower power in 2×2 tables relative to Barnard's exact test. Based on a two-tailed test with sample sizes of $N_{finished} = 19$ and $N_{cancelled} = 20$ and our results of Experiment 1 ($p_1 = .0$ and $p_2 = .25$), the achieved power was only .59. On this basis, an a priori power analysis [$\alpha = .05$ and $(1 - \beta) = .95$] suggested a sample size of $N = 40$ for each group (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007).

The second aim was to replicate the observed response time patterns in the cancelled group, the finished group, and the active PM group. We dropped the no-PM group because in Experiment 1 the finished and the no-PM groups showed similar minor increases in reaction time after the PM cue, and it seems reasonable to assume that the finished group did not retrieve the intention.

The third aim was to investigate whether failure to suppress the PM response is critical to commission errors in the delay–execute PM paradigm. We addressed this by adding divided attention variants of the cancelled and finished groups in which participants had to work on an additional task during the final phase. If PM response suppression is critical to avoidance of commission errors, one would expect to observe more commission errors in the final phase in the cancelled+divided attention group (cancelled+DA) than in the cancelled group, because suppression should be negatively influenced by the additional task. Such a result would mimic results from commission error research using a habitual retrieve–execute PM paradigm including divided attention (Pink & Dodson, 2013) or populations with reduced executive control (Scullin et al., 2012; Scullin et al., 2009).

A similar argument can be made for the finished and the finished+divided attention (finished+DA) group. More commission errors in the final phase in the finished+DA group than in the finished-PM group would imply that resources are needed to suppress the retrieval or execution of the PM task, because the imposition of the additional task should reduce the resources available for other processes.

The fourth aim was to address the effect of interruptions during the delay. We expected to replicate the finding that in the cancelled-PM group interruptions during the delay result in fewer commission errors than in uninterrupted trials.

Method

The method of Experiment 2 followed the method of Experiment 1. Therefore, only deviations from Experiment 1 methods are described.

Participants

In the study a total of 161 students participated in exchange for partial course credit (students at the Institute of Human-Computer-Media, 29% of sample) or were paid 8€ (other students at the Julius-Maximilians-Universität Würzburg). Twenty participants were excluded from the analysis ($N_{finished} = 7$, $N_{cancelled} = 6$, $N_{finished+DA} = 2$, $N_{cancelled+DA} = 2$, $N_{activePM} = 3$) because they could not correctly recall the PM task at the end of the experiment (6 participants) or due to deviations from the instructions such as pressing "q" immediately upon seeing the red screen (14 participants). These participants committed no commission errors. The final sample of 141 participants had a mean age of 23 years (range = 18–38 years), and 74% of the participants were female.

Design

The factor interruption (interruption vs. no interruption) was manipulated within participants while instructions before the final phase were alternated between participants in five different groups. In addition to the finished, cancelled, and active PM groups, we included a finished divided attention group (finished+DA) and a cancelled divided attention group (cancelled+DA), which received the same instruction regarding the PM task as the finished and cancelled groups, respectively, but got the additional instruction to count the number of odd digits presented via headphones during the final phase.

Materials and procedure

The instruction phase was the same as that in Experiment 1 but because divided attention groups needed their non-preferred hand to count the odd digits using a clicker, all participants were required to indicate their response with the index and middle finder of their preferred hand by pressing the "n" and "m" key. In addition, the divided attention groups were instructed to count the number of odd digits using a clicker whenever they heard digits read out loud via the headphones. We used digits from one to nine, which were presented either with the onset of each question or with a delay of 0.5 s. Delay and digit were determined randomly with an equal proportion of delay types but a ratio of 2:1 for odd digits compared to even digits.

In the final phase, with the exceptions of the blocks 4, 9, 11, 15, 18, and 22, the divided attention groups were presented with digits during all blocks. Therefore, all PM blocks were combined with divided attention, and divided attention was continued in the following block to be present during the window of opportunity.

Results

Prospective memory hits

Participants in the finished group had a mean PM hit rate of 71.25% ($SD = 29.72$), and participants in the finished+DA group had a mean PM hit rate of 57.50% ($SD = 33.54$). The difference was non-significant, $F(1, 58) = 2.62$, $MSE = 962.28$, $p = .111$, $\eta_p^2 = .04$. All but three participants showed at least one PM hit. In the final phase, participants in the active group had a mean PM hit rate of 73.02% ($SD = 22.65$).

Commission errors

Our first aim was to replicate Experiment 1. Replicating the results, we observed that significantly more participants committed commission errors in the cancelled group (13 of 40, 32.5%) than in the finished group (5 of 40, 12.5%, $p = .034$, two-tailed Barnard's exact test).

Our third aim was to investigate the effect of divided attention during the final phase. We observed fewer commission errors in the cancelled+DA group (0 of 20, 0%) than in the cancelled group (13 of 40, 32.5%, $p = .004$, two-tailed Barnard's exact test). We observed no significant difference between the finished+DA group (1 of 20, 5%) and the finished group (5 of 40, 12.5%, $p = .431$, two-tailed Barnard's exact test).

Our fourth aim addressed interruptions. We repeated the analysis from Experiment 1 and only included participants who committed PM hits ($N_{activePM} = 21$) or commission errors ($N_{cancelled} = 13$, $N_{finished} = 5$) .The divided attention groups were omitted due to the low commission error rates. In the active PM group, PM hits were significantly more frequent in trials without an interruption ($M = 93.65\%$, $SD = 13.41$) than in trials with an interruption ($M = 52.38\%$, $SD = 41.60$), $z = -3.18$, $p = .001$. In the cancelled group, commission errors were significantly more frequent in trials without an interruption ($M = 97.44\%$, $SD = 9.25$) than in trials with interruption ($M = 46.15\%$, $SD = 39.76$), $z = -2.84$, $p = .005$. In the finished group, commission errors were significantly more frequent in trials without an interruption ($M = 80.00\%$, $SD = 29.81$) than in trials with an interruption ($M = 53.33\%$, $SD = 29.81$), $z = -2.00$, $p = .046$.

Reaction times

We used the same reaction time procedure as that in Experiment 1 (removing 1.98% of the data). Figure 3 gives an overview of the z-standardized reaction times of Experiment 2.

Our second aim was to test the effect of PM status on the reaction to the post cue trial. A one-way ANOVA with the factor PM status (finished, cancelled, active PM) revealed no significant effect, $F(2, 97) = 3.02$, $MSE = 0.29$, $p = .054$, $\eta_p^2 = .06$. However, planned contrasts indicated significantly faster reactions in the finished group than in the cancelled group, $F(1, 77) = 3.02$, $MSE = 0.30$, $p = .031$, $\eta_p^2 = .06$, and no difference between the active group and the cancelled group, $F(1, 59) = 0.00$, $MSE = 0.26$, $p = .995$, $\eta_p^2 = .00$. As in Experiment 1, we tested the possibility that "no" or "yes" answers for the post-trials biased our reaction times, but found no significant effect of group, $F(2, 95) = 0.18$, $MSE = 0.15$, $p = .834$.

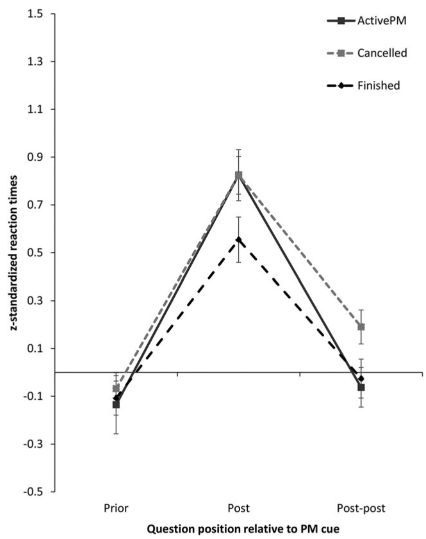

Figure 3. *Z*-standardized reaction times of Experiment 2 separated by question position relative to the prospective memory (PM) cue (prior, post, post-post) and PM task status (finished, cancelled, active PM). Error bars represent standard errors.

To achieve more statistical power, we combined the data from Experiment 1 and Experiment 2 and repeated the above analysis. The results are shown in Figure 4. A one-way ANOVA for the post-trial showed a significant effect of PM status, $F(2, 154) = 13.28$, $MSE = 0.30$, $p < .001$, $\eta_p^2 = .15$. Planned contrasts indicated significant differences between the finished group and cancelled group, $F(1, 116) = 14.80$, $MSE = 0.29$, $p < .001$, $\eta_p^2 = .11$, as well as between the finished and active PM group, $F(1, 95) = 22.27$, $MSE = 0.31$, $p < .001$, $\eta_p^2 = .19$. Finally, the cancelled and active PM group did not differ significantly, $F(1, 97) = 2.20$, $MSE = 0.30$, $p = .141$, $\eta_p^2 = .02$.

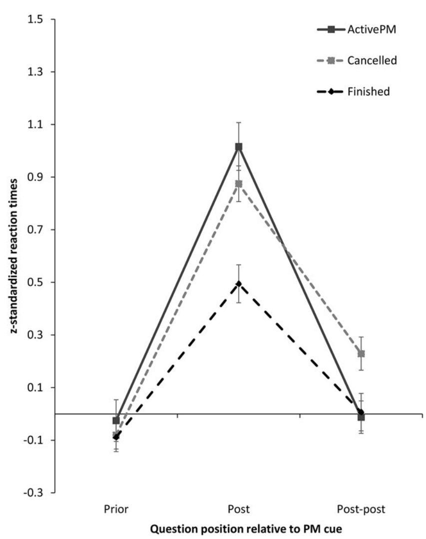

Figure 4. *Z*-standardized reaction times of combined data from Experiments 1 and 2 separated by question position relative to the prospective memory (PM) cue (prior, post, post-post) and PM task status (finished, cancelled, active PM). Error bars represent standard errors.

Ongoing task accuracy

The mean accuracy was $M = 0.84$ ($SD = 0.07$) for the finished group, $M = 0.84$ ($SD = 0.06$) for the cancelled group, $M = 0.83$ ($SD = 0.07$) for the active PM group, $M = 0.81$ ($SD = 0.06$) for the finished+DA group, and $M = 0.82$ ($SD = 0.06$) for the cancelled+DA group. A one-way ANOVA with the factor PM status (finished, cancelled, active PM, finished+DA, cancelled+DA) showed no significant effect, $F(4, 136) = 1.08$, $MSE = 0.00$, $p = .370$, $\eta_p^2 = .03$.

Discussion

Our first aim was to replicate the commission error finding of Experiment 1. As expected, we observed more commission errors in the cancelled than in the finished group.

The second aim was to test whether intention retrieval after the PM cue presentation was different in the cancelled group compared to the active group or the finished group. Replicating Experiment 1, the reaction time analysis of Experiment 2 and the combined analyses of Experiments 1 and 2 showed that participants in the cancelled and active PM groups appear to retrieve the intention whereas participants in the finished group do not.

The third aim was to investigate whether suppressing the PM response is relevant to the occurrence of commission errors in the delay–execute PM paradigm. There were almost no commission errors in the cancelled+DA and the finished+DA groups. In comparison to the effect of divided attention in habitual retrieve–execute PM (Pink & Dodson, 2013), divided attention did not result in a higher commission error rate in a finished group in the delay–execute PM paradigm. This also held true for the cancelled group. Caution is needed when comparing our results with those of Pink and Dodson (2013), however, owing to the differences between paradigms and tasks.

The fourth aim was to investigate the effect of interruptions during the delay between PM cue and response opportunity. Replicating Experiment 1, we observed that interrupted trials resulted in fewer PM hits (active PM group) and fewer commission errors (cancelled group and finished group). We discuss the theoretical implications of Experiment 2 in the general discussion.

General discussion

In the present experiments, we investigated the effect of PM task status on the occurrence of commission errors in the delay–execute paradigm and reported three main findings relating to commission errors, task interference caused by the PM cue, and manipulation of attentional resources during the delay. We discuss these findings separately before turning to their theoretical implications and the conclusion.

Commission errors

We replicated Bugg and Scullin's (2013) results on commission errors in the retrieve–execute paradigm. We observed significantly more commission errors in a subsequent block of trials when the PM task was cancelled rather than being declared finished after a number of PM trials had been performed. However, the very occurrence of commission errors in the delay–execute paradigm is surprising. Because there is a delay between PM cue and the window of opportunity the results cannot be explained by a combination of spontaneous retrieval of the PM task and failed suppression of the PM response as has been suggested in the context of retrieve–execute PM (Pink & Dodson, 2013; Scullin et al., 2012).

Prospective memory cue interference

We found interference with performance on the ongoing task after presentation of the PM cue in the cancelled group but not the finished group. In addition, replicating previous work (Ball et al., 2013), we observed more PM cue-related interference in the active PM group than in the no-PM group, which had not been exposed to the PM task instructions.

By comparing the finished and cancelled groups with the active and no-PM groups, respectively, with respect to interference, we can make inferences about PM task retrieval. Considering the finished group, we observed similar interference to the PM cue to that in the no-PM group and significantly less interference than in the active group. This result supports the idea that participants who are told the PM task is finished deactivate the related intention. This deactivation might be complete, as reported in some retrieve–execute PM studies (Marsh, Hicks, & Bink, 1998; Scullin et al., 2009); alternatively, residual activation may remain (Walser et al., 2012), resulting in very brief PM task retrieval in response to the PM cue, which is insufficient to interfere with the ongoing task on the following trial (Cohen et al., 2005; Scullin et al., 2012). Considering the cancelled group, we consistently observed similar levels of interference in the cancelled and active groups, which were higher than in the finished and no-PM groups. This indicates that the cancelled group did not deactivate the intention, and it was retrieved and potentially reformulated to execute the intention during the window of opportunity (Ball et al., 2013).

Attentional resources

Dividing participants' attention during the final phase resulted in almost no commission errors in the finished or the cancelled groups. This result contrasts with findings from retrieve–execute PM tasks. In these PM tasks, participants with reduced executive functioning commit more commission errors on retrieve–execute tasks (Scullin et al., 2012; but see Bugg et al., 2013). The finding in the retrieve–execute task is explained by a reduced ability to suppress a PM response upon encountering the PM cue when it is no longer relevant. We interpret our findings as evidence that commission errors in the delay–execute paradigm are not exclusively due to failure to suppress a PM response in the response window.

However, our divided attention manipulation affected retrieval of the PM task in response to the PM cue, possible maintenance during the delay, and execution of the PM response during the window of opportunity; it is thus unclear which process or processes were affected by the manipulation. It should also be noted that suppression of the PM response is only required if the intention is still active when the window of opportunity begins. If the intention is no longer active, no response suppression is required, and the effect of divided attention becomes irrelevant.

Current explanations of PM performance in the delay–execute paradigm suggest that the PM task is retrieved and reformulated when the PM cue is encountered, and that participants rely on long-term memory to perform the task when the question type changes (Ball et al., 2013). Since participants did not seem to actively maintain the intention in our study[1] or in other experiments (Ball et al., 2013) it seems unlikely that compromised maintenance during the delay affected PM performance. Furthermore, interruptions during the delay phase reduced commission errors compared to delays without interruption. Together these findings suggest that divided attention is likely to have affected task execution; however, further research into the effects of divided attention, using techniques that can dissociate the various processes involved in successful PM task performance, is necessary.

Previous research (Ball et al., 2013; Einstein et al., 2003; McDaniel et al., 2004) and the results presented here indicate that interruptions reduce the PM hit rate in the delay–execute paradigm. Because PM hits and commission errors are similarly affected by both attention manipulations, we suggest that in the active PM and the cancelled PM groups the PM task is retrieved when the PM cue is presented, but reduced attentional resources result in participants forgetting to execute the PM action during the window of opportunity.

Theoretical implications

As we described in the introduction, the general pattern of commission errors in the delay–execute paradigm and the observed difference between errors in the finished group and the cancelled group are consistent with the Zeigarnik effect (Zeigarnik, 1938), episodic trace view (Hommel et al., 2001), and deactivation view (Scullin et al., 2009).

The PM task interference effects we observed are consistent with the Zeigarnik effect (Zeigarnik, 1938) and deactivation view (Scullin et al., 2009). Both predict that cancelled intentions are more likely to be recalled than finished intentions. However, the interference effects we observed are not consistent with the episodic trace view of commission errors (Hommel et al., 2001); this view posits that a strong associative link between PM cue and PM reaction will result in task recall (manifested in slower responding on the ongoing task) but that a no-go memory will lead to suppression of the PM response. We did not find task interference in the finished group similar to the active PM group, indicating no such link was present.

Although our results support the idea that intentions are completely deactivated in the finished group, there are two lines of findings in the literature on retrieve–execute PM that are inconsistent with this view.

The first comes from research reporting only partial deactivation of finished intentions (e.g., Cohen et al., 2005; Cohen, Kantner, Dixon, & Lindsay, 2011; Penningroth, 2011; Walser et al., 2012). There are, however, several methodological differences that may explain this inconsistency. First, there are differences in the chronology of experiments. All the studies that have reported partial deactivation used a very short delay (less than a minute) between the finish instruction and presentation of the PM cue; hence the observed partial deactivation might reflect residual activation —that is, deactivation in progress—as proposed by Walser et al. (2012). As an anonymous reviewer of this paper pointed out, however, Walser, Plessow, et al. (2014) reported after-effects but almost no commission errors for non-salient focal cues, irrespective of the interval between finished instruction and PM cue presentation.

Second, the "deactivation" instructions vary between studies. For example, in some studies participants learned scripts and were then informed whether the script should be executed or should be ignored/ not performed (Cohen et al., 2011; Penningroth, 2011). Because scripts were never performed before the execute or ignore instruction, one might argue that in these studies the deactivation instruction is more similar to our cancelled than to the finished instructions, and hence the observation of incomplete deactivation is unsurprising. Furthermore, Penningroth (2011) reported that participants expected to be asked about the learned but to-be-ignored scripts, which is likely to result in maintenance of the to-be-ignored scripts and hence a heightened state of activation.

Third, in all of the above studies, participants worked on several blocks. Each block included a PM intention, which was declared finished at the end of the block, and in the next block a new PM intention had to be learned. Walser et al. (2012) noted that the observed partial deactivation might be the result of a trade-off between monitoring for currently relevant cues while suppressing the execution of the PM actions to previously relevant cues. However, as pointed out by an anonymous reviewer, Walser et al. (Walser, Goschke, et al., 2014; Walser, Plessow, et al., 2014) also observed after-effects of finished intentions when analysing the first block, only.

Fourth, in our experiments the PM cue (i.e., the red screen) was presented for a rather long period, 1000 ms. Given that residual activation effects may last less than 100 ms (Walser et al., 2012), one may argue that the effects of residual activation in the finished group were masked by this procedure. The intention may have been retrieved but immediately deactivated within the 1000-ms presentation of the PM cue. Based on comparisons between the finished group and the other groups (cancelled; active PM; no-PM), we infer that the finished group did not retrieve the PM task, but we cannot completely rule out the possibility of partial deactivation.

The second line of findings relates to the occurrence of commission errors. Following a finished instruction some participants committed commission errors (present Experiment 2; see also Bugg et al. 2013; Bugg & Scullin 2013, Experiment 3; Walser, Plessow, et al., 2014, Experiment 2), and some did not (present Experiment 1; see also Bugg & Scullin 2013, Experiment 1 and 2); if a finished instruction consistently produces complete deactivation, the commission error rate should always be zero afterwards.

For retrieve–execute tasks, spontaneous retrieval processes in response to the cue may explain commission errors in the finished group (Scullin et al., 2012). In the delay–execute paradigm, spontaneous retrieval processes are likely to contribute to commission errors in the finished and the cancelled groups. It seems that in the cancelled group, the intention is retrieved and reformulated when encountering the PM cue. Given that no monitoring was observed during the delay it seems that participants rely on spontaneous processes to recall the task and execute the intention when the question type changes. Even though the intention has not been previously recalled in reaction to the PM cue, we suggest that participants in the finished group may have erroneously recalled the intention in reaction to the question type change and executed it immediately.

The variance in commission error rates within the cancelled and finished groups could be explained by individual differences between participants' state versus action orientation (Goschke & Kuhl, 1993; Penningroth, 2011) and field dependence (Witkin & Goodenough, 1977). For example, theory on state versus action orientation posits that state-oriented individuals ponder irrelevant goals or tasks whereas action-oriented individuals do not show similar rumination (Penningroth, 2011). In our experiments, such rumination might be linked to higher availability of the finished or cancelled PM task, which in turn would predict more commission errors for state-oriented participants than for action-oriented participants. In addition, state-oriented participants show increased after-effects of completed intentions (Walser, Goschke, et al., 2014); in our experiments this should be reflected in more pronounced slowing after PM cue presentation.

Finally, the experimental design could be improved by replacing the filler maths tasks, which are presented to all groups except the finished group during the intermediate phase (Figure 1), with blocks of the ongoing task to ensure that all groups have similar practice with the ongoing task.

Conclusion

Based on the reviewed literature and the present results, we suggest that commission errors in the delay–execute paradigm are primarily due to a failure to deactivate an intention that is retrieved when encountering the PM cue. Retrieval may result in a conscious, deliberate decision to execute the intention at the end of the delay. If attention resources are reduced during the delay it is less probable that the erroneous intention will result in a commission error. We consider that a commission error reflects a conscious decision to execute the PM response because the 45-second delay rules out a spontaneous or reflexive response to retrieval of the intention. Furthermore, interruptions during the delay reduced the commission error rate, which suggests that participants planned to execute the intention but were not able to maintain the plan until the end of the delay.

Future research is needed to explain why some participants make commission errors, and others do not. Our results confirm that never having executed the intention increases the likelihood of commission errors (Bugg & Scullin, 2013) but reported commission error rates in conditions in which participants have executed the intention vary between 0% and 25%. We have also proposed that commission errors are the result of a conscious decision. Future research could involve probing participants during the delay phase to determine whether they are aware of their erroneous intention and whether they are in any doubt about their plan.

Note

1. For the analysis of the delay phase of non-interrupted PM blocks we calculated separate per-participant averages for reaction times for trials before the red screen (pre-phase: Trials 2–5) and after the red screen, excluding

the trial immediately after the red screen (post-phase: Trials 7–20; cf. Ball et al., 2013). We calculated a 4 (PM status: finished, cancelled, active PM, no-PM) × 3 (phase: pre-phase, post-trial, post-phase) mixed ANOVA. There were effects of phase, $F(2, 128) = 91.59$, $p < .001$, $\eta_p^2 = .59$, and group, $F(3, 64) = 5.18$, $p = .003$, $\eta_p^2 = .20$, as well as an interaction, $F(6, 128) = 4.69$, $p < .001$, $\eta_p^2 = .18$. Bonferroni-corrected post hoc tests showed significant differences between pre-phase and post-trial ($p < .001$) and between post-trial and post-phase ($p < .001$), but not between pre-phase and post-phase ($p = .615$). Separate one-way ANOVAs for the pre-phase, $F(3, 73) = 0.67$, $p = .576$, $\eta_p^2 = .03$, and the post-phase, $F(3, 73) = 1.79$, $p = .157$, $\eta_p^2 = .07$, did not reveal any group differences, indicating that there was no active monitoring or maintenance of the intention in the pre-phase and the post-phase, respectively.

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Disclosure statement

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Annex D: **Study 4 - Commission errors with forced response lag**

Schaper, P., & Grundgeiger, T. Commission errors with forced response lag. [Currently under major revision]

Author	Contribution
Schaper, P.	Literature review, experimental design, data collection, data analysis, manuscript preparation and revision
Grundgeiger, T.	Contributed to experimental design, manuscript revision

Commission Errors with Forced Response Lag

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Abstract

It is often necessary to retrieve intentions once a certain cue occurs in the environment. However, such prospective memory (PM) tasks can also be erroneously recalled even though they are no longer relevant, and may result in commission errors. According to the dual mechanism account, commission errors occur because the intention is spontaneously retrieved, and there is a subsequent failure to suppress the associated action, resulting in erroneous instant execution. In three experiments, we tested whether failed response suppression is a prerequisite for commission errors. We set up a response lag condition in which participants had to delay their response to ongoing task trials for one second (Experiment 1) or two seconds (Experiments 2 and 3) and a pause condition in which the delay occurred between ongoing task trials. In both conditions, participants learned about a PM task and were then told that the PM task was cancelled. Later, all participants encountered several irrelevant PM cues. If failed response suppression is a prerequisite for commission errors, commission error rates should be non-existent in the response lag conditions, because participants had designated time to suppress the PM action. In fact, however, commission errors occurred at an equal rate in all lag and pause conditions. In a modified dual mechanism account, we suggest that erroneous intentions are formed when encountering the former PM cue and persist over delays between formation and execution. These commission errors are not caused by failed response suppression.

Keywords: prospective memory; commission errors; retrieve-execute paradigm

Commission Errors with Forced Response Lag

Remembering and executing an intention once a certain cue appears in the environment, or after a delay, is referred to as prospective memory (PM, Einstein & McDaniel, 1990). Once the intention is no longer relevant, either because the intention has been executed and declared finished, or it has been declared cancelled without being executed at all, after-effects may remain (Anderson & Einstein, 2016; Bugg, Scullin, & McDaniel, 2013; Walser, Fischer, & Goschke, 2012). Indeed, if the PM cue still occurred at a later point in time, researchers observed commission errors, that is, the erroneously repeated execution of the PM task following previously relevant cues (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017; Scullin, Bugg, & McDaniel, 2012). The dual mechanism account of commission errors (Bugg, Scullin, & Rauvola, 2016; Scullin & Bugg, 2013) states that commission errors are the result of spontaneous retrieval and subsequent failure to suppress the execution of the intention. In the present experiments, we test whether the account's proposition that failed suppression of the execution is a requirement for commission errors can be experimentally supported.

In a commission error experiment, participants first encode a PM task, namely, pressing "6" on a keyboard if a cue appears during an ongoing task. In the cancelled condition, the PM task is cancelled after the participants have been instructed, and have been told that they should not react to the cue by pressing "6". In the finished condition, the PM task is executed in a first phase (Phase 1); after this phase, the PM task is declared finished, and the participants are instructed to no longer react to the cue by pressing "6". In Phase 2 of the experiment, the participants with cancelled and finished instructions are presented with an ongoing task, which includes multiple PM cues, which were no longer relevant (see Figure 1 for an overview of the cancelled condition). The difference between finished and cancelled PM instructions appears to be minor, but researchers consistently found that the proportion of participants who made a commission error with cancelled instructions was significantly larger than with finished instructions (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017).

Theoretically, Scullin et al. (2012) suggested that “commission errors occur when a completed intention is spontaneously retrieved, and individuals fail to suppress executing the intention” (p. 52). Recently, Bugg et al. (2016) called this view the dual mechanism account. This view is based on the idea that participants do not actively monitor for the former PM cues, because they are no longer relevant, but may spontaneously retrieve the intention in the presence of a salient cue. Depending on the degree of cognitive control of the participant, the intention is either correctly suppressed, or, if the cognitive control is impaired, erroneously executed. Support for this account is based on larger commission error rates in older adults than in younger adults (Scullin et al., 2012), especially among older participants with diminished inhibitory executive control abilities (Scullin, Bugg, McDaniel, & Einstein, 2011). In addition, Pink and Dodson (2013) showed in a modified version of the procedure described above that divided attention during Phase 2 results in more commission errors compared to full attention (but see Boywitt, Rummel, and Meiser (2015) for methodological concerns regarding the experiment).

However, the effect of the inhibition measure could not be replicated in a subsequent study using an implementation intention encoding condition (Bugg et al., 2013), and the correlation between inhibition score and commission errors is limited to older adults (Scullin et al., 2011). Furthermore, Schaper and Grundgeiger (2017) observed commission errors in younger adults in the delay-execute paradigm. In this paradigm, there is a delay of 45 seconds between the PM cue and the window of opportunity for the associated action, during which the participants continue to work on the ongoing task. This result contradicts the dual mechanism account, because suppression should take place directly after the no longer relevant cue and not during the window of opportunity. Instead, one may argue that participants should be able to rethink and suppress the erroneous action during the delay.

There is no theoretical prediction why participants would consistently remember the no longer relevant cue for 45 seconds until the window of opportunity, subsequently recall the intention during the window of opportunity and then fail to suppress it. However, it could be argued that an erroneous intention to execute the PM task is formed in response to the no longer relevant PM cue and is executed once the window of opportunity presents itself.

In the present experiments, we investigated the effect of a brief artificially created lag, before an ongoing task or PM response could be given in the retrieve-execute PM paradigm. By introducing the response lag, we aimed to provide participants with additional time to rethink and suppress an erroneous PM response, and therefore to test whether the dual mechanism account's proposition that failed suppression of the execution is a requirement for commission errors can be experimentally supported. In the context of information-processing research, delays as short as 350ms have been shown to be sufficient to enable participants to ignore irrelevant stimuli in simple experimental tasks (Simon, Acosta, Mewaldt, & Speidel, 1976). Similarly, Hubner and Mishra (2013) showed that a predictable but short response lag of 200ms allowed participants to allocate resources to suppress irrelevant cues consistently. These experiments suggest that suppression processes can be activated and completed within the first 400ms after cue presentation. In the context of PM research, a study by Loft and Remington (2013) showed that short response lag manipulations (200–400ms) resulted in improved focal and nonfocal PM performance (i.e., more PM hits). With longer response lags (600–1600ms) PM performance in focal and nonfocal PM tasks was identical, indicating that response lags longer than 600ms are long enough for participants to recognize the stimuli as a PM cue and react appropriately. Introducing a response lag of comparable length in a commission error experiment should, therefore, enable participants to assess the no longer relevant PM cue adequately, suppress an erroneous response, and hence improve performance (i.e., make fewer commission errors). In the present studies, we used a one second response lag in Experiment 1 and a two second response lag in Experiments 2 and 3, which should have been sufficient time to assess the stimuli and suppress a PM response.

We used an adapted version of the finished and cancelled conditions described by Bugg and Scullin (2013). We first introduced the ongoing task and the PM task to the participants. In the response lag condition, participants could not enter their response to the ongoing task until a given amount of time had elapsed, while participants in the pause condition could input their choice immediately but experienced a delay corresponding to the response lag length between each trial (Figure 1). Salient cues were used for the prospective memory task, to initiate spontaneous retrieval (McDaniel & Einstein, 2000) and rule out that participants have to detect the PM cue. If failed response suppression is a necessary condition for commission errors, introducing a response lag should help participants to rethink and consequently suppress their response. According to the dual-mechanism account (Bugg et al., 2016), introducing the response lag should result in no commission errors while significantly more participants should make commission errors in the pause condition.

Experiment 1

In Experiment 1, the lag and the pause conditions included cancelled instructions for the PM task (i.e., the PM task was cancelled immediately after the PM instructions). We used cancelled instructions because they resulted in more commission errors than finished instructions (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017). The delay for the response lag, or the pause between ongoing task trials, was one second, in the respective groups. For the response lag group, the answer choices for the ongoing task were not presented until the lag had occurred. According to the dual-mechanism account (Bugg et al., 2016), the lag condition should result in no commission errors.

Method

Participants. We conservatively selected a commission error probability of $p_1 = 0.30$ for the pause group (Bugg and Scullin (2013), reported a commission error probability of at least 40% for a similar condition), and no commission errors in the response lag group ($p_2 = 0$). The analysis resulted in a sample of 2 × 21 participants (Fisher's exact test, 2-tailed, alpha = .05, power = .8; calculation conducted with G*POWER 3, Faul, Erdfelder, Lang, & Buchner, 2007). Our sample consisted of 44 undergraduate students who participated for partial course credit or were paid € 5. Five of the participants were excluded from the analysis, either because they could not correctly recall the PM task (one student), or because they could not correctly describe the cancelled instructions (four students) at the end of the experiment. The 19 participants in the pause group had a mean age of 20.37 years (63% female), and the 20 participants in the response lag group had a mean age of 21.5 years (75% female).

Design. We used two groups, which differed only in the timing of the ongoing task. The response lag group had to wait one second until the answer choices for the ongoing task were shown on the screen, and the pause group experienced a delay of one second after each ongoing task trial. The main dependent variable was commission error occurrence. In addition, we assessed reaction time and accuracy of the ongoing task during Phase 2.

Material. We used a lexical decision task as the ongoing task, including 120 words and 120 non-words. The words were five to eight letters long. The order of words was selected randomly for each participant. To control for repeated exposure, we also included five words, which were repeated two, three, and four times each. For the non-words we used four strings, which were repeated five times to match the frequency of PM cues and control words, as well as five non-words, which were repeated two, three, and four times each. The other 65 words and non-words occurred only once.

Procedure. The experimental procedure had four main phases: (1) instructions, (2) Phase 1, (3) Phase 2, and (4) questionnaire.

First, participants were informed about the ongoing task. Participants needed to work on a lexical decision task and indicate their answer by pressing either "x" or "m" on a keyboard, corresponding to the response key assignments displayed on a monitor (e.g., “x = word” and “m = non-word”). The strings of letters were displayed in a white font on a black background. Participants were instructed to use the index fingers of their left and right hands and to keep these fingers on the keys throughout the experiment. The key configuration was counterbalanced within each group. Participants conducted a short training period without feedback after the instruction.

Each trial started with a fixation cross which lasted randomly between 250 and 500ms. For the response lag group, there was a delay of one second before the response key assignments were displayed and participants were told that they had to delay their answer until the key assignments were displayed. The next trial was displayed immediately after an input was made (ongoing task response or PM response). For the pause group, the response key assignments were displayed simultaneously with the letter string, and a black screen was shown for one second after participants made an input.

Next, both groups received instructions for the PM task – pressing “6” if one of two target words occurred on a red background. Another pair of words and a blue background were used as controls. The word pairs were counterbalanced (pair 1: noon, summit; pair 2: committee, furniture – translated from German). After the instructions, participants had to reproduce the PM instructions in their own words in writing. The instructions were displayed again, and the participants were subsequently asked to reproduce the instruction again, using different wording. The PM task was cancelled in both groups immediately afterwards by telling the participants that they were assigned to a condition in which they no longer needed to press “6” in the presence of target words. That task was declared cancelled and should not be performed.

Second, in Phase 1, both groups worked on 80 lexical decision task trials without former PM cues or control trials. Before and after Phase 1, participants had to work on a simple addition task for one minute.

Third, in Phase 2, both groups worked on 260 trials of the ongoing task, including 10 trials with the former PM cues with the respective background color (target 1 in trials 17, 62, 115, 161, 221; target 2 in trials 31, 81, 142, 192, 253) and 10 control trials using a differently colored background (control 1 in trials 23, 73, 128, 185, 237; control 2 in trials 41, 102, 153, 204, 258). For the pause group, the change in background color had already occurred during the delay before the next task, including the appearance of the fixation cross. For the response lag group, the change in background color occurred simultaneously with the fixation cross (see Figure 1).

Fourth, we assessed demographic data and asked the participants to reproduce the PM task instructions. Participants were tested individually or in pairs. The experiment lasted approximately 30 minutes.

Results

The statistical analysis was conducted using SPSS Statistics 23 (Chicago, IL). For all tests, alpha was set at .05.

Commission errors. A commission error was defined as pressing “6” in the trial with the PM cue. As in previous research (Bugg & Scullin, 2013), a participant was considered to make commission errors if she/he made at least one error during Phase 2.

We found nearly identical rates of participants making commission errors in the response lag group (35%) and the pause group (37%). The mean proportion of participants with commission errors did not differ significantly between both groups, $\chi^2(1) = .01$, $p = .905$. From 100 commission errors eight (8%) were made during the response lag. Removing these responses did not change the pattern of results because these eight errors were made by a single participant, who also reacted with a PM response after the response lag.

Ongoing task performance. We analyzed performance only for Phase 2. First, we excluded the first ten questions for each participant, all trials including former PM cues or control cues and the two subsequent trials. All means are summarized in Table 1.

For the reaction time analyses, we analyzed only correct responses and responses within 2.5 standard deviations of the participant’s mean response time (removing 2.85% of the data; Ball, Knight, Dewitt, & Brewer, 2013). The response lag group showed significantly faster responses compared to the pause group, $t(37) = 15.01$, $p < .001$, $d = 4.83$.

Next, we tested for possible differences in reaction times of participants with and without commission errors within the groups. Due to the small number of participants making commission errors, we used Bonferroni-corrected Wilcoxon signed-ranked tests. In the pause group, there was no significant difference in reaction time between participants with and without commission errors ($U = 26$, $p = .392$). In the response lag group, there was also no significant difference between participants with and without commission errors ($U = 41$, $p = 1$).

To test whether participants without commission errors were more cautious in the ongoing task after encountering the first cue, which was no more relevant, an additional mixed ANOVA was conducted on the mean reaction time before and after the first cue which was no longer relevant in Phase 2. For the pre-cue phase, we removed the first ten trials, as well as incorrect trials, but did not remove trials deviating by more than 2.5 standard deviations from the mean due to the small number of applicable trials (11–16). There was no significant difference in reaction time before and after the first cue, $F(1, 23) = 1.38$, $p = .252$, $\eta_p^2 = .06$, and no significant interaction with the group, $F(1, 23) = .47$, $p = .501$, $\eta_p^2 = .02$, although the main effect of the group was still significant, $F(1, 23) = 110.62$, $p < .001$, $\eta_p^2 = .83$.

For ongoing task accuracy, participants reacted more accurately in the response lag group, compared to the pause group, $t(37) = 2.48$, $p = .018$, $d = .79$. In the pause group, a Bonferroni-corrected Wilcoxon signed-ranked test showed no significant difference in accuracy between participants with and without commission errors, $U = 21.5$, $p = .086$. In the response lag group, there was also no significant difference in accuracy between participants with and without commission errors, $U = 40.5$, $p = .711$.

Discussion

Based on the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013), commission errors result from spontaneous retrieval and subsequent failure to suppress the execution of the intention. Therefore, commission errors should not occur if participants have sufficient additional time to exert executive control and suppress the intention. Contrary to this prediction, we observed that a considerable proportion of participants in both groups made commission errors (35% and 37%). Furthermore, the proportions were not significantly different.

For the pause group, it could be argued that the pre-exposure of the change in background color without the associated PM cue could have resulted in spontaneous retrieval and an immediate response as soon as the former PM cue occurred, which would be in line with the idea of failed suppression. However, the commission errors in the response lag group cannot be explained by this reasoning, because the participants had an additional second without any distraction to suppress the action, and because commission errors were only made (except for one participant) after the response lag had occurred. However, one may ask whether an additional second was enough time to suppress the PM response. We address this issue in Experiment 2.

In the ongoing task data, we found a significant effect of group for both reaction times and accuracy, with faster and more accurate reactions in the response lag group than in the pause group. It is likely that participants in the response lag group prepared their response to the ongoing task before input was possible. There were no significant differences in the ongoing task data within each group when comparing participants with and without commission errors. In particular, there was no indication that participants without commission errors responded more cautiously in the ongoing task after the first cue, which was no longer relevant, occurred.

Experiment 2

In Experiment 2, we planned to replicate the results of Experiment 1 but to provide a response lag of two seconds to allow even more time to enable response suppression if needed. In addition, we included a response lag condition with finished instructions (Bugg & Scullin, 2013) as a control condition for commission errors, and especially for ongoing task performance. Participants in the finished group performed the PM task in Phase 1 including four PM events and were subsequently told that the PM task was finished. As in Experiment 1, in Phase 2 all groups worked on the ongoing task and encountered 10 former PM cues. Because finished instructions usually result in low or nonexistent rates of commission errors (Bugg & Scullin, 2013), we did not include an additional condition with finished instructions and without response lag.

We expected to replicate the results of Experiment 1 and to find a similar proportion of participants with commission errors in the response lag group and the pause group with cancelled instructions. In addition, we expected to find a significantly smaller proportion of participants making a commission error in the finished condition compared to both groups with cancelled instructions (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017). Finally, we expected to replicate Experiment 1 in terms of reaction time and accuracy for the ongoing task, with faster and more accurate results in the groups with a response lag. However, we expected no differences between the finished response lag and the cancelled response lag conditions.

Method

The method of Experiment 2 essentially followed the method of Experiment 1. Therefore, only the deviations are described.

Participants. Our sample consisted of 70 undergraduate students who participated for partial course credit or were paid € 5. Six participants were excluded from the analysis because they could not correctly recall the PM task at the end of the experiment (cancelled pause group n = 1, cancelled response lag group n = 2, finished response lag group n = 1), or reacted to all cues, including the controls (cancelled response lag group n = 1, finished response lag group n = 1). The 22 participants in the cancelled pause group had a mean age of 20.18 years (68% female), the 20 participants in the cancelled response lag group had a mean age of 21.90 years (70% female), and the 22 participants in the finished response lag group had a mean age of 20.86 years (72% female).

Design. We used three groups, which differed in the timing of the ongoing task, and in their PM status: cancelled instruction and response lag, cancelled instruction and pause, finished instruction and response lag. The response lag groups had to wait two seconds before the answer choices for the ongoing task were shown onscreen, and the pause group had a delay of two seconds after each ongoing task trial.

Procedure. The instruction phase was the same as in Experiment 1 for the response lag and pause group. For the finished group, the PM instruction was not cancelled, but participants executed the intention in Phase 1. In Phase 1, the finished group worked on 80 lexical decision task trials with four PM cues (target 1 in trials 18, 45; target 2 in trials 31, 79) and four control cues (control 1 in trials 12, 59; control 2 in trials 26, 72). Afterwards, the PM task was declared finished. Both groups with cancelled instructions worked on 80 lexical decision tasks without former cues or controls. Phase 2 was identical to Experiment 1 for all three groups.

Finally, we removed the change in background color for the pause group during the pause and the fixation cross before former PM cues and the change in background color for the response lag group during the fixation cross (Figure 1). These changes remove the possible confound of preparation for the complete PM cue and suppression of the PM task when it is no longer relevant.

Results

Prospective memory hits. We calculated the percentage of correct PM responses out of four PM events during Phase 1 for the finished response lag group. The mean PM hit rate was 94.32% (*SD* = 21.73), and all but one participant had at least one PM hit. Out of 83 prospective memory hits, 40 (48%) were made during the response lag.

Commission errors. The proportion of participants with commission errors did not differ significantly between the cancelled group with response lag (25%) and the cancelled group with pause (45%), χ^2 (1) = 1.91, $p = .167$. In the finished group with response lag none of the participants made a commission error (0%), which represented a significantly lower proportion compared to the cancelled group with pause, χ^2 (1) = 12.94, $p = .001$, and to the cancelled group with response lag, χ^2 (1) = 6.24, $p = .018$. Out of 40 commission errors, six (15%) were made during the response lag. Removing these responses did not change the pattern of results.[1]

Ongoing task performance. To analyze Phase 2, we used the same data trimming procedure as in Experiment 1 (removing 2.79% of the data for the reaction time analysis). All means are summarized in Table 1.

A one-way ANOVA showed a significant main effect between the groups for reaction time, $F(2, 61) = 175.95$, $p < .001$, $\eta_p^2 = .85$. Bonferroni-corrected post-hoc tests showed significantly slower reaction times in the cancelled pause group compared to the cancelled response lag group ($p < .001$) as well as between the cancelled pause group and the finished response lag group ($p < .001$). The cancelled and finished groups with response lag did not differ significantly ($p = .189$).

We used Bonferroni-corrected Wilcoxon signed-ranked tests to compare reaction times of participants with and without commission errors for the cancelled groups. In the pause group, there was no significant difference in reaction times between participants with and without commission errors, $U = 33$, $p = .150$. In the response lag group, there was also no significant difference in the reaction times between participants with and without commission errors, $U = 20$, $p = .252$.

We repeated the mixed ANOVA on the mean reaction time before and after the first PM cue, which was no longer relevant in Phase 2 for participants without commission errors. The same selection criteria as described for Experiment 1 were used. There was no significant difference in reaction time before and after the first cue, $F(1, 46) = 1.79$, $p = .188$, $\eta_p^2 = .04$, and no significant interaction with the group, $F(2, 46) = .17$, $p = .847$, $\eta_p^2 = .01$, although the main effect of the group was still significant, $F(2, 46) = 95.08$, $p < .001$, $\eta_p^2 = .81$.

For ongoing task accuracy, a one-way ANOVA showed a significant main effect between the groups, $F(2, 61) = 13.82$, $p < .001$, $\eta_p^2 = .31$. Bonferroni-corrected post-hoc tests showed significant differences in ongoing task accuracy between the cancelled pause group and the cancelled response lag group ($p = .001$) as well as between the cancelled pause group and the finished response lag group ($p < .001$). The cancelled and finished groups with response lag did not differ significantly ($p = .710$).

Bonferroni-corrected Wilcoxon signed-ranked tests were used to compare the accuracy of participants with and without commission errors for the cancelled groups. In the pause group, accuracy was lower for participants making commission errors compared to participants without commission errors ($U = 24.5$, $p = .034$). In the response lag group, the same pattern was found for participants making commission errors compared to participants without commission errors ($U = 8.5$, $p = .016$).

Discussion

Replicating the results of Experiment 1, we observed that a considerable proportion of participants made commission errors in the response lag and pause cancelled groups, with no significant differences between the groups. Again, these results indicate that failed response suppression is not a prerequisite for commission errors. However, in Experiment 2, we observed a descriptive difference between the response lag and pause cancelled groups, with an achieved power for finding such a difference of only .27. Therefore, compromised response suppression may increase commission error rates. Finally, we replicated the results of Bugg and Scullin (2013) with significantly more commission errors after cancelled instructions in comparison to finished instructions.

For ongoing task performance, as in Experiment 1, we found faster and more accurate reactions for both response lag groups compared to the pause group, because participants could prepare their response before it could be entered. Again, we did not find differences in reaction time within the cancelled groups for participants with and without commission errors. However, in contrast to Experiment 1, we observed significantly lower ongoing task accuracy in both cancelled groups for participants making commission errors. This difference may be explained in two ways.

First, accuracy in the ongoing task and making commission errors might be linked by an underlying trait. We discuss this idea in more detail in the general discussion. Second, the differences in accuracy might be due to the descriptive differences in reaction time. Participants who made commission errors in the pause group had descriptively faster reaction times but lower ongoing task accuracy. We did not observe such a speed-accuracy trade-off for the response lag group, but this may have been because participants in the response lag group had enough time to prepare an answer. Therefore, the reaction time for this group has to be interpreted carefully. As in Experiment 1, we did not find any indication that participants without commission errors reacted more cautiously in the ongoing task trials after the first PM cue, which was no longer relevant, occurred in Phase 2 of the experiment.

Experiment 3

Experiment 3 was conducted to address the descriptive but non-significant difference in commission error occurrence between the response lag and pause conditions in Experiment 2. Based on Experiment 2, we used a commission error probability of approximately $p_1 = 0.45$ for the pause group, and $p_2 = .25$ for the response lag group for the power analysis. The analysis resulted in a sample of 2 × 98 participants (Fisher's exact test, 2-tailed, alpha = .05, power = .8). The increase in sample size also allowed us to test if the effect of lower ongoing task accuracy for participants making commission errors in both cancelled conditions, as observed in Experiment 2, could be replicated.

Due to the increase in sample size, the experiment was conducted online using the online recruiting tool Prolific (www.prolific.ac). The procedure of Experiment 3 was almost identical with the procedure of Experiment 2, with three exceptions. First, we implemented a warning in the response lag groups, which appeared if a response was given during the lag. Second, the cancelled instruction was placed between Phase 1 and 2, in order to give the cancelled and finished instructions at the same point in time during the experimental procedure in all groups. Third, the instructions and stimuli were translated into English, Phase 2 was shortened from 260 to 102 trials (cf. Bugg et al., 2016; Experiment 2), and the questions in the post experiment questionnaire were adjusted slightly to be more suitable for online research.

We expected to replicate the results of Experiments 1 and 2 and therefore to find no significant difference in commission error occurrence between the cancelled response lag group and the cancelled pause group. The finished response lag group was also realized for this experiment, but with a smaller sample size compared to both other groups, because the expected replication of a significantly lower proportion of commission errors compared to the cancelled conditions did not require comparable sample sizes. The replication of the consistent effect of a lower commission error rate after finished relative to cancelled instructions (e.g., Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017), enabled an adequate comparison between the experiments in laboratory settings and the online experiment. Finally, we expected to replicate Experiments 1 and 2 in terms of reaction time and accuracy for the ongoing task, with faster and more accurate results in the groups with the response lag. However, we expected no differences between the finished response lag and the cancelled response lag groups.

Method

The method of Experiment 3 followed the method of Experiment 2; therefore, only deviations are described.

Participants. A total of 310 participants completed the experiment and were paid £ 2 for participation. Participants were preselected by the recruiting site (www.prolific.ac) with the requirement that they should be a student aged between 18 and 30 and with English as their first language.

We excluded 21 participants from the analysis because it was not clear from either their first or second answer that they understood the PM task instructions correctly (cancelled pause group n = 11, cancelled response lag group n = 9, finished response lag group n = 1). All 33 participants who could not correctly recall the PM task at the end of the experiment, were also excluded (cancelled pause group n = 19, cancelled response lag group n = 9, finished response lag group n = 5). Excluding these 54 participants did not change the pattern of results.[2] Three participants reacted to all control cues and were therefore removed from the analysis (cancelled response lag group n = 1, finished response lag group n = 2). One participant in the cancelled pause group used the PM key to respond to all ongoing task trials during Phase 1 and was also excluded.

The final 109 participants in the cancelled pause group had a mean age of 22.86 years (50% female), the final 109 participants in the cancelled response lag group had a mean age of 22.61 years (45% female), and the final 34 participants in the finished response lag group had a mean age of 23.29 years (50% female).

Procedure. The following changes were made. First, if participants in the response lag groups entered any response during the delay, the warning "Please wait until the choices are shown" appeared on the screen until the next trial. Second, the instruction phase was the same as in Experiment 2 for all groups, with the exception that the PM task was not cancelled before Phase 1, but rather immediately after Phase 1. This way, all participants were instructed that the PM task was finished or cancelled at the same time, depending on the assigned group. Third, Phase 2 was shortened to 102 trials and only contained four trials with the former PM cues (target 1 in trials 17, 62; target 2 in trials 31, 81) and four control trials (control 1 in trials 23, 73; control 2 in trials 41, 102).

Results

Prospective memory hits. We calculated the percentage of correct PM responses during Phase 1 for the finished response lag group, out of four PM events. The mean PM hit rate was 97.79% (*SD* = 7.20), and every participant showed at least one PM hit. Out of 133 prospective memory hits, 47 (35%) were made during the response lag.

Commission errors. The commission error rate in the cancelled group with response lag (19%) was descriptively higher compared to the cancelled group with pause (10%), but the difference was not statistically significant, χ^2 (1) = 3.66, p = .084. In the finished group with response lag, only one participant made a commission error (3%). Out of 53 commission errors, 21 (39%) were made during the response lag. Removing these responses did not change the pattern of results.[3]

Ongoing task performance. To analyze Phase 2, we removed reaction times longer than six seconds (removing 1.11% of the data) before applying the selection of values with individual z-scores below 2.5 and above -2.5 (removing 3.36% of the data). All means are summarized in Table 1.

A one-way ANOVA showed a significant main effect between the groups for reaction time, $F(2, 252) = 69.68$, $p < .001$, $\eta_p^2 = .36$. Bonferroni-corrected post-hoc tests showed significantly slower reaction times in the cancelled pause group compared to the cancelled response lag group ($p < .001$) as well as between the cancelled pause group and the finished response lag group ($p < .001$). The cancelled and finished groups with response lag did not differ significantly ($p = 1$).

We used Bonferroni-corrected Wilcoxon signed-ranked tests to compare the reaction times of participants with and without commission errors for the cancelled groups. In the pause group reaction times were significantly slower for the participants making commission errors compared to the participants without commission errors, $U = 492$, $p = .031$. In the response lag group, reaction times did not differ significantly between participants committing commission errors compared to the participants without commission errors, $U = 951$, $p = .476$.

For ongoing task accuracy, a one-way ANOVA showed a significant main effect between the groups, $F(2, 249) = 7.30$, $p = .001$, $\eta_p^2 = .06$. Bonferroni-corrected post-hoc tests showed significantly lower ongoing task accuracy in the cancelled pause group compared to the cancelled response lag group ($p = .014$) as well as between the cancelled pause group and the finished response lag group ($p = .003$). The cancelled and finished groups with response lag did not differ significantly ($p = .481$).

Bonferroni-corrected Wilcoxon signed-ranked tests were used to compare the accuracy of participants with and without commission errors for the cancelled groups. In the pause group, accuracy was lower for participants making commission errors compared to participants without commission errors, $U = 288$, $p = .010$. In the response lag group, participants making commission errors were also less accurate compared to participants without commission errors, $U = 317$, $p < .001$).

Discussion

Experiment 3 was conducted to address the descriptive but non-significant difference in commission error occurrence between the cancelled pause and cancelled response lag groups in Experiment 2, with sufficient statistical power. We replicated the results of both previous experiments and found no significant difference between the groups. Indeed, descriptively, the commission error rate was larger in the response lag group than in the pause group. Therefore, the results further support the idea that failed response suppression is not a prerequisite for commission errors, contrary to the predictions of the dual mechanism account (Bugg et al., 2016). Again, we replicated the established effect of a lower proportion of commission errors after finished instructions relative to cancelled instructions (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017).

For ongoing task performance, we found faster and more accurate reactions for both response lag groups compared to the pause group, replicating the results of Experiments 1 and 2. The improved performance in the ongoing task in the response lag groups can be attributed to the time available before an input was possible and allowed to prepare a response.

In addition, we replicated the effect of lower ongoing task accuracy for the participants making commission errors in both groups with cancelled instructions. In the pause group, the lower accuracy in the ongoing task might be interpreted as an unsuppressed, premature response to the ongoing task and indicate a suppression deficit in participants who make commission errors. However, we observed lower accuracy in both groups (pause and response lag) with cancelled instructions. Including the response lag resulted in faster and more accurate ongoing task performance. It seems therefore unlikely that a suppression deficit of the participants is the reason for the worse ongoing task accuracy.

Instead, an underlying trait might be responsible for lower ongoing task accuracy and commission error occurrence as suggested in the discussion of Experiment 2 and further developed in the general discussion. The proposal that an underlying trait is responsible is further supported by the significantly slower reaction time in the ongoing task reaction times for participants making commission errors compared to those not making commission errors in the pause group.

The results of Experiment 2 indicated, that a speed-accuracy trade-off might have occurred in the pause group, with faster but less accurate ongoing task performance in the participants with commission errors. Finding less accurate as well as slower ongoing task reaction times in the pause group in Experiment 3 indicates that such a trade-off does not occur.

General Discussion

We conducted three experiments to assess whether failed suppression of the associated reaction to a former PM cue is critical in the occurrence of commission errors, as suggested by the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013). To this end, we introduced a response lag of one second (Experiment 1) or two seconds (Experiments 2 and 3) to delay the input to the ongoing task. If failed suppression of the intention is critical, the additional time available for suppressing the associated action should have prevented commission errors, compared to conditions where participants could give their input immediately. The results of all three experiments failed to match the prediction of the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013). First, despite the response lag, commission errors still occurred (i.e., commission error rates were not 0%). Second, we observed no significant differences between participants who made commission errors between the cancelled response lag group and the cancelled pause group (in which the delay was introduced between the single ongoing task trials).

One may question whether participants in the response lag group did actually use the additional time to suppress the answer or whether participants start to answer the lexical decision task immediately. Due to the salience of the former PM cues (red or blue background compared to a black background for all other trials), it is reasonable to assume that all participants immediately noticed the PM cue and retrieved the PM task. Indeed, previous research showed that such cues result in PM performance of 92% to 98% (Bugg & Scullin, 2013). Therefore, the participants needed to decide first whether to respond to the PM cue by pressing the “6” key and only the participants who did not press the “6” key eventually answered the lexical decision trial. As a result, the entire duration of the response lag could have been used to suppress the execution of the intention.

Furthermore, we argue that even longer delays are unlikely to change the pattern of the results. The response lag in the present experiments exceeded the time frame of successful PM retrieval and execution (Loft & Remington, 2013) and required response suppression time in other paradigms (Simon et al., 1976). Loft and Remington (2013) showed that with a response lag of 600ms even non-focal cues – cues that are not processed as part of the ongoing task and usually require more effort for good PM performance (Brewer, Knight, Marsh, & Unsworth, 2010) – are sufficiently processed to be recognized as PM cues. In the present experiment, we used salient cues, which usually result in fast spontaneous retrieval and provided a response lag of up to 2000ms. In principle, this period should have given participants enough time to reconsider an initial, automatic impulse to press the “6” key and make a commission error.

In Experiments 2 and 3, we replicated the finding that fewer participants show commission errors after finished instructions compared to cancelled instructions (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017). These results increase the validity of our experiments because they match the study reported by Bugg and Scullin (2013) which we adapted for the pause and response lag manipulation. This replication is especially noteworthy for Experiment 3 because the effect could also be replicated in an online experiment outside of a strictly controlled laboratory environment.

Overall, our results indicate that failed suppression of an intention is not a requirement for commission errors to occur as suggested by Scullin and Bugg (2013). Such a conclusion raises two questions. First, what would be an alternative explanation for the occurrence of commission errors? Second, how can an alternative explanation account for prior results that supported the dual mechanism account?

Concerning the first question, we suggest a modified version of the dual mechanism account as an alternative explanation. The main aspects of the dual mechanism account are (1) spontaneous retrieval of the intention and (2) subsequent failure to suppress the associated response. We agree that the previously relevant intention is spontaneously recalled in response to the no longer relevant salient cue. Furthermore, we suggest that the retrieved intention is either directly implemented to be executed or tagged for suppression. Whether the intention is implemented for execution or tagged for suppression depends on the available cognitive resources at the point of spontaneous retrieval. If resources are not available, the intention is implemented for execution and the participant will execute the intention during the window of opportunity. If resources are available, the participant can recall the cancelled/finished instruction and realizes that the intention should not be executed and tags the intention for later suppression. In the case of such a suppression tag, the participant might still execute the intention during the window of opportunity if her/his ability to suppress the intention at this point in time is low.

The availability of cognitive resources depends on the cognitive demands of the situation (i.e., full or divided attention) and on individual traits (i.e., working memory capacity). If a participant's personal threshold for cognitive resources is exceeded, the participant makes commission errors. The situation can easily be manipulated by dividing a participant’s attention, results of Pink and Dodson (2013) show that divided attention results in more commission errors.

In relation to traits, working memory capacity, which has been linked to PM performance in prior studies (Ball et al., 2013; Kliegel, McDaniel, & Einstein, 2000), could be one trait influencing commission error occurrence. The significantly lower accuracy in the ongoing task trials for participants with commission errors compared to participants without commission errors in Experiments 2 and 3 supports this idea. When working on the relatively simple ongoing task, the intention is spontaneously but erroneously recalled in reaction to the former PM cue. For most participants, enough working memory capacity should be available to tag the intention for suppression. However, for some participants these demands may exceed their resources and the recalled intention is less likely to be tagged for suppression but instead is likely to be set to be implemented, resulting in more commission errors.

To clarify the difference between the dual mechanism account and the modified dual mechanism account, we consider the occurrence of a commission error in the response lag group. Once the salient cue occurs, the PM task is spontaneously recalled along with the associated intention to press the “6” key.

Based on the dual mechanism account the participant would start to move the finger from the key for the ongoing task to the “6” key and during this movement and while waiting for the window of opportunity to occur, fails to exert control over this action and erroneously presses the “6” key. Based on the modified dual mechanism account, we propose that the intention to execute the intention is implemented for execution at the moment of retrieval and the participant does not reconsider to execute the intention. The participant is not aware that the plan to implement the action is wrong before execution.

We now consider how this modified dual mechanism account can accommodate previous research. First, research showed that older adults show more commission errors (Scullin et al., 2011; but see Bugg & Scullin, 2013 and Bugg et al., 2016, Experiment 2). Age is associated with lower working memory capacity (Hedden & Gabrieli, 2004), and therefore this result can be explained by the modified dual mechanism account. Scullin et al. (2011) also reported that lower inhibition scores were associated with more commission errors in a group of older adults (but see Bugg et al., 2013). Because this result could not be replicated in a later study (Bugg et al., 2013) and has not been tested in younger adults the role of suppression within commission error occurrence should be further researched.

Second, Pink and Dodson (2013) reported more commission errors for finished habitual PM tasks, in cases where cognitive resources were less available. Pink and Dodson used a digit-monitoring task throughout the phase in which participants could make commission errors and argued that lower levels of cognitive resources compromised intention suppression. The modified dual mechanism account would suggest that, due to the high task demand, resources were compromised and recalled intentions were not tagged for suppression.

Third, fatigue has been associated with more commission errors because fewer resources to suppress the action are available (Bugg et al., 2013). However, this conclusion is based on a post-hoc analysis, and prospective studies are missing. Nevertheless, the modified dual mechanism account would suggest that the intention is not tagged for suppression if the intention is recalled during a phase where cognitive resources are decreased (i.e., fatigue).

Fourth, we consider the results from prospective memory research using the delay-execute paradigm. In this paradigm, participants have to continue working on the ongoing task after the prospective memory cue, until the ongoing task changes, before the prospective memory task intention has to be executed (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). In the delay-execute paradigm, commission errors still occurred after a delay of 45 seconds between the former PM cue (i.e., the screen flashing red for one second) and the window of opportunity, to execute the intention (Schaper & Grundgeiger, 2017); a finding that cannot be explained by the dual mechanism account. Based on the modified dual mechanism account, first, participants spontaneously recalled the intention. Second, participants with enough resources managed to recall the cancelled instructions and tagged the intention as not to be executed, while participants without sufficient resources implemented the intention for execution during the window of opportunity.

In summary, the modified dual mechanism account of commission errors can account for both the previous and the current results, extending the range of effects, which can be accounted for. Additionally, the results from the delay-execute paradigm (Schaper & Grundgeiger, 2017) and the results of the present Experiments, which do not match the dual mechanism account, can be explained by the modified dual mechanism account.

By assuming that some participants' resources are overloaded by the ongoing task demands, the occurrence of former PM cues and the associated cancelled and finished instructions might explain, to a certain degree, why commission errors occur at all. However, besides working memory capacity, other individual traits might make participants either more or less likely to make commission errors. For example, individuals with a state orientation compared to an action orientation showed increased aftereffects of completed intentions (Walser, Goschke, & Fischer, 2014) and therefore might also show more commission errors. Action versus state orientation might also explain why some participants make commission errors while others do not, and might also be relevant for cancelled instructions, because state-oriented participants should recall cancelled instructions more easily.

The modified dual mechanism account argues that participants are not aware that the intention to execute the former prospective memory task is wrong. In some instances participants appear to realize their error after making it, leaving them with the impression not to have suppressed the execution (Scullin et al., 2012). To investigate if participants were aware of their error, previous studies used self-report data, which is often inconsistent (Bugg et al., 2013). Future studies should address this question by questioning participants about their reaction, without indicating if the response was an error or not.

To conclude, the present experiments indicated that failed suppression of the intention as suggested by the dual mechanism account is not a necessary condition for the occurrence of commission errors. Future research on interindividual differences should, therefore, address the contribution of stable attributes such as working memory capacity and action versus state orientation as possible predictors of commission error occurrence.

[1] In an additional analysis for Experiment 2, we removed the PM responses during the response lag. One participant in the cancelled response lag group committed errors solely during the response lag and was therefore considered not to have committed errors. The proportion of participants who committed at least one commission error dropped to 20%. The analysis still resulted in no significant difference between both cancelled groups ($\chi^2(1) = 3.01$, $p = .077$). Additionally, the proportion of participants committing commission errors in the finished group and the cancelled response lag group still differed significantly ($\chi^2(1) = 4.86$, $p = .043$).

[2] We repeated the analysis for commission error occurrence without removing participants due to their responses in the questionnaire. The commission error rates between the cancelled group with response lag (22%) and the cancelled group with pause (16%) were not significantly different χ^2 (1) = 1.68, $p = 1.95$.

[3] In an additional analysis for Experiment 3, we removed the PM responses during the response lag. The commission error rates between the cancelled group with response lag (10%) and the cancelled group with pause (10%) were not significantly different χ^2 (1) = 0, $p = 1$. In the finished group with response lag, the only participant who committed a commission error (3%) committed this error after the response lag.

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Table 1

Commission error occurrence, ongoing task reaction time and accuracy during Phase 2 for Experiment 1, 2 and 3.

		Commission error	Reaction time	Accuracy	Reaction time		Accuracy	
					Participants with Commission error	Participants without commission error	Participants with Commission error	Participants without commission error
Experiment 1	Cancelled - Pause group 1s	37% (7 out of 19)	848.34 (89.25)	.94 (.02)	816.54 (100.48)	866.90 (80.67)	.93 (.02)	.95 (.02)
	Cancelled - Response lag 1s	35% (7 out of 20)	407.71 (92.93)	.96 (.02)	405.39 (115.92)	408.96 (83.37)	.96 (.03)	.96 (.02)
Experiment 2	Cancelled - Pause group 2s	45% (10 out of 22)	891.54 (93.40)	.94 (.05)	855.03 (82.78)	921.96 (93.94)	.91 (.06)	.96 (.02)
	Cancelled - Response lag 2s	25% (5 out of 20)	469.77 (64.52)	.97 (.02)	520.20 (60.19)	416.18 (108.97)	.95 (.02)	.98 (.01)
	Finished - Response lag 2s	0% (0 out of 22)	416.18 (108.97)	.98 (.01)	-	-	-	-
Experiment 3	Cancelled - Pause group 2s	10% (11 out of 109)	1018.69 (272.59)	.96 (.04)	1161.23 (337.68)	994.16 (253.96)	.93 (.04)	.96 (.04)
	Cancelled - Response lag 2s	19% (21 out of 109)	639.27 (226.68)	.97 (.04)	663.27 (217.80)	632.12 (230.04)	.94 (.05)	.98 (.03)
	Finished - Response lag 2s	3% (1 out of 34)	655.23 (247.97)	.98 (.02)	*	*	*	*

Note: Standard deviations are in parentheses. Only one participant in the cells marked with *

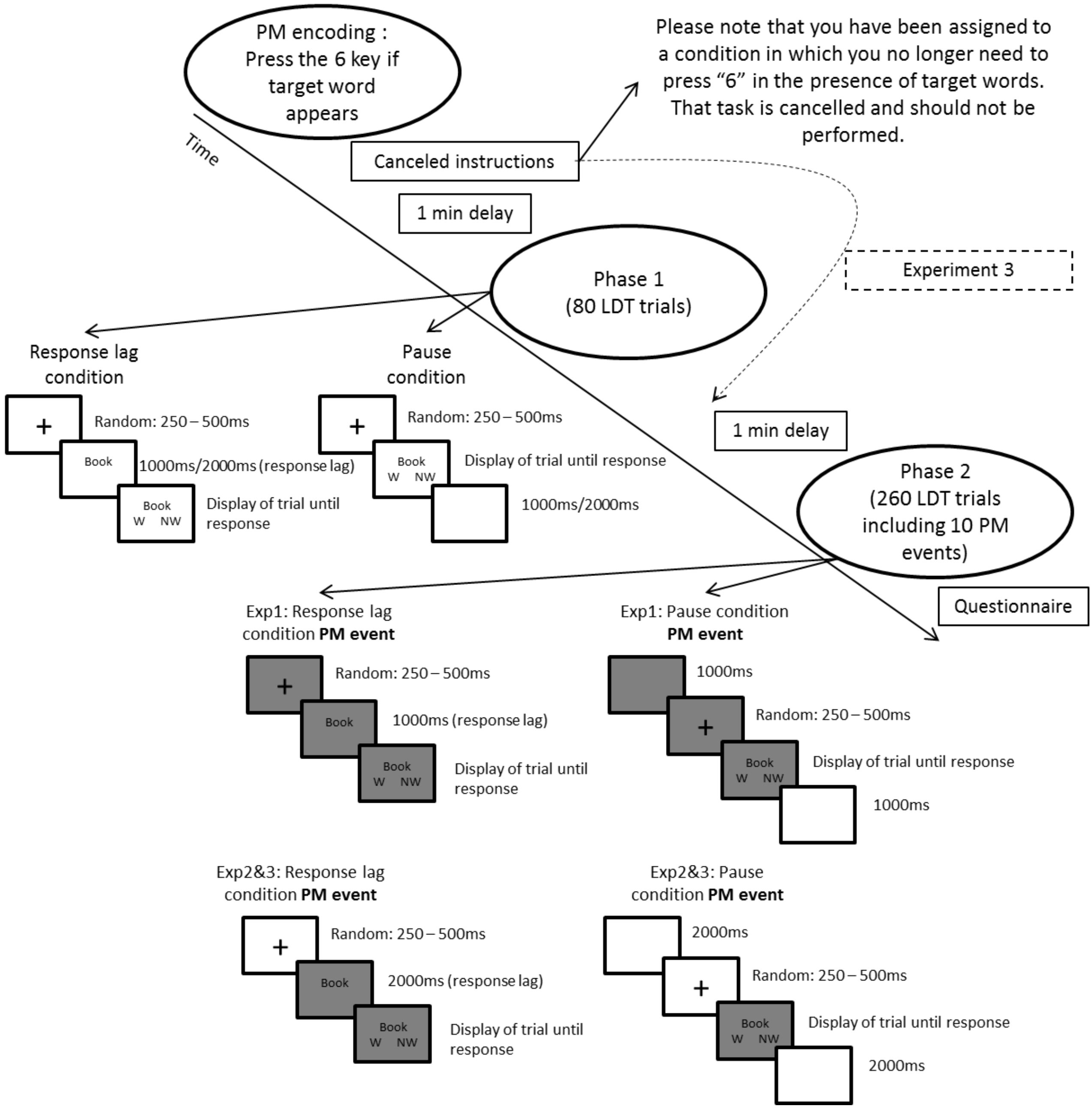

Figure 1. Design and procedure of Experiment 1, 2, and 3.

Annex E: **Study 5 - The role of response suppression in the occurrence of commission errors: The effect of divided attention and response ease**

Schaper, P., & Grundgeiger, T. The role of response suppression in the occurrence of commission errors: The effect of divided attention and response ease. [Prepared for submission]

Author	Contribution
Schaper, P.	Literature review, experimental design, data collection, data analysis, manuscript preparation and revision
Grundgeiger, T.	Contributed to experimental design, manuscript revision

The Role of Response Suppression in the Occurrence of Commission Errors: The Effect of Divided Attention and Response Ease

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Abstract

Intentions are often retrieved if an associated cue is encountered. Such prospective memory (PM) tasks can also be recalled after they are no longer relevant and may result in commission errors. Based on the dual mechanism account, commission errors occur due to the spontaneous retrieval of the intention and the failed response suppression of the execution. In a modified dual mechanism account, we suggested that intentions are only tagged for suppression if enough cognitive resources are available during the initial intention retrieval. Otherwise, the intention is set to be executed. We experimentally contrasted the predictions of both accounts. In Phase 1, participants executed a PM task several times, and were subsequently told that the PM task was finished. In Phase 2, all participants encountered several PM cues that were no longer relevant. The control group received instructions for the ongoing and PM tasks only. The divided attention group had to work on an additional digit monitoring task during Phase 2. The slip group received the same instructions as the control group, but with easier access to the key for the former PM task. We observed a higher commission error rate in the divided attention group than in the control and the slip groups, as well as no differences between the latter groups. The results matched the predictions of the modified dual mechanism account, given that commission error rates were high if resources were limited during intention retrieval. In contrast, making the response suppression more difficult with easier response key access for the slip group did not increase commission error rates.

Keywords: prospective memory; commission errors; retrieve-execute paradigm; divided attention

The Role of Response Suppression in the Occurrence of Commission Errors: The Effect of Divided Attention and Response Ease

In a prospective memory (PM) task an intention is associated with a specific cue or time, which can initiate retrieval and subsequent execution of the intention (Einstein & McDaniel, 1990). However, in some instances the intention should be discontinued, while the associated cues may still be present in the environment; for example, if a medication had to be taken after breakfast, but the treatment has been discontinued. In these situations, aftereffects still occur in the presence of former PM cues (Walser, Goschke, Möschl, & Fischer, 2016). Sometimes, the intention, which is no longer relevant, is still executed (e.g., Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017; Scullin, Bugg, & McDaniel, 2012). In the example above, the medication could be erroneously taken again after finishing breakfast. These erroneous reactions to previously relevant cues are referred to as commission errors. In the present paper, we compared two theoretical accounts that address the occurrence of commission errors.

It has been suggested that “commission errors occur when a completed intention is spontaneously retrieved and individuals fail to suppress executing the intention” (Scullin et al., 2012, p. 52), this idea was later called the dual mechanism account (Bugg, Scullin, & Rauvola, 2016; Scullin & Bugg, 2013). The dual mechanism account proposes that after an intention has been spontaneously recalled, a cognitive demanding suppression process occurs, which prevents execution if the intention is suppressed on time (Scullin et al., 2012; Scullin, Bugg, McDaniel, & Einstein, 2011).

Several results have recently been published, which could not be explained by the dual mechanism account. For example, in the delay-execute paradigm, Schaper and Grundgeiger (2017) observed that commission errors occurred even if the cue and the window of opportunity to react to the cues were separated by 45 seconds. Even though participants worked on the ongoing task during this delay, it could be argued that enough time should have been available to suppress the spontaneous execution of the intention. Furthermore, in related work on the retrieve-execute paradigm, Schaper and Grundgeiger (manuscript submitted for publication) introduced an additional response lag of one or two seconds between cue presentation and the opportunity to enter a response in order to provide more time to suppress the erroneous action, but the response lag did not reduce commission error rates.

Schaper and Grundgeiger (manuscript submitted for publication) suggested a modified dual mechanism account, which proposes that spontaneously retrieved intentions are only tagged for possible suppression when cognitive resources are available at the time of intention retrieval. This difference appears to be minor; however, the modified dual mechanism account suggests that intentions, which have been set to be executed (i.e., are not tagged for suppression), are not reconsidered, but are deliberately executed. The modified dual mechanism account proposes a mechanism that can explain why commission errors occur, even though there would have been enough time to suppress the execution due to a response lag (Schaper & Grundgeiger, manuscript submitted for publication) or in the delay-execute paradigm (Schaper & Grundgeiger, 2017).

The modified dual mechanism can also account for other commission error research. Older adults made more commission errors than younger adults (Scullin et al., 2012). Because working memory capacity declines with age (Hedden & Gabrieli, 2004), the modified dual mechanism account can explain the age difference in commission. The proposed influence of fatigue on commission error occurrence (Bugg, Scullin, & McDaniel, 2013)is also in line with the account because fatigue could, in principle, also affect the tagging process instead of the suppression process. Finally, the increased commission error rate for finished habitual PM tasks reported by Pink and Dodson (2013) can also be explained by reduced resources for the tagging process. The modified dual mechanism account can therefore not only account for previous research, but can also account for results, which were not in line with the dual mechanism account (Bugg et al., 2016).

The present experiment was set up to directly compare predictions of the dual mechanism account and the modified dual mechanism account. To this end, the PM task was first introduced and executed several times by all participants (Phase 1). As an ongoing task, participants had to decide whether a letter string is a word or a non-word. Participants in the control and divided attention groups did this by pressing the left or right arrow, while their PM response with their dominant hand was “Q”. Participants in the slip group gave their response by pressing “T” and “U”, while their PM response key was the SPACE bar. In the slip key configuration, both thumbs were automatically placed on the SPACE bar. Our intention was to make it as easy as possible to press the PM response key and therefore more difficult to suppress an erroneous response. The data from our pre-study (see Method section) showed that this key configuration indeed makes response suppression more difficult.

Next, the PM task was declared finished, while the former PM cues still occurred during the final ongoing task block (Phase 2). Commission errors have been consistently shown to be dependent on the status of the former PM task. If the task has been executed and declared finished, a lower proportion of participants made commission errors compared to a condition in which the task is cancelled and never executed (Bugg & Scullin, 2013; Scullin et al., 2012; Scullin, Einstein, & McDaniel, 2009). The finished manipulation is therefore more suited to the detection of increases in commission error occurrence.

Salient cues were used as PM cues, because the intention should be spontaneously recalled once the cue is represented (Einstein & McDaniel, 2005; Scullin & Bugg, 2013). In the control and slip groups, participants only worked on the ongoing task during Phase 2. The divided attention group received instructions concerning an additional digit-monitoring task, which had to be continuously worked on during Phase 2 of the experiment.

The dual mechanism account (Bugg et al., 2016) as well as the modified dual mechanism account (Schaper & Grundgeiger, manuscript submitted for publication) predict increased commission error rates in the divided attention group compared to the control group although the mechanism differs. The dual mechanism account postulates a resource demanding suppression process, which is hindered by the additional task, whereas the modified dual mechanism account predicts that intentions, which are recalled while the additional task is active, are not tagged for suppression and therefore executed. Considering the slip manipulation, the dual mechanism account (Bugg et al., 2016) predicts that more participants should make commission errors in the slip group compared to the control group because response suppression is more difficult. Finally, the modified dual mechanism account predicts no differences between the control group and the slip group because the key configuration does not affect resource availability at the time of intention retrieval.

Method

Pre-Study

As a manipulation check, we conducted a pre-study to test whether the keyboard configuration for the slip group facilitated errors compared to the configuration of the control and divided attention groups. The participants worked on a lexical decision task (LDT) with different colored letter strings. Participants received the additional task of pressing a different key, if the string was written in red. Due to the high frequency of red font, the pre-study could be considered as a multitasking situation rather than as a PM task (Einstein & McDaniel, 1990; Ellis, Kvavilashvili, & Milne, 1999).

Participants. The sample consisted of 20 undergraduate students. One of the participants was excluded from the study because the task was incorrectly reproduced in the post-experimental questionnaire. The nine participants in the control group had a mean age of 22.1 years (22% female), while the ten participants in the slip group had a mean age of 23.0 years (20% female).

Design. We used two groups, which only differed in the key mapping for the ongoing task. The main dependent variable was false alarms, in addition, we assessed reaction times.

Material and Procedure. The stimuli of the LDT were strings of letters that showed the name of ten different colors names (words) or one of the color names with a changed vowel (a non-word). The strings were presented in colored writing (ten different colors). Participants in the control group were instructed to indicate whether or not the string was a word by pressing the left and right arrow keys (counterbalanced within conditions) with their index fingers. In addition, they were asked to press the "Q" key with their dominant hand if the string was written in red font. In the slip group, the task was identical, but the key configuration differed; word and non-word had to be indicated by the "T" and "U" keys, while the SPACE bar had to be used for strings in red font. After the instructions, the participants took part in a brief training session and could ask questions. Next, the participants worked on 100 LDT trials. After the experiment, they completed a questionnaire about demographic data and a retrospective understanding of the instructions.

Results. A Fisher exact test showed that more participants in the slip group conducted at least one false alarm (7 out of 10, 70%) compared to the control group (1 out of 9, 11%; $p = .020$, two-tailed).

There was no significant difference in the reaction times for all correctly answered trials without red font, between the slip group ($M = 829.30$, $SD = 50.97$) and the control group ($M = 852.05$, $SD = 57.57$), $t(17) = .30$, $p = .770$.

Discussion. The pre-study showed that changing the key configuration, as described, resulted in increased false alarms in response to non-target strings. Placing both thumbs on the SPACE bar in the slip condition allowed the execution of an error with the twitch of a finger, because the time to suppress the action was minimized.

Participants

As in previous experiments (Bugg & Scullin, 2013; Scullin et al., 2009), we expected a commission error rate to be close to zero in the control group ($p_1 = 0.05$) and, based on both accounts, a high commission error rate in the divided attention group ($p_2 = 0.40$). The analysis resulted in a sample of 3 × 24 participants (Fisher's exact test, 2-tailed, alpha = .05, power = .8; calculation conducted with G*POWER 3, Faul, Erdfelder, Lang, & Buchner, 2007).

Our sample consisted of 97 undergraduate students who participated in return for partial course credit. Six of the participants were excluded from the analysis because they could not correctly recall the PM task at the end of the experiment. The 31 participants in the control group had a mean age of 19.6 years (71% female), the 32 participants in the divided attention group had a mean age of 20.5 years (75% female) and the 28 participants in the slip group had a mean age of 20.5 years (71% female).

Design

We used three groups, which received the same ongoing task and PM instructions, but differed in the positioning of the response keys and attentional demands. The control and divided attention groups used the left and right error as ongoing task response keys and "Q" as PM response key. The slip group used "T" and "U" as ongoing task response keys and the SPACE bar as PM response key. The divided attention group received an additional divided attention task in Phase 2. The main dependent variable was commission error occurrence. In addition, we assessed reaction time and accuracy of the ongoing task during Phase 2.

Material

We used an LDT as an ongoing task, whose stimuli were 5 to 8 letters long. The order of words was selected randomly for each participant. For Phase 1, we used 34 words and 34 non-words. To control for repeated exposure, four randomly selected words were presented twice. Additionally, each of the two respective PM cues and two controls occurred twice, resulting in 80 trials for Phase 1.

For Phase 2, we used 41 new words and 41 new non-words. Four randomly selected words were once again shown twice to control for repeated exposure. Additionally, each of the two PM cues that were no longer relevant and two controls occurred twice, resulting in

102 trials for Phase 2. For the divided attention group, we generated sound files with the numbers one to nine in random order, but the odd numbers occurred in a ratio of 2:1. A number was read out every 1.5 seconds.

Procedure

The experiment had four main phases: (1) instructions, (2) Phase 1, (3) Phase 2, and (4) questionnaire. First, the participants were informed about the ongoing task. Participants had to work on an LDT and indicate their answer by pressing two designated keys on a keyboard in correspondence to the response key assignments displayed on a monitor. The control group was instructed to use both index fingers and place them on the left and right arrow keys to indicate their answers. The divided attention group was instructed to use the same keys, but use the index and middle finger. The participants in the slip group were instructed to place both index fingers on the “T” and “U” keys, and use these keys to work on the ongoing task. The strings of letters were displayed in white font on a black background. Participants were instructed to keep their fingers on the keys throughout the experiment. The key configuration for indicating words or non-words was counterbalanced within each group. Participants conducted a short training session without feedback after receiving the instructions. Each trial started with a fixation cross which lasted randomly between 250 and 500ms. The string of letters and the answer options were displayed at the same time and remained onscreen until a response was given. After each trial, the screen remained blank for 500ms before the next fixation cross appeared.

Next, all groups received instructions for the PM task i.e., to press a designated key if one of two target words occurred on a red screen. Participants in the control and divided attention groups were instructed to press the “Q” key with their dominant hand, while participants in the slip group were told to use the SPACE bar. Another pair of target words and a blue screen were used as controls. The word pairs and background colors were counterbalanced within each group (pair 1: noon, summit; pair 2: committee, furniture –

translated from German). After the instructions, participants had to reproduce the PM instructions in their own words in writing. The instructions were displayed again and the participants were subsequently asked to reproduce the instruction once more using a different wording. The divided attention group received additional instructions and training for a counting task. In their non-dominant hand, they held a counter and were instructed to press it once they heard two consecutive odd numbers.

Second, in Phase 1, all groups worked on 80 LDT trials including both respective PM cues (target 1 in trials 18 and 45; target 2 in trials 31 and 79) and control cues (control 1 in trials 12 and 59; control 2 in trials 26 and 72). The divided attention group heard no numbers during this phase. Before and after Phase 1, participants had to work on a simple addition task for one minute. The PM task was declared finished for all groups immediately afterwards by telling the participants that the additional task (to press their respective key in the presence of target words) was completed.

Third, in Phase 2, all groups worked on 102 trials for the ongoing task, including four trials with the former PM cues (target 1 in trials 17 and 62; target 2 in trials 31 and 81) and four control trials (control 1 in trials 23 and 73; control 2 in trials 41 and 102). For the divided attention group, the additional counting task was active during the whole of Phase 2.

Fourth, we collected demographic data and asked the participants to reproduce the PM task. Participants were tested individually or in pairs. The experiment lasted approximately 30 minutes.

Results

Statistical analysis was conducted with SPSS 23 (Chicago, IL). For all tests, alpha was set at .05.

PM performance

A PM hit was defined as pressing the designated key in the trial with the PM cue in Phase 1. We used the relative proportion of PM hits in percent for the analysis. A one-way

ANOVA showed no significant effect of group, $F(2, 91) = 1.58$, $p = .211$, $\eta_p^2 = .04$. The average PM performance was 98.39% ($SD = 6.24$) for the control group, and 90.63% ($SD = 21.77$) for the divided attention group, and 93.75% ($SD = 19.98$) for the slip group.

Commission errors

A commission error was defined as pressing the designated key in the trial with the former PM cue during Phase 2. As in previous research (Bugg & Scullin, 2013), a participant was considered to have made commission errors if she/he had made at least one error during Phase 2.

We observed that 59% of participants (19 out of 32) in the divided attention group made at least one commission error, while this proportion was 14.29% for the slip group (4 out of 28) and 16.13% for the control group (5 out of 31). For the statistical analysis, we used a Bonferroni-correction (alpha = .017) because multiple tests were conducted. The proportion of participants with commission errors was significantly higher in the divided attention group compared to the control group, $\chi^2(1) = 12.49$, $p < .001$, as well as the slip group, $\chi^2(1) = 12.84$, $p < .001$. The mean proportion of participants with commission errors was not significantly higher in the control group than the slip group, $\chi^2(1) = .04$, $p = 1$.

Ongoing task performance

We only analyzed ongoing task performance in Phase 2. First, we excluded the first ten questions for each participant, all trials with former target or control cues and the two trials immediately after targets and controls. For the reaction time analyses, we only analyzed correct responses and responses within 2.5 standard deviations of the participants mean response time (removing 8.42% of the data; Ball, Knight, Dewitt, & Brewer, 2013). All means are summarized in Table 1.

For ongoing task response times, a one-way ANOVA showed a significant effect of group $F(2, 88) = 27.23$, $p < .001$, $\eta_p^2 = .38$. Bonferroni-corrected post-hoc tests showed significantly longer reaction times for the divided attention group than for to the control group

($p < .001$) and the slip group ($p < .001$). The control group and the slip group did not differ significantly ($p = 1$).

Next, we tested for possible differences in reaction times among participants with and without commission errors within the groups. Due to the small number of participants who made commission errors in the control and slip groups, we used Bonferroni-corrected Wilcoxon signed-ranked tests. In all groups, there was no significant difference in reaction times between participants with and without commission errors (control: $U = 54$, $p = 1$; divided attention: $U = 140$, $p = 1$; slip: $U = 56$, $p = 1$).For ongoing task accuracy, a one-way ANOVA showed no significant effect of group, $F(2, 88) = 1.70$, $p = .189$, $\eta_p^2 = .04$. In all groups, a Bonferroni-corrected Wilcoxon signed-ranked showed no significant difference in accuracy between participants with and without commission errors (control: $U = 60.5$, $p = 1$; divided attention: $U = 176.5$, $p = .123$; slip: $U = 57.5$, $p = 1$).

Discussion

The experiment was conducted to directly compare the dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013) and the modified dual mechanism account of commission errors (Schaper & Grundgeiger, manuscript submitted for publication). We observed a significantly higher commission error rate in the divided attention group than in the slip and control groups, while the latter groups did not differ significantly.

The dual mechanism account (Bugg et al., 2016; Scullin & Bugg, 2013) considers commission errors as results of spontaneous retrieval and subsequent failure to suppress the execution of the intention. The modified dual mechanism account predicts that commission errors occur if the spontaneously recalled intention is not tagged for suppression and therefore deliberately executed, even with a delay between cue and window of opportunity (Schaper & Grundgeiger, manuscript submitted for publication). The finding that a significantly higher proportion of participants made commission errors in the divided attention group compared to the control group matched the predictions of both accounts. Based on the dual mechanism account (Bugg et al., 2016), the erroneous reaction is executed because fewer cognitive resources are available to suppress the intention. The modified dual mechanism account suggests that, if not enough cognitive resources are available at the point of intention retrieval, the spontaneously recalled intention is not tagged for suppression and is therefore executed. Participants therefore do not fail in to suppress the execution of the intention; they erroneously plan to implement it.

The dual mechanism account (Bugg et al., 2016) also predicted a higher proportion of participants with commission errors in the slip condition, given that a timely suppression of the intention should have been more difficult due to the position of the key associated with the PM task. The results of our pre-study suggested that the slip key configuration indeed facilitated erroneous actions. The modified dual mechanism account (Schaper & Grundgeiger, manuscript submitted for publication) predicted no difference in commission error occurrence compared to the control group, because sufficient resources were available to correctly tag the intention during retrieval. Because there was no significant difference in the proportion of participants committing commission errors between the control and slip groups, these results support the modified dual mechanism account compared to the dual mechanism account.

The modified dual mechanism account (Schaper & Grundgeiger, manuscript submitted for publication) is in line with previous research and further supported by the results of the present experiment. We reevaluate previous research in relationship to the modified dual mechanism account to highlight the better match of data and prediction given the modification. First, we will briefly address studies that match the predictions of the dual mechanism account (Bugg et al., 2016), as well as the modified dual mechanism account (Schaper & Grundgeiger, manuscript submitted for publication). Second, we consider studies with conflicting predictions of both theories.

In line with both accounts, a higher proportion of older participants make commission errors compared to younger participants (Scullin et al., 2012). Both accounts predict more errors if fewer cognitive resources are available, either during suppression or during retrieval, because working memory capacity is diminished in older adults (Hedden & Gabrieli, 2004). As a result, higher rates of commission errors are predicted by both accounts. These predictions also apply if the cognitive resources are diminished experimentally by introducing additional tasks, as in the present study as well, as in the experiment conducted by Pink and Dodson (2013). Finally, Bugg et al. (2013) reported that fatigue (due to prolonged ongoing task demands) results in more commission errors. Again, this result can be explained by compromised suppression as suggested by the dual mechanism account, or by the fact that the spontaneously recalled intention is not tagged for suppression as suggested by the modified dual mechanism account.

To demonstrate the benefit of modifying the dual mechanism account, we consider studies with conflicting predictions between both accounts in more detail as well as conflicting results within the literature. First, in the study by Scullin et al. (2012), older participants showed more commission errors relative to young participants, there was also a positive correlation of diminished inhibitory executive control and commission error occurrence among the older participants. But contrary to Scullin et al. (2012), the age difference in commission error occurrence was not observed in a previous study (Scullin et al., 2011). In the light of the modified dual mechanism account the results by Scullin et al. (2011) can be interpreted differently. Younger and older participants had enough cognitive resource available to tag the spontaneously retrieved intention correctly and therefore did not make commission errors. Because younger as well as older participants did not make any commission errors, this corresponds to the pattern predicted by the modified dual mechanism account. This might also explain why the age affect, as well as the effect of the inhibition measure by Scullin et al. (2012) could not replicated by Bugg et al. (2013). Overall, these results indicate that age by itself, as well as inhibition ability are not suitable predictors for commission error occurrence, as suggested by Scullin et al. (2011).

Second, it has been shown that commission errors still occur if a delay of one or two seconds between the former PM cue and the chance to execute the intention is introduced (Schaper & Grundgeiger, manuscript submitted for publication). The dual mechanism account erroneously predicts no commission errors with this manipulation, because the delay should be long enough to suppress the execution of the intention. The modified dual mechanism account predicts no significant decrease in commission error occurrence relative to a control group, which could react instantaneously, because the tag to commit the error is set in the moment of retrieval.

Third, commission errors also occur in the delay execute paradigm (Schaper & Grundgeiger, 2017), in this paradigm the PM cue is separated from the window of opportunity to execute the intention by a delay of 45 seconds, in which participants continue the ongoing task (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). This finding is in line with the modified dual mechanism account, because the intention to execute the commission error is set during retrieval and not actively suppressed during the delay between cue and window of opportunity. Contrary, the dual mechanism account predicts no commission errors in this paradigm because there is enough time to suppress the execution of the intention.

The present experiment, as well as the previous research, therefore indicates that the failed suppression of an intention, as suggested by the dual mechanism account (Bugg et al., 2016), is not a requirement for commission errors. Instead, the occurrence of commission errors appears to be dependent on the cognitive resources available during cue presentations as suggested by the modified dual mechanism account of commission errors (Schaper & Grundgeiger, manuscript submitted for publication).

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Table 1

Ongoing Task Reaction Time and Accuracy During Phase 2.

	Commission error	Reaction time	Accuracy	Reaction time		Accuracy	
				Participants with Commission error	Participants without commission error	Participants with Commission error	Participants without commission error
Control group	16% (5 out of 31)	743.08 (95.78)	.96 (.03)	709.48 (30.55)	749.54 (102.91)	.95 (.03)	.96 (.03)
Divided attention group	59% (19 out of 32)	1386.70 (638.49)	.95 (.04)	1362.02 (435.02)	1422.76 (875.73)	.96 (.02)	.93 (.05)
Slip group	14% (4 out of 28)	753.12 (169.23)	.97 (.03)	796.42 (213.26)	745.91 (165.25)	.98 (.03)	.96 (.03)

Note. Standard deviations are in parentheses.

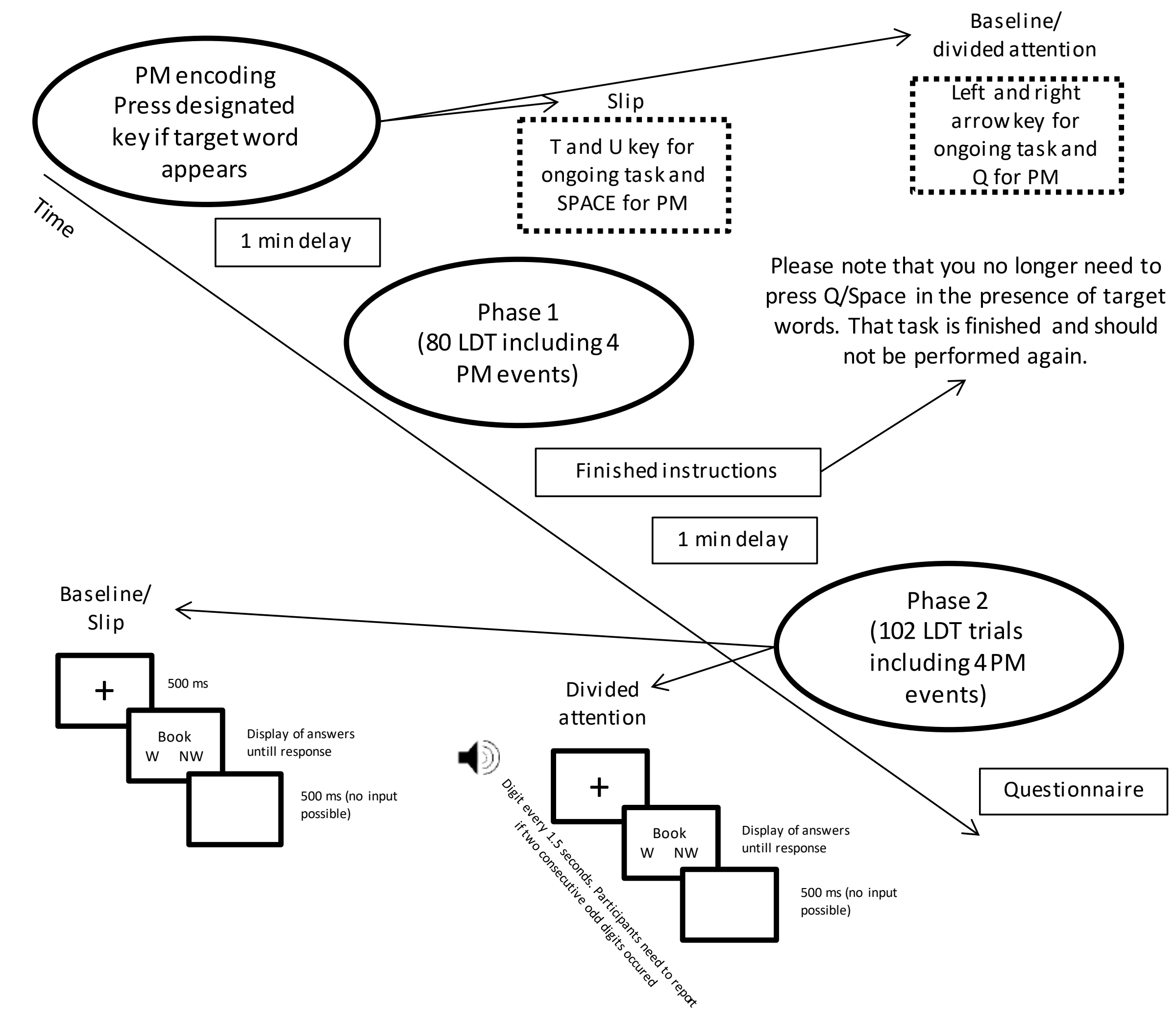

Figure 1. Design and procedure of the experiment.

Appendices

***Appendix A:* Materials Study 1**

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 60 Minuten dauern und mit einer Versuchspersonenstunde vergütet.

In unserer Studie untersuchen wir wie gut Menschen Aufgaben mit Unterbrechungen bearbeiten können. Sie werden gebeten, verschiedene Arten von Entscheidungsaufgaben zu bearbeiten und werden dabei durch eine andere Aufgabenart unterbrochen. Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 60 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „Multitasking IX“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. E für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87		Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss		Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87	
☐	☐	☐	☐	☐	☐	☐	☐

Alter: ___________ Geschlecht: ◻ m ◻ w Studiengang:__________

Händigkeit: ◻ links ◻ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? ◻ ja ◻ nein

Haben Sie eine deutsche weiterführende Schule besucht? ◻ ja ◻ nein

1. Was mussten Sie tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

___

___

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

___

___

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktive erinnert“ **1** **2** **3** **4** **5** **6** **7** „Werde mich schon daran erinnern“

4. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

___

___

Fragebogen: „Multitasking IX“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
☐	☐	☐☐	☐☐	☐☐

Alter: ___________ Geschlecht: ◻ m ◻ w Studiengang:__________

Händigkeit: ◻ links ◻ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? ◻ ja ◻ nein

Haben Sie eine deutsche weiterführende Schule besucht? ◻ ja ◻ nein

1. Haben Sie in irgendeiner Form auf den roten Bildschirm reagiert? Falls ja: Was haben Sie getan?

---

2. Haben Sie das Gefühl gehabt, dass der rote Bildschirm Sie bei der Bearbeitung der Entscheidungsaufgaben gestört hat?

---

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 60 Minuten dauern und mit 10 Euro vergütet.

In unserer Studie untersuchen wir wie gut Menschen Aufgaben mit Unterbrechungen bearbeiten können. Sie werden gebeten, verschiedene Arten von Entscheidungsaufgaben zu bearbeiten und werden dabei durch eine andere Aufgabenart unterbrochen. Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 60 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „Multitasking X“

□□	□□	□□	□□
Die letzten beiden Buchstaben des Geburtsnamens Ihrer Mutter	Die Anzahl der Buchstaben des (ersten) Vornamens Ihrer Mutter	Die beiden letzten Buchstaben des (ersten) Vornamens Ihres Vaters	Ihr eigener Geburtstag (nur der Tag)

Alter: ____________ Geschlecht: □ m □ w Studiengang:___________

Händigkeit: □ links □ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Was mussten Sie tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktive erinnert“	**1**	**2**	**3**	**4**	**5**	**6**	**7**	„Werde mich schon daran erinnern“

4. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking X“

□□	□□	□□	□□
Die letzten beiden Buchstaben des Geburtsnamens Ihrer Mutter	Die Anzahl der Buchstaben des (ersten) Vornamens Ihrer Mutter	Die beiden letzten Buchstaben des (ersten) Vornamens Ihres Vaters	Ihr eigener Geburtstag (nur der Tag)

Alter: ____________ Geschlecht: □ m □ w Studiengang:___________

Händigkeit: □ links □ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Haben Sie in irgendeiner Form auf den roten Bildschirm reagiert? Falls ja: Was haben Sie getan?

____

____

2. Haben Sie das Gefühl gehabt, dass der rote Bildschirm Sie bei der Bearbeitung der Entscheidungsaufgaben gestört hat?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Appendix B: Materials Study 2

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 60 Minuten dauern und mit einer Versuchspersonenstunde vergütet.

In unserer Studie untersuchen wir wie gut Menschen Aufgaben mit Unterbrechungen bearbeiten können. Sie werden gebeten, verschiedene Arten von Entscheidungsaufgaben zu bearbeiten und werden dabei durch eine andere Aufgabenart unterbrochen. Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 40 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „Multitasking VIII“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
☐	☐	☐☐	☐☐	☐☐

Alter: ___________ Geschlecht: ◻ m ◻ w Studiengang:__________

Händigkeit: ◻ links ◻ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? ◻ ja ◻ nein

Haben Sie eine deutsche weiterführende Schule besucht? ◻ ja ◻ nein

1. Was mussten Sie tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktiv erinnert“ **1** **2** **3** **4** **5** **6** **7** „Werde mich schon daran erinnern“

4. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

	Wort	Kein Wort
SCHNIPS	☐	☐
PLASTIK	☐	☐
BUHNHOF	☐	☐
TAUFE	☐	☐
LAPPEN	☐	☐
SCHMIRZ	☐	☐
BLOSE	☐	☐
VISUM	☐	☐
VERDECK	☐	☐
PANZER	☐	☐
SPINAT	☐	☐
RAMPU	☐	☐
NETRIUM	☐	☐
HUNKEL	☐	☐
RADIO	☐	☐
KORSCHE	☐	☐
AUSFLEG	☐	☐
BASER	☐	☐
ACHTUNG	☐	☐
TEILUNG	☐	☐

	Wort	Kein Wort
KOLIBRI	☐	☐
FREIZEOT	☐	☐
ZEMANT	☐	☐
LUBER	☐	☐
LECHTUNG	☐	☐
PILIZIST	☐	☐
ZIEGE	☐	☐
FLUGZEUG	☐	☐
DRACKER	☐	☐
SCHNITT	☐	☐
MORGIN	☐	☐
EINLUGE	☐	☐
TICKET	☐	☐
GRANIT	☐	☐
ALGORIEN	☐	☐
ZEIGER	☐	☐
ABBAU	☐	☐
JUNGE	☐	☐
PEITSCHE	☐	☐
HYGIANE	☐	☐

	Wort	Kein Wort
FLAGBAHN	☐	☐
ONFUG	☐	☐
TONBAND	☐	☐
FEIND	☐	☐
SCHALE	☐	☐
MAGAZIN	☐	☐
MEDUL	☐	☐
AWIGKEIT	☐	☐
FALKE	☐	☐
SPRIDEL	☐	☐
ELEGANZ	☐	☐
LIMONADE	☐	☐
EHEGATTE	☐	☐
VOLLMOND	☐	☐
SOLISTIN	☐	☐
HULLE	☐	☐
UNGLOCK	☐	☐
FOHRT	☐	☐
VIELFELT	☐	☐
FAHRPLAN	☐	☐

	Wort	Kein Wort
GRAMM	☐	☐
BREMSO	☐	☐
DOSIS	☐	☐
LUFTRAUM	☐	☐
POSSIV	☐	☐
PHOBIE	☐	☐
BLUTUNG	☐	☐
MADENNA	☐	☐
HAMPEN	☐	☐
MOHNUNG	☐	☐
AKKORD	☐	☐
REIFEN	☐	☐
BUNDIT	☐	☐
NOVIZE	☐	☐
ZINTNER	☐	☐
SCHUHI	☐	☐
FAKTUR	☐	☐
ZENSER	☐	☐
BIERFESS	☐	☐
WOILE	☐	☐

	Wort	Kein Wort
HIFTOR	☐	☐
WINDRAD	☐	☐
BIEST	☐	☐
ADVURB	☐	☐
TAXTUR	☐	☐
HARKE	☐	☐
KONISTER	☐	☐
ERDENG	☐	☐
MEDIZIN	☐	☐
TIGER	☐	☐
DEUTING	☐	☐
KLAMMER	☐	☐
STITUE	☐	☐
ALBENO	☐	☐
MIMOSE	☐	☐
ORAKEL	☐	☐
LEUCHTE	☐	☐
FARCHE	☐	☐
INDIANER	☐	☐
QUARZ	☐	☐

	Wort	Kein Wort
SUPPE	☐	☐
HICHAUS	☐	☐
GULLE	☐	☐
EPILOG	☐	☐
BRIOF	☐	☐
IMPFUNG	☐	☐
SPRIY	☐	☐
HEKTAR	☐	☐
TASTATUR	☐	☐
EINBROCH	☐	☐
WAGGANG	☐	☐
NEPTAN	☐	☐
ABFIHRT	☐	☐
DREIECK	☐	☐
SCHRANKE	☐	☐
ELEND	☐	☐
VISION	☐	☐
KAPITAL	☐	☐
POPRIKA	☐	☐
URLIUBER	☐	☐

	Wort	Kein Wort
SCHURADE	☐	☐
UMBRICH	☐	☐
SCHIFF	☐	☐
TABLETT	☐	☐
BUMERANG	☐	☐
DIPLIKAT	☐	☐
ZEMENT	☐	☐
SONNE	☐	☐
VEILCHAN	☐	☐
LAWONE	☐	☐
DUABETES	☐	☐
KREUZUNG	☐	☐
ANORAK	☐	☐
GEWEHR	☐	☐
FAKTION	☐	☐
ALBUM	☐	☐
BEICHTE	☐	☐
CHRIST	☐	☐
OHNMACHT	☐	☐
TANTE	☐	☐

	Wort	Kein Wort
EIGNUNG	☐	☐
PILITUR	☐	☐
WICHS	☐	☐
LEHRER	☐	☐
HIGEL	☐	☐
GEDUIH	☐	☐
RUKLAME	☐	☐
BRUNNEN	☐	☐
SCHMANKE	☐	☐
ISOTOP	☐	☐
SARDINE	☐	☐
AITISMUS	☐	☐
KATZE	☐	☐
FENSTER	☐	☐
ADLER	☐	☐
PISTOLE	☐	☐
REFERANT	☐	☐
ISOTOP	☐	☐
HAKEN	☐	☐
SPEICHER	☐	☐

	Wort	Kein Wort
POPPE	☐	☐
GASPEDAL	☐	☐
FIHLEN	☐	☐
KALORIE	☐	☐
WOKINGER	☐	☐
ZWERG	☐	☐
BIOLOGIE	☐	☐
ZUVIL	☐	☐
KARTON	☐	☐
BALSAM	☐	☐
FORELLE	☐	☐
TULEFON	☐	☐
RUMMEL	☐	☐
SCHMIED	☐	☐
ASKOT	☐	☐
INSEKT	☐	☐
CLAWN	☐	☐
NITSTAND	☐	☐
QUILLE	☐	☐
EINBRACH	☐	☐

	Wort	Kein Wort
AZEAN	☐	☐
BAROCK	☐	☐
MERKIR	☐	☐
INDOZ	☐	☐
HINGABE	☐	☐
PELLE	☐	☐
SEHNE	☐	☐
PATHUR	☐	☐
DENKMAL	☐	☐
SCHABU	☐	☐
KUNST	☐	☐
TORPEDO	☐	☐
BLUCKADE	☐	☐
DIRST	☐	☐
NETZHAUT	☐	☐
IDOAL	☐	☐
SCHODEN	☐	☐
HEFTLING	☐	☐
VIOLINE	☐	☐
EINUGUNG	☐	☐

	Wort	Kein Wort
LEERLAUF	☐	☐
KURZFALM	☐	☐
RUCHTECK	☐	☐
RUGGEN	☐	☐
KILLNER	☐	☐
LENKRAD	☐	☐
SCHURE	☐	☐
SCHEITEL	☐	☐
KLIRUS	☐	☐
AMBITION	☐	☐
ACHSI	☐	☐
MANOKEL	☐	☐
TEPPICH	☐	☐
TULESKOP	☐	☐
HOCHZEIT	☐	☐
WARTUNG	☐	☐
ROMANTIK	☐	☐
WAAGE	☐	☐
UNGEDULD	☐	☐
DICHTUNG	☐	☐

	Wort	Kein Wort
GARAGE	☐	☐
GOGANT	☐	☐
SCHEPPEN	☐	☐
JOGHURT	☐	☐
GREPPE	☐	☐
CHARURG	☐	☐
NURMANNE	☐	☐
GRIPHIT	☐	☐
PHANTOM	☐	☐
ENTZIG	☐	☐
PAPIER	☐	☐
JACHT	☐	☐
GEROPPE	☐	☐
KUCHEN	☐	☐
FIASKO	☐	☐
RIMMEL	☐	☐
WINTER	☐	☐
QUUCKE	☐	☐
SPITZE	☐	☐
ISLOM	☐	☐

	Wort	Kein Wort
QUALM	☐	☐
THOATER	☐	☐
URLAUB	☐	☐
NUDUL	☐	☐
WERBEL	☐	☐
CHUMIE	☐	☐
KUMMUR	☐	☐
HURRA	☐	☐
MYTHOS	☐	☐
GORILLA	☐	☐
STRIUSEL	☐	☐
POKAL	☐	☐
PFOIL	☐	☐
LANDRAT	☐	☐
LATTERIE	☐	☐
BROTT	☐	☐
PFENNUG	☐	☐
STADTRAT	☐	☐
LANDHOUS	☐	☐
WECHSEL	☐	☐

	Wort	Kein Wort
EMIGRANT	☐	☐
ARRSINN	☐	☐
PIDIUM	☐	☐
MILCH	☐	☐
METZGER	☐	☐
PUDDING	☐	☐
HORMON	☐	☐
SERUP	☐	☐
MARMOR	☐	☐
BATANIK	☐	☐
ZERKEL	☐	☐
MULDE	☐	☐
SUCHEL	☐	☐
DIESEL	☐	☐
TELPE	☐	☐
NEIGUNG	☐	☐
ANMOT	☐	☐
TIMPO	☐	☐
DRUCKOR	☐	☐
SESSEL	☐	☐

	Wort	Kein Wort
DIAGNOSE	☐	☐
OBERHAND	☐	☐
MONOLOG	☐	☐
WURST	☐	☐
RHETORIK	☐	☐
REHSTOFF	☐	☐
KONZEL	☐	☐
HAUSARZT	☐	☐
FLANKE	☐	☐
BOLKEN	☐	☐
FLUMME	☐	☐
ABSCHIED	☐	☐
LUNEAL	☐	☐
ZIPFEN	☐	☐
QUITTUNG	☐	☐
LIEBLING	☐	☐
QUATSCH	☐	☐
DURST	☐	☐
TIFEL	☐	☐
NACHWIIS	☐	☐

	Wort	Kein Wort
MEINEOD	☐	☐
KLASTER	☐	☐
BUTTER	☐	☐
RUCHE	☐	☐
ORDNUR	☐	☐
UNART	☐	☐
HUCHT	☐	☐
FOHDE	☐	☐
ONKEL	☐	☐
KRUCHEN	☐	☐
MUNISTER	☐	☐
NEUHEIT	☐	☐
ABDRUCK	☐	☐
APTIMIST	☐	☐
HULZWEG	☐	☐
HEXEREI	☐	☐
TOLLWET	☐	☐
WAGGEN	☐	☐
VOGEL	☐	☐
RIGIE	☐	☐

Fragebogen: „Schwierigkeit“

Beziehen Sie sich bei der Beantwortung der Fragen bitte auf die Anforderung der letzten beiden bearbeiteten Aufgabenblöcke.

Geistige Anforderungen: Wie viel geistige Anstrengung war bei der Informationsaufnahme und bei der Informationsverarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen ...)? War die Bearbeitung leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder ist sie fehlertolerant?	gering hoch
Körperliche Anforderungen: Wie viel körperliche Aktivität war erforderlich (z.B. ziehen, drücken, drehen, steuern, aktivieren ...)? War die Bearbeitung leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?	gering hoch
Zeitliche Anforderungen: Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?	gering hoch
Ausführung der Aufgaben: Wie erfolgreich haben Sie ihrer Meinung nach die von Ihnen selbst gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?	gering hoch
Anstrengung: Wie hart mussten Sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?	gering hoch
Frustration: Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Bearbeitung?	gering hoch

	5 8 2	3 7 6	9 6 3	1 4 8	3 7 6	3 7 6	9 4 1
1	4 7 1	8 9 5	7 4 8	2 9 3	8 9 5	8 9 5	6 2 3
	9 3 6	4 2 1	5 1 2	6 5 7	4 2 1	4 2 1	8 7 5

	2 3 9	6 5 7	3 7 6	6 5 7	2 3 9	7 2 5	6 5 7
2	7 5 6	1 8 4	8 9 5	1 8 4	7 5 6	3 1 9	1 8 4
	4 1 8	2 3 9	4 2 1	2 3 9	4 1 8	8 6 4	2 3 9

VpNr ______

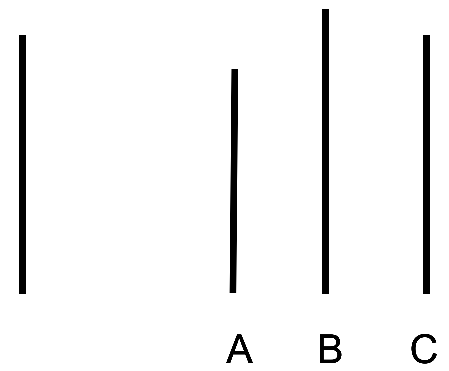
	5 8 2	3 7 6	9 6 3	1 4 8	3 7 6	3 7 6	9 4 1
1	4 7 1	8 9 5	7 4 8	2 9 3	8 9 5	8 9 5	6 2 3
	9 3 6	4 2 1	5 1 2	6 5 7	4 2 1	4 2 1	8 7 5

	2 3 9	6 5 7	3 7 6	6 5 7	2 3 9	7 2 5	6 5 7
2	7 5 6	1 8 4	8 9 5	1 8 4	7 5 6	3 1 9	1 8 4
	4 1 8	2 3 9	4 2 1	2 3 9	4 1 8	8 6 4	2 3 9

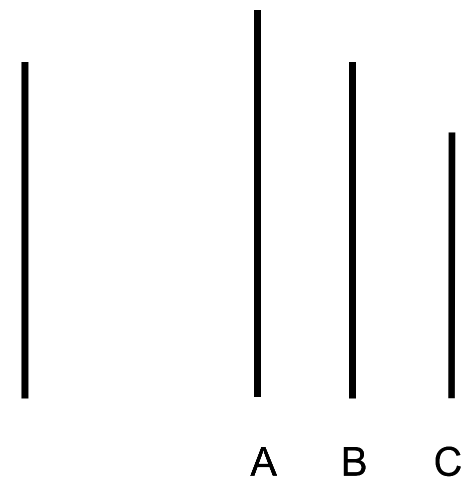
VpNr ______

Bitte ungerade Zahlen zählen	VPNr____
1	2

1



2



Appendix C: Materials Study 3

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 50 Minuten dauern. Die Teilnahme wird mit einer Versuchspersonenstunde vergütet.

In unserer Studie untersuchen wir wie gut Menschen Aufgaben mit Unterbrechungen bearbeiten können. Sie werden gebeten, verschiedene Arten von Entscheidungsaufgaben zu bearbeiten und werden dabei durch eine andere Aufgabenart unterbrochen. Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 80 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Tobias Grundgeiger, tobias.grundgeiger@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die folgende Einwilligungserklärung.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
---------------------------------------	---------------------------------------	---------------------------

Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
---------------------------------------	---------------------------------------	---------------------------

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Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
--------------------------------------	--------------------------------------	--------------------------

Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
--------------------------------------	--------------------------------------	--------------------------

Fragebogen: „Multitasking III“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
☐	☐	☐☐	☐☐	☐☐

Alter: ____________ Geschlecht: ◻ m ◻ w Studiengang:___________

Händigkeit: ◻ links ◻ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? ◻ ja ◻ nein

Haben Sie eine deutsche weiterführende Schule besucht? ◻ ja ◻ nein

1. Was mussten Sie im ersten Teil des Versuchs tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktiv erinnert“ **1** **2** **3** **4** **5** **6** **7** „Werde mich schon daran erinnern“

4. Haben Sie im zweiten Teil noch auf den roten Bildschirm reagiert? Falls ja: Wie kam es dazu?

____

____

5. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking III“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87		Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss		Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87

Alter: ____________ Geschlecht: □ m □ w Studiengang:___________

Händigkeit: □ links □ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Wie hätten Sie auf den roten Bildschirm reagieren müssen, wenn er für Sie relevant gewesen wäre? Wann mussten Sie dies tun?

____

____

2. Haben Sie trotzdem auf den roten Bildschirm reagiert? Falls ja: Wie kam es dazu?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking III“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
□	□	□□	□□	□□

Alter: ____________ Geschlecht: □ m □ w Studiengang:___________

Händigkeit: □ links □ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Haben Sie in irgendeiner Form auf den roten Bildschirm reagiert? Falls ja: Was haben Sie getan?

____

____

2. Haben Sie das Gefühl gehabt, dass der rote Bildschirm Sie bei der Bearbeitung der Entscheidungsaufgaben gestört hat?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking III“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87

Alter: ___________ Geschlecht: □ m □ w Studiengang:__________

Händigkeit: □ links □ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Was mussten Sie tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktiv erinnert“ **1** **2** **3** **4** **5** **6** **7** „Werde mich schon daran erinnern“

4. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Informationen zur Studie

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Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 120 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

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Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „Multitasking V“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
☐	☐	☐☐	☐☐	☐☐

Alter: ___________ Geschlecht: □ m □ w Studiengang:__________

Händigkeit: □ links □ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Was mussten Sie im ersten Teil des Versuchs tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktiv erinnert“	**1**	**2**	**3**	**4**	**5**	**6**	**7**	„Werde mich schon daran erinnern“

4. Haben Sie im zweiten Teil noch auf den roten Bildschirm reagiert? Falls ja: Wie kam es dazu?

____

____

5. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking V“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87	Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss	Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87
☐	☐	☐☐	☐☐	☐☐

Alter: ____________ Geschlecht: ◻ m ◻ w Studiengang:___________

Händigkeit: ◻ links ◻ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? ◻ ja ◻ nein

Haben Sie eine deutsche weiterführende Schule besucht? ◻ ja ◻ nein

1. Wie hätten Sie auf den roten Bildschirm reagieren müssen, wenn er für Sie relevant gewesen wäre? Wann mussten Sie dies tun?

____

____

2. Haben Sie trotzdem auf den roten Bildschirm reagiert? Falls ja: Wie kam es dazu?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Fragebogen: „Multitasking V“

Erster Buchstabe Vorname Mutter Bsp. **A** für Anna	Letzter Buchstabe Vorname Vater Bsp. **E** für Uwe	Tag des Geburtstags Bsp. **04** für Geburtstag am 04.12.87		Erster und letzter Buchstabe der Geburtsstadt Bsp. **NS** für Neuss		Monat des Geburtstags Bsp. **12** für Geburtstag am 04.12.87	
☐	☐	☐	☐	☐	☐	☐	☐

Alter: ____________ Geschlecht: ☐ m ☐ w Studiengang:___________

Händigkeit: ☐ links ☐ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? ☐ ja ☐ nein

Haben Sie eine deutsche weiterführende Schule besucht? ☐ ja ☐ nein

1. Was mussten Sie tun wenn der rote Bildschirm erschien? Wann mussten Sie dies tun?

____

____

2. Haben Sie eine bestimmte Strategie benutzt um die Aufgabe aus Frage 1 zu erledigen?

____

____

3. Haben Sie eher versucht sich aktiv an die Aufgabe aus Frage 1 zu erinnern oder sind Sie eher davon ausgegangen, dass Sie sich schon daran erinnern werden wenn es so weit ist?

„Aktiv erinnert“	**1**	**2**	**3**	**4**	**5**	**6**	**7**	„Werde mich schon daran erinnern“

4. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

***Appendix D:* Materials Study 4**

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 30 Minuten dauern und mit einer halben Versuchspersonenstunde vergütet.

Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 100 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „OnlinePretest"

☐☐	☐☐	☐☐	☐☐
Die letzten beiden Buchstaben des Geburtsnamens Ihrer Mutter	Die Anzahl der Buchstaben des (ersten) Vornamens Ihrer Mutter	Die beiden letzten Buchstaben des (ersten) Vornamens Ihres Vaters	Ihr eigener Geburtstag (nur der Tag)

Alter: ___________ Geschlecht: □ m □ w Studiengang:__________

Händigkeit: □ links □ rechts

Muttersprache ___________

Wie lange sprechen Sie schon Deutsch? ___________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Beschreiben Sie bitte wann und wie Sie bei der Zusatzaufgabe hätten reagieren müssen.

____

____

2. Haben Sie während des Experiments noch auf die Zusatzaufgabe reagiert? Und wenn ja, warum?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 60 Minuten dauern und mit einer Versuchspersonenstunde vergütet.

Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 60 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „OnlinePretest2“

☐☐	☐☐	☐☐	☐☐
Die letzten beiden Buchstaben des Geburtsnamens Ihrer Mutter	Die Anzahl der Buchstaben des (ersten) Vornamens Ihrer Mutter	Die beiden letzten Buchstaben des (ersten) Vornamens Ihres Vaters	Ihr eigener Geburtstag (nur der Tag)

Alter: ____________ Geschlecht: ☐ m ☐ w Studiengang:___________

Händigkeit: ☐ links ☐ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? ☐ ja ☐ nein

Haben Sie eine deutsche weiterführende Schule besucht? ☐ ja ☐ nein

1. Beschreiben Sie bitte wann und wie Sie bei der Zusatzaufgabe hätten reagieren müssen.

___

___

2. Haben Sie während des Experiments noch auf die Zusatzaufgabe reagiert? Und wenn ja, warum?

___

___

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

___

___

Appendix E: Materials Study 5

Informationen zur Studie

Willkommen zu unserer Studie und danke, dass Sie mit Ihrer Teilnahme unsere Forschung unterstützen. Die Studie wird ca. 30 Minuten dauern und mit einer halben Versuchspersonenstunde vergütet.

In unserer Studie untersuchen wir wie gut Menschen verschiedene Arten von Entscheidungsaufgaben bearbeiten können. Für die erfolgreiche Durchführung der Studie ist es von großer Bedeutung, dass Sie alle Aufgaben so genau und schnell wie möglich bearbeiten, wie Sie können. Instruktionen über den genauen Versuchsablauf bekommen Sie gleich über den Bildschirm sowieso von dem anwesenden Versuchsleiter.

Wir werden Ihre Daten nicht individuell auswerten, sondern nur für die Gesamtgruppe der Teilnehmenden. Ungefähr 90 Personen werden an dieser Untersuchung teilnehmen. Nur Mitarbeiter dieses Forschungsprojektes haben Zugang zu Ihren Daten. Ihre Daten werden in anonymisierter Form bis zum Abschluss des Projekts unter Verschluss bzw. passwortgeschützt aufbewahrt.

Es steht Ihnen frei, an dieser Untersuchung teilzunehmen oder die Untersuchung zu irgendeinem Zeitpunkt zu beenden. Sie werden dann nur für die teilgenommene Zeit entlohnt.

Wenn Sie Fragen zu dieser Studie haben, wenden Sie sich bitte nun an den/die anwesende(n) Versuchsleiter/-in oder nehmen Sie Kontakt zu Philipp Schaper, philipp.schaper@uni-wuerzburg.de auf.

Es ist für unsere Forschung sehr wichtig, dass künftige Teilnehmer keine speziellen Strategien benutzen. Das würde unsere Daten leider verfälschen. Bitte teilen Sie möglichen zukünftigen Teilnehmern daher bitte nichts über dieses Experiment mit.

Wenn Sie an der Studie weiterhin teilnehmen wollen, unterschreiben Sie nun die beiliegenden Einwilligungserklärungen.

Einwilligungserklärung (verbleibt mit Versuchsleiter/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Einwilligungserklärung (verbleibt mit Teilnehmer/-in)

Ich habe die Informationen zur Studie gelesen und verstanden. Ich hatte die Möglichkeit, Fragen zu stellen. Ich bin damit einverstanden an der Untersuchung teilzunehmen und weiß, dass ich diese jederzeit abbrechen kann. Bei einem Abbruch der Studie entstehen keine Nachteile und ich erhalten eine anteilige Auszahlung der Vergütung.

Teilnehmer

Name in Druckbuchstaben	Unterschrift	Datum
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Versuchsleiter

Name in Druckbuchstaben	Unterschrift	Datum
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Fragebogen: „Multitasking XI“

□□	□□	□□	□□
Die letzten beiden Buchstaben des Geburtsnamens Ihrer Mutter	Die Anzahl der Buchstaben des (ersten) Vornamens Ihrer Mutter	Die beiden letzten Buchstaben des (ersten) Vornamens Ihres Vaters	Ihr eigener Geburtstag (nur der Tag)

Alter: ____________ Geschlecht: □ m □ w Studiengang:___________

Händigkeit: □ links □ rechts

Muttersprache ____________

Wie lange sprechen Sie schon Deutsch? ____________ Jahre

Haben Sie eine deutsche Grundschule besucht? □ ja □ nein

Haben Sie eine deutsche weiterführende Schule besucht? □ ja □ nein

1. Haben Sie in irgendeiner Form auf Wörter mit farbigem Hintergrund reagiert? Falls ja: Was haben Sie getan?

____

____

2. Haben Sie das Gefühl gehabt, dass die farbigen Hintergründe Sie bei der Bearbeitung der Entscheidungsaufgaben gestört haben?

____

____

3. Haben Sie schon einmal an einem solchen Experiment teilgenommen bzw. hatten Sie Vorinformationen zu diesem Thema?

____

____