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The Failure of Deactivating Intentions: Aftereffects of Completed Intentions in the Repeated Prospective Memory Cue Paradigm

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We used a newly developed experimental paradigm to investigate aftereffects of completed intentions on subsequent performance that required the maintenance and execution of new intentions. Participants performed an ongoing number categorization task and an additional prospective memory (PM) task, which required them to respond to PM cues that differed from standard stimuli in 1 particular visual feature. Although the feature defining the to-be-acted-upon PM cue changed in each block, the irrelevant PM cue of the previous PM task block was occasionally repeated in the subsequent block. In 4 experiments we found that performance in the ongoing task was substantially slowed for repeated PM cue trials compared to oddball trials, which also differed in a visual feature from standard stimuli but never served as PM cues. This aftereffect decreased as a function of delay after intention completion. These findings indicate that intentions can exhibit persisting activation even after they have been completed and may interfere with the execution of the new relevant task. Possible mechanisms and boundary conditions of this intention deactivation failure are discussed.

Keywords: intention, prospective memory, intention-superiority effect

In everyday life, people must constantly remember to perform intended actions such as taking medication at a specific time or posting a letter when passing a mailbox. Numerous studies have been dedicated to investigating prospective memory (PM), that is, the ability to form, maintain, recall, and execute intentions at the appropriate time or in the appropriate context (for an overview, see Kliegel, McDaniel, & Einstein, 2008).

One strand of research has focused on the question of whether representations of uncompleted intentions exhibit special dynamic properties in terms of persisting heightened activation. This research was partly instigated by Goschke and Kuhl (1993), who showed that words from a later-to-be-executed script produced faster latencies in a recognition test than words from an equally well learned but not to-be-executed script. This so-called *intention-superiority effect* (ISE) has been interpreted as evidence that intention-related memory contents exhibit a heightened or more sustained level of subthreshold activation in long-term memory and has since been repeatedly replicated in the laboratory as well as with respect to the retrieval of real-life intentions (Cohen, Dixon, & Lindsay, 2005; Freeman & Ellis, 2003; Marsh, Hicks, & Bink, 1998; Marsh, Hicks, & Bryan, 1999; Marsh, Hicks, & Watson, 2002; Maylor, Darby, & Della Sala, 2000; Meilán, 2008; for an overview, see Goschke & Kuhl, 1996; McDaniel & Einstein, 2007).

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Although the ISE has been discussed in terms of increased activation of uncompleted intentions, the fate of intentions once the intended action goal has been completed is less well understood. Yet, the ability to deactivate completed intentions is highly relevant, given that a failure to disengage from completed or canceled intentions may incur costs in terms of perseverative behavior (such as overmedication), intrusive thoughts, and reduced cognitive capacity required for the pursuit of new realistic goals (Kazén, Kaschel, & Kuhl, 2008; Kuhl & Goschke, 1994; Penningroth, 2005). Previous research showed that completing an intention may instigate specific aftereffects on subsequent performance in terms of changing accessibility of material related to the completed intention (e.g., Förster, Liberman, & Higgins, 2005; Freeman & Ellis, 2003; Marsh et al., 1998, 1999; Penningroth, 2011).

Several authors hypothesized that intentions should be inhibited once they have been performed (Badets, Blandin, Bouquet, & Shea, 2006; Freeman & Ellis, 2003), as indicated by the fact that compared to neutral items, items related to a completed intention produced increased lexical decision latencies and/or reduced Stroop interference (Förster et al., 2005; Marsh et al., 1998, 1999). These findings suggest that inhibition presumably plays a functional role, as it prevents proactive interference during the pursuit of novel intentions (Liberman, Förster, & Higgins, 2007; see also Mayr & Keele, 2000). However, these findings are not undisputed, as several studies failed to obtain evidence for the inhibition of completed intentions even though similar paradigms were applied. Therefore, it is also conceivable that, at least under certain conditions, intentions may be immediately deactivated and return to a baseline level after the intention is completed (Meilán, 2008). Finally, completed intentions may remain activated immediately after intention completion and gradually decay over time (e.g., Cohen et al., 2005; Penningroth, 2011). Cohen et al. (2005) found an increased Stroop interference for intention-related words compared to neutral words in an uncompleted compared to a completed intention condition. Importantly, however, in the completed intention condition, the Stroop interference was still increased for intention-related words compared to neutral words.

Therefore, the relatively few studies that investigated the activation status of intentions after completion yielded mixed results, with evidence for inhibition, immediate return to baseline, and/or persisting (presumably decaying) activation. Furthermore, besides these inconsistent findings, two important issues with respect to aftereffects of completed intentions have received little attention and will be the focus of the present study.

First, whereas most previous studies focused on aftereffects of the retrospective component of completed intentions and examined the accessibility of the content of the intention (i.e., the verbal or motor representation of the to-be-performed action), less is known about the fate of the *prospective component* of intentions. This refers to successfully remembering the intent to perform the intended action at a specific point of time (i.e., time-based PM) or in a specific situation (i.e., event-based PM; e.g., Einstein & McDaniel, 1990).

Preliminary evidence for aftereffects of the prospective component of completed intentions was reported by West, McNerney, and Travers (2007). They presented participants with a specific PM cue word (e.g., "Chicago") prior to each experimental block. A specific display (i.e., "perform" vs. "forget" the PM cue) at the beginning of each block instructed participants whether to perform or to ignore the PM task. Despite the "forget" instruction, participants' responses were slower in trials that contained the to-be-forgotten PM cue word than in standard trials. However, on the basis of those findings it can be argued that the specific "forget" instruction might have counteracted the sufficient deactivation of the PM cue, as the instruction not to think of a particular word may even increase its activation state (Wegner, Schneider, Carter, & White, 1987). Also, it remains unclear whether these data are generalizable to completed intentions, as participants had to forget PM cues but never performed a PM task as response to these cues.

On the other hand, Scullin and colleagues reported that (at least in young adults) PM cues affected subsequent performance only when the related intentions were suspended and not when the intention was completed (Scullin, Bugg, McDaniel, & Einstein, 2011; Scullin, Einstein, & McDaniel, 2009). In their studies, participants first performed an image-rating task with an embedded event-based PM task, which required pressing the *Q* key when a specific PM cue appeared (e.g., the word *dancer*). Then, participants were told that the PM task was either suspended or completed. In a subsequent lexical decision task, participants in the suspended intention condition responded more slowly to words that had previously served as PM cues than to control words. If intentions were merely suspended, the encounter of a PM cue in the subsequent lexical decision task led to an automatic retrieval of the PM-related response interfering with the ongoing task. Importantly, if participants were told that intentions were completed, performance for PM cues and control words did not differ, and therefore, aftereffects of completed intentions were not found. This indicates that PM cues no longer automatically elicit retrieval of the intention once the intention is completed.

The reason for the inconsistent findings obtained by West et al. (2007) and Scullin et al. (2009, 2011) might be manifold, as the studies also differ methodologically. However, the findings of PM cues not affecting performance after intention completion might be related to the strong context change between the PM task performance and the measurement of PM aftereffects in the Scullin et al. paradigm. Also, aftereffects of completed intentions (e.g., increased RTs on repeated PM cues) might be observable only after a short delay between intention completion and measurement of aftereffects (as in West et al.'s study) and might disappear in longer delays as applied by Scullin et al. (2009, 2011).

Consequently, it appears important to investigate potential aftereffects of completed intentions immediately after intention completion and to possibly track more precisely how their activation level evolves as a function of increasing delay. Therefore, our first aim in the present study was to investigate the aftereffects of the prospective component of completed intentions and their activation pattern as a function of delay after intention completion.

A second, largely neglected issue in the study of aftereffects of completed intentions refers to the fact that previous studies examined such aftereffects in the absence of the requirement to maintain and execute other uncompleted intentions.[1] This contrasts with everyday life, where we constantly form, maintain, initiate, and perform new intentions, regardless of whether or not other intentions have been completed.

Our second aim in the study was, therefore, to examine aftereffects of completed intentions on subsequent performance in a task that required the maintenance and execution of new intentions. It is conceivable that aftereffects of completed intentions—concerning both content and PM cue—may strongly depend on whether or not a new intention must be performed simultaneously. Whereas it appears plausible that inhibition of completed intentions may be increased in order to enable allocating cognitive resources to the processing of new intentions, we tested the hypothesis that the activation state of a completed intention may remain elevated when new but similar intentions are pursued.

The Present Study

In order to examine aftereffects of completed intentions while participants had to perform new intentions, we developed a new experimental paradigm that we term the *repeated PM cue paradigm*. Participants performed a series of blocks in which they had to categorize digits as odd or even as the ongoing task (see Figure 1). In addition, they had to perform a PM task that required them to make a different response (pressing the space bar) whenever a PM cue appeared that differed from standard digits with respect to a specific feature (e.g., font type, orientation, color). The feature defining the relevant PM cue changed from block to block. Here, in contrast to typical PM studies, the performance in these PM trials was of less interest. Critically, PM cues from the preceding block (so-called $PM_{REPEATED}$ trials) were occasionally interspersed with currently relevant PM cues to assess aftereffects of completed intentions. Participants were required to perform the digit categorization task (rather than the PM task) on these $\mathrm{PM}_{\mathrm{REPEATED}}$ trials.

Our critical measure to assess aftereffects of completed intentions was participants' performance on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials as

[1] With the exception, of course, of intentions participants pursued outside the laboratory, which constitute a constant background of uncompleted intentions and should produce no systematic effects in the context of the experimental tasks.

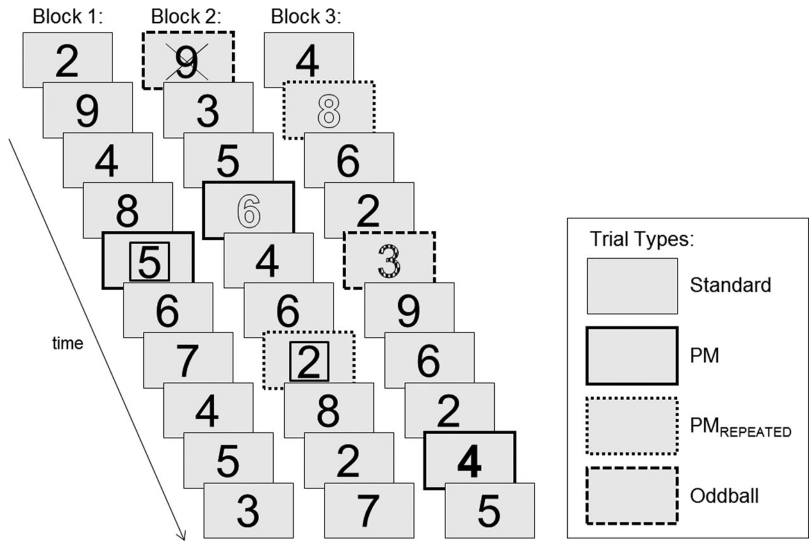

Figure 1. Procedure in Experiment 1. Examples for 10 trials for Blocks 1 to 3 are shown. On standard trials participants had to perform a parity judgment on digits ranging from 2 to 9. Prior to each block, participants were instructed to press the space bar on trials where targets were displayed in a specific format (i.e., on prospective memory [PM] trials). In the pictured example, participants would have to press the space bar in Block 1 when a digit surrounded by a square appears, in Block 2 when a transparent digit with a black outline appears, and in Block 3 when a digit in bold font appears. In all further trials participants had to perform the digit categorization task, even though stimuli were presented in the same format as in PM trials of the previous block (i.e., on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials) or in a different format unrelated to that of the previous block (i.e., on oddball trials). A fixation cross (500 ms) preceded each imperative stimulus. Note that framing of trial types was not present in the experiment but serves exclusively to illustrate different trial types in this figure.

compared to performance on control trials (i.e., so-called *oddball* trials). Like $\mathrm{PM}_{\mathrm{REPEATED}}$ trials, oddball trials differed from standard trials with respect to specific deviant stimulus features (see Figure 1) but never served as PM cues throughout the experiment. If deviant stimulus features automatically capture attention and lead to an orientation reaction, this should be reflected in prolonged response times (RTs) both on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials and on oddball trials as compared to standard trials (cf. Polich, 2007; Sokolov, 1963; Yamaguchi, Hale, D'Esposito, & Knight, 2004). Consequently, comparing possible RT prolongations on oddball trials and $\mathrm{PM}_{\mathrm{REPEATED}}$ trials enabled us to dissect RT costs that were due to an orientation reaction to any deviant stimuli from possible aftereffects of completed intentions on RTs in $\mathrm{PM}_{\mathrm{REPEATED}}$ trials.

If specific intentions were inhibited after their completion, the deviant (now irrelevant) PM cue features (leading to orientation reactions and/or response conflict) should be less accessible. That is, any kind of inhibitory influences on task-irrelevant PM cue features should facilitate the performance in the ongoing task. Consequently, responses to $\mathrm{PM}_{\mathrm{REPEATED}}$ trials should be even faster than those to oddball trials. Alternatively, if intentions were deactivated immediately after PM task completion, $\mathrm{PM}_{\mathrm{REPEATED}}$ trials should elicit at most an orientation reaction that is comparable to that of the oddball trials. Finally, if the intention activation level remains elevated after intention completion (i.e., after the PM task), the onset of $\mathrm{PM}_{\mathrm{REPEATED}}$ trials should lead to an automatic retrieval of the PM response that interferes with the ongoing task response, thereby causing prolonged RTs as compared to those on oddball trials.

Furthermore, potential aftereffects of completed intentions may be sensitive to temporal variations between intention completion and the assessment of the aftereffects. If PM cues were transiently inhibited or persist activated before returning to baseline activation, aftereffects should vary as a function of the delay after intention completion. That is, assumed benefits in ongoing task performance for $\mathrm{PM}_{\mathrm{REPEATED}}$ trials (due to inhibition of irrelevant PM cue features below baseline activation) as well as costs in ongoing task performance for $\mathrm{PM}_{\mathrm{REPEATED}}$ trials (due to elevated activation levels of irrelevant PM cue features) should be more pronounced immediately after intention completion and should dissipate over time.

Finally, we hypothesized that the maintenance and execution of a new PM task might determine the occurrence of aftereffects of previously completed intentions. In this vein, a new intention might override the old PM task set and support a fast deactivation or inhibition of the completed intention to reduce interference. In this case, aftereffects should be minimized in conditions of additional new intention pursuit compared to conditions without a new intention. Alternatively, a new intention to respond to PM cues might promote the processing of deviant stimuli in general (including the processing of stimuli that contain features of the completed and now irrelevant intention). Consequently, this would even increase aftereffects of completed intentions (as compared to conditions in which no new intention has to be processed after intention completion).

Experiment 1

Method

Participants. Twelve students of the Technische Universität Dresden (2 male; age $M = 22.25$ years, $SD = 3.19$, range 19–30 years) participated in Experiment 1. All participants reported normal or corrected-to-normal vision. The participants attended a single experimental session lasting about 50 min and received 5 € or course credit.

Apparatus and stimuli. Participants were tested individually in a sound-attenuated booth. The experiment was performed on a Windows XP SP2 personal computer running Presentation software (Version 0.71; www.neurobs.com). Stimuli were presented on a 17-in. monitor at a resolution of 1280 × 1024 pixels. Participants sat at a distance of approximately 60 cm in front of the computer screen.

Stimuli were the digits 2 to 9 presented in Arial font (font size: 80 pixels/visual angle ~ 2.24°) in black against a gray background. Stimuli on PM trials, $\text{PM}_{\text{REPEATED}}$ trials, and oddball trials could deviate from standard stimuli with respect to one of 15 different features. Digits could appear (a) on a pink background, (b) surrounded by a black square, (c) in Engravers MT font, (d) underlined, (e) in blue font color, (f) in small font size (40 pixels), (g) with a shadow, (h) tilted to the left, (i) with a black-white texture, (j) transparent with a black outline, (k) in italics, (l) vertically displaced, (m) crossed out, (n) three-dimensional and rotated, or (o) in bold font.

A standard German (*QWERTZ*) computer keyboard was used to record responses. Participants used the right index finger to press the *L* key for even digits and the left index finger to press the *S* key for odd digits. Participants had to press the space bar with the thumb of their dominant hand in response to PM trials.

Procedure and design. The experiment started with two practice blocks, each comprising 16 trials. Participants were instructed by the computer to judge digits according to parity as fast and as accurately as possible. Whereas in the first practice block only standard trials were presented, in the second practice block trials entailing the 15 different deviant stimulus features were shown in addition to one standard trial.

The experimental blocks started subsequently. At the beginning of each experimental block, participants were instructed by the computer to press the space bar instead of performing the digit categorization task on trials in which a specific PM cue was presented (e.g., a digit surrounded by a black square). A sample PM cue was depicted during the instruction. The imperative PM cue type changed in each block. The instruction remained on the computer monitor until participants started the task by pressing the space bar.

Each trial started with the presentation of a black fixation cross (font size: 18 pixels/visual angle ~ 0.50°) for 500 ms. This was followed by the imperative stimulus, which remained on the screen until a response was given (or a maximum of 3,000 ms). If no response was given or an error was committed, the feedback *zu langsam* (too slow) or *Fehler* (error) was displayed for 200 ms simultaneously with a feedback tone (700 Hz) delivered through headphones. At the end of each block, participants were informed about their mean RT and error rate and were reminded to respond as quickly and accurately as possible.

The experiment consisted of eight experimental blocks each comprising 208 trials. That is, each digit (2–9) was presented 26 times in each block. Digits were randomly drawn to serve as standard trial, PM trial, $\text{PM}_{\text{REPEATED}}$ trial, or oddball trial, the only constraint being that the same digit was not repeated in two consecutive trials. The first block contained 202 standard trials and six PM trials. The remaining blocks contained 190 standard trials, six PM trials, six $\text{PM}_{\text{REPEATED}}$ trials, and six oddball trials. In the first block only one of the 15 deviant stimulus features was assigned to serve as PM trials. The remaining 14 features were distributed as PM trials or oddball trials for the subsequent seven blocks.

Results

The first block of trials was excluded from the analyses because it did not contain $\text{PM}_{\text{REPEATED}}$ trials. For the remaining blocks, error trials (5.7%) were excluded. Trials with RTs 2.5 standard deviations (*SD*s) above or below a participant's mean RT for a given trial type (2.7%) were excluded. A repeated-measurements analysis of variance (ANOVA) with the factor trial type (standard, $\text{PM}_{\text{REPEATED}}$, oddball) was conducted on RTs and error data of the ongoing task (see Figure 2).

RTs. The ANOVA yielded a highly reliable effect of trial type, $F(2, 22) = 74.74$, $p < .001$, $\eta^2 = .87$. Planned contrasts revealed that RTs were reliably faster on standard trials ($M = 559$ ms, $SD = 104$ ms) than on oddball trials ($M = 716$ ms, $SD = 118$ ms), $F(1, 11) = 41.18$, $p < .001$, $\eta^2 = .79$. Most important, responses on $\text{PM}_{\text{REPEATED}}$ trials ($M = 842$ ms, $SD = 131$ ms) were reliably slower than responses on oddball trials, $F(1, 11) = 39.71$, $p < .001$, $\eta^2 = .78$.

In order to elucidate the dependence of aftereffects on the delay to intention completion, we compared the performance on $\text{PM}_{\text{REPEATED}}$ and oddball trials with respect to the occurrence of $\text{PM}_{\text{REPEATED}}$ trials and oddball trials within each block (i.e., first three encounters vs. last three encounters of each trial type). Most important, the aftereffects of completed intentions for $\text{PM}_{\text{REPEATED}}$ trials in the first half of the block ($M = 170$ ms, $SD = 95$ ms; $\text{PM}_{\text{REPEATED}}$ trials: $M = 931$ ms, $SD = 156$ ms; oddball trials: $M = 761$ ms, $SD = 128$ ms), $t(11) = 4.36$, $p = .001$, $d = 0.72$, were larger than those in the second half of the block ($M = 83$ ms, $SD = 66$ ms; $\text{PM}_{\text{REPEATED}}$ trials: $M = 759$ ms, $SD = 112$ ms; oddball trials: $M = 676$ ms, $SD = 117$ ms), $t(11) = 4.36$, $p = .001$, $d = 0.72$, as revealed by the significant interaction between trial type and block position, $F(1, 11) = 11.90$, $p = .005$, $\eta^2 = .52$.

Errors. Error data generally mirrored the RT data. We found a reliable main effect of trial type, $F(2, 22) = 5.18$, $p = .014$, $\eta^2 = .32$. As for the RT data, planned contrasts indicated that participants committed fewer errors on standard trials ($M = 5.1\%$, $SD = 2.2\%$) than on oddball trials ($M = 8.5\%$, $SD = 4.4\%$), $F(1, 11) = 10.96$, $p = .007$, $\eta^2 = .50$, whereas error rates did not differ significantly between $\text{PM}_{\text{REPEATED}}$ trials ($M = 9.9\%$, $SD = 7.2\%$) and oddball trials ($F < 1$). Taking into account the different types of errors that were committed on $\text{PM}_{\text{REPEATED}}$ trials and on oddball trials, a further analysis showed that participants committed 3.4% false alarms (i.e., the erroneous execution of the PM

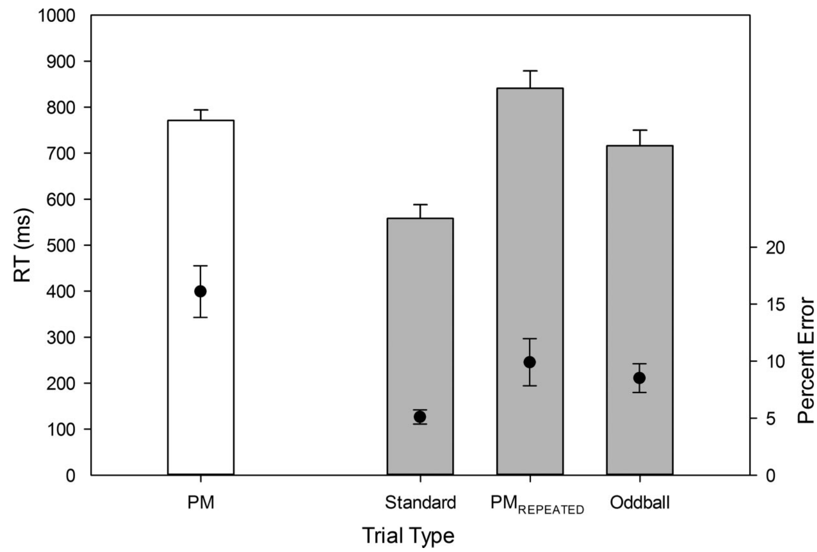

Figure 2. Mean response time (RT) and percent error as a function of trial type (prospective memory [PM], standard, $PM_{REPEATED}$, oddball) in Experiment 1. Error bars represent standard errors.

response) on $PM_{REPEATED}$ trials but only 0.8% false alarms on oddball trials, $t(11) = 2.55$, $p = .027$, $d = 1.01$.

As in the RT data, more errors were committed during $PM_{REPEATED}$ trials when the delay to intention completion was short ($M = 11.5\%$) rather than long ($M = 6.9\%$). This is revealed by the significant interaction between trial type and block position, $F(1, 11) = 6.30$, $p = .029$, $\eta^2 = .36$.

Discussion

In Experiment 1, participants responded more slowly and committed more false alarms on $PM_{REPEATED}$ trials than on oddball trials. In addition, the slowing on $PM_{REPEATED}$ trials compared to oddball trials was more pronounced in the first half of the experimental block than in the second half of the experimental block, suggesting a dependence of aftereffects on the temporal delay to intention completion. In particular, repeated (i.e., irrelevant) PM cues from the previous block that were related to a completed intention still triggered the associated PM response, thus causing interference with the correct response in the digit categorization task. Furthermore, participants responded more slowly and committed more errors on oddball trials than on standard trials. This indicates that deviant stimulus features—which occurred both on oddball trials and on $PM_{REPEATED}$ trials—automatically captured attention and elicited an orientation reaction.

Taken together, the results of Experiment 1 seem to be consistent with the assumption that the additional RT slowing on $PM_{REPEATED}$ trials compared to oddball trials can be attributed to a heightened level of activation of the completed intention, the effects of which decrease over the time course of the experimental block.

Experiment 2

Experiment 2 was designed to replicate and extend findings of Experiment 1. We argued that due to the specific deviant features, oddball trials as well as intention-related trials may automatically capture attention and elicit an orientation reaction. Accordingly, in Experiment 1 we found prolonged RTs for $PM_{REPEATED}$ trials as well as for oddball trials compared to standard trials. One may argue, though, that an orientation reaction to a deviant feature may be stronger when this feature is familiar due to previous encounters. Thus, an orientation reaction might be stronger for $PM_{REPEATED}$ trials than for oddball trials because $PM_{REPEATED}$ trials were more familiar to the participants (cf. Scullin et al., 2011).

To exclude that the increased RTs for $PM_{REPEATED}$ trials compared to oddball trials were merely due to differences in the strength of the orientation reaction to repeated and novel deviations, we not only repeated PM cues from one block to the next in Experiment 2 but also included repetitions of previous oddball items (so-called $oddball_{REPEATED}$ trials). If increased RTs on $PM_{REPEATED}$ trials compared to oddball trials in Experiment 1 were due only to differences in the orienting response, there should be no reliable RT difference between $PM_{REPEATED}$ trials and $oddball_{REPEATED}$ trials.

Method

Participants. Twelve students of the Technische Universität Dresden (6 male; age $M = 22.17$ years, $SD = 2.76$, range 18–27 years) who had not participated in Experiment 1 took part in Experiment 2. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. In Experiment 2, 16 different features were used to define PM cues and oddballs. In addition to the formats used in Experiment 1, digits could appear in big font size (120 pixels/visual angle ~ 3.36°).

Procedure and design. The procedure of Experiment 2 was the same as in Experiment 1 except for the following changes. In contrast to Experiment 1, in Experiment 2 oddball trials were additionally interspersed in the first trial block. Furthermore, in each block two to eight oddball trials from the preceding block were repeated (i.e., $\text{oddball}_{\text{REPEATED}}$ trials). The first block contained 196 standard trials, six PM trials, and six oddball trials. Each of the following blocks contained 184 standard trials, six PM trials, six $\text{PM}_{\text{REPEATED}}$ trials, six oddball trials, and six $\text{oddball}_{\text{REPEATED}}$ trials.

Results

The first block of trials was excluded prior to analyses because it did not contain $\text{PM}_{\text{REPEATED}}$ trials. For the remaining blocks, error trials (5.9%) were excluded. RTs exceeding the outlier criterion (+/−2.5 *SD* per participant and condition mean; 2.9% of trials) were excluded from the analyses. A repeated-measurements ANOVA with the factor trial type (standard, $\text{PM}_{\text{REPEATED}}$, $\text{oddball}_{\text{REPEATED}}$, oddball) was conducted on RTs and error data of the ongoing task (see Figure 3).

RTs. The ANOVA yielded a highly reliable effect of trial type, $F(3, 33) = 43.51$, $p < .001$, $\eta^2 = .79$. Planned contrasts revealed that participants' RTs were faster on standard trials ($M = 594$ ms, $SD = 77$ ms) than on oddball trials ($M = 747$ ms, $SD = 150$ ms), $F(1, 11) = 33.97$, $p < .001$, $\eta^2 = .76$. As in Experiment 1, we found evidence for persisting intention activation, indicated by slower RTs on $\text{PM}_{\text{REPEATED}}$ trials ($M = 887$ ms, $SD = 144$ ms) than on oddball trials, $F(1, 11) = 21.31$, $p = .001$, $\eta^2 = .66$. The most important contrast showed that responses to $\text{oddball}_{\text{REPEATED}}$ trials ($M = 698$ ms, $SD = 135$ ms) were faster than responses to $\text{PM}_{\text{REPEATED}}$ trials, $F(1, 11) = 34.03$, $p < .001$, $\eta^2 = .76$.

As in Experiment 1, a subsequent ANOVA on oddball and $\text{PM}_{\text{REPEATED}}$ trials revealed only that aftereffects were again strongest in the first compared to the second half of the experimental block, $F(1, 11) = 14.50$, $p = .003$, $\eta^2 = .57$. Yet, at neither time point did aftereffects decrease completely, as significant aftereffects of 190 ms ($SD = 123$ ms; $\text{PM}_{\text{REPEATED}}$ trials: $M = 974$ ms, $SD = 141$ ms; oddball trials: $M = 784$ ms, $SD = 166$ ms), $t(11) = 5.37$, $p < .001$, $d = 1.23$, and 94 ms ($SD = 108$ ms; $\text{PM}_{\text{REPEATED}}$ trials: $M = 805$ ms, $SD = 158$ ms; oddball trials: $M = 711$ ms, $SD = 146$ ms), $t(11) = 3.01$, $p = .012$, $d = 0.62$, were found in the first and second parts of the experimental block.

Errors. The ANOVA for error rates did not yield a reliable main effect of trial type, $F(3, 33) = 1.72$, $p = .196$, $\eta^2 = .14$. Also, the rate of false alarms (i.e., erroneously executed the PM response) differed only numerically between $\text{PM}_{\text{REPEATED}}$ trials (2.8%) and oddball trials (1.4%), $t(11) = 1.20$, $p = .253$, $d = 0.54$, and $\text{oddball}_{\text{REPEATED}}$ trials (0.8%) and oddball trials, $t(11) = -0.71$, $p = .491$, $d = -0.32$. Error aftereffects did not vary as a function of within-block position (*p*s > .25).

Discussion

The results of Experiment 2 closely replicated those of Experiment 1. First, participants responded more slowly on trials associated with a completed intention than on control (oddball) trials. Second, the slowing on $\text{PM}_{\text{REPEATED}}$ trials compared to oddball trials decreased as a function of within-block position. Most important, however, for the aim of Experiment 2, participants responded faster on $\text{oddball}_{\text{REPEATED}}$ trials than on $\text{PM}_{\text{REPEATED}}$ trials. This finding in particular clearly rules out the hypothesis that prolonged RTs on $\text{PM}_{\text{REPEATED}}$ trials were simply due to an increased orientation reaction to repeated deviant stimuli.

In Experiments 3 and 4 we moved away from using $\text{oddball}_{\text{REPEATED}}$ trials in order to decrease the ratio of deviant stimuli to standard stimuli to a level comparable to that in Experiment 1. In addition, the results of Experiment 2 revealed RT benefits on $\text{oddball}_{\text{REPEATED}}$ trials not only in comparison to $\text{PM}_{\text{REPEATED}}$ trials but also to regular oddball trials (as also used in Experiment 1). Therefore, for our purpose, the comparison of $\text{PM}_{\text{REPEATED}}$ trials with regular oddball trials reflects the more conservative measure of aftereffects of completed intentions.

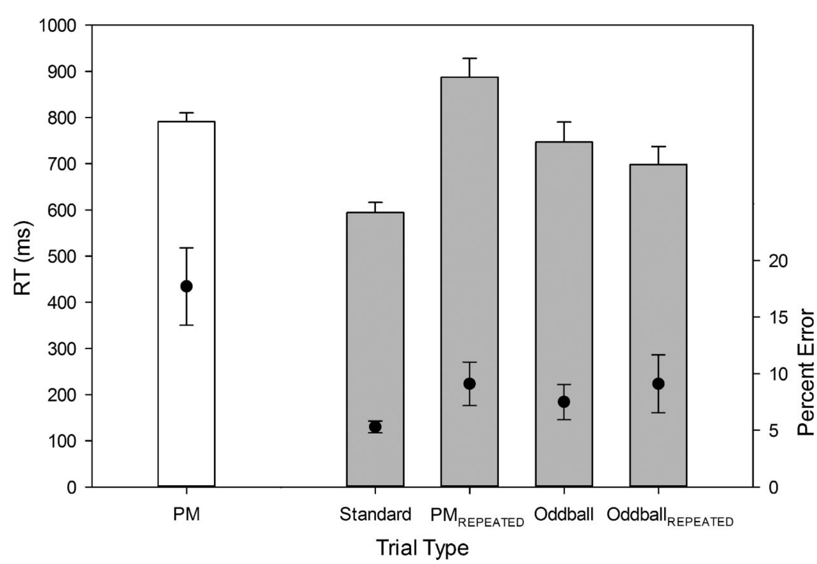

Figure 3. Mean response time (RT) and percent error as a function of trial type (prospective memory [PM], standard, $\text{PM}_{\text{REPEATED}}$, oddball, $\text{oddball}_{\text{REPEATED}}$) in Experiment 2. Error bars represent standard errors.

Experiment 3

Although Experiments 1 and 2 provided evidence for aftereffects of completed intentions that seem to hint toward elevated intention-related activation levels, both experiments required the performance of a new intention simultaneously with the ongoing primary task. Therefore, we conducted a third experiment to investigate whether aftereffects of completed intentions as in Experiment 1 could also be observed in conditions in which participants were not required to perform a new intention in parallel. To this end, we implemented blocks in Experiment 3 that did not contain any PM tasks and thus did not contain any intention to respond on deviant stimulus features (*ongoing-task-only* condition). The finding of aftereffects of completed intentions in ongoing-task-only conditions can rule out an alternative assumption that explains increased RT levels to $\mathrm{PM}_{\mathrm{REPEATED}}$ trials in Experiment 1 as a consequence of other simultaneous intentions also requiring responses to prespecified deviant stimuli.

In Experiment 3 we further aimed to compare potential aftereffects obtained in conditions without additional PM task performance with conditions of aftereffects observed when an additional PM task accompanied the ongoing task. This was realized in a between-experiment comparison (Experiments 1 and 3), because, obviously, a within-experiment comparison was not possible. The alternating presentation of PM-task blocks (including a PM task) and ongoing-task-only blocks (including $\mathrm{PM}_{\mathrm{REPEATED}}$ trials but no PM task) in Experiment 3 excluded the possibility of $\mathrm{PM}_{\mathrm{REPEATED}}$ trials in the PM-task blocks.

In addition, the inclusion of ongoing-task-only blocks in Experiment 3 provided the possibility of investigating more specifically which mechanisms might have contributed to the present pattern of aftereffects of completed intentions. In particular, we were interested in how monitoring processes might contribute to aftereffects of completed intentions in our experimental design.

The preparatory attentional and memory processes (PAM) theory, for example, holds that successful PM retrieval entails resource-demanding processes to monitor whether the PM cue is present; if so, the PM response can be executed (Smith, 2003; Smith & Bayen, 2004; Smith, Hunt, McVay, & McConnell, 2007). Depending on several criteria, in the multiprocess view on the other hand, PM retrieval may also occur without additional cognitive resources (McDaniel & Einstein, 2000, 2007). In the context of our Experiment 3, we were able to test whether capacity-demanding preparatory attentional processes were involved in PM retrieval by comparing the performance in the ongoing task in conditions with and without the embedded event-based PM task. Costs for preparatory attentional processes would be reflected in increased RTs and/or error rates in ongoing tasks including an additional PM-task compared to ongoing-task-only conditions (Smith, 2003). One might hypothesize that monitoring for PM cues might increase their activation level, resulting in increased aftereffects as compared to those in conditions in which no monitoring is required. Accordingly, Scullin et al. (2009, 2011) did not find evidence for monitoring processes, which might have contributed to their null findings of aftereffects of completed intentions in young adults.

Method

Participants. Twelve students of the Technische Universität Dresden (6 male; age M = 24.42 years, SD = 2.58, range 21–29 years) who had not participated in Experiments 1 and 2 took part in Experiment 3. All participants reported normal or corrected-to-normal vision.

Procedure and design. The procedure of Experiment 3 was identical to that in Experiment 1 with the following exceptions. Here, in contrast to Experiments 1 and 2, participants performed only the PM task in Blocks 1, 3, 5, and 7 (PM-task condition), whereas they performed only the ongoing digit categorization task (ongoing-task-only condition) in Blocks 2, 4, 6, and 8.

Results

For the main aim of Experiment 3 we report the results for the even-numbered blocks, which represent the ongoing-task-only condition. Error trials (4.7%) as well as RTs that exceeded the outlier criterion (+/−2.5 SD per participant and condition mean; 2.9%) were excluded from the RT analyses. A repeated-measurements ANOVA with the factor trial type (standard, $\mathrm{PM}_{\mathrm{REPEATED}}$, oddball) was conducted on RTs and error data of the ongoing task (see Figure 4).

RTs. The ANOVA yielded a highly reliable effect of trial type, $F(2, 22) = 17.16$, $p < .001$, $\eta^2 = .61$. Planned contrasts showed that RTs were faster on standard trials (M = 530 ms, SD = 77 ms) than on oddball trials (M = 606 ms, SD = 153 ms), $F(1, 11) = 9.82$, $p = .010$, $\eta^2 = .47$. Most important, responses to $\mathrm{PM}_{\mathrm{REPEATED}}$ trials (M = 653 ms, SD = 151 ms) were significantly slower than responses to oddball trials, $F(1, 11) = 8.65$, $p = .013$, $\eta^2 = .44$.

Because participants had to perform the PM task on every second block of trials, one could argue that once participants realized that PM-task blocks and ongoing-task-only blocks alternated (i.e., from Block 3 on), attention might be specifically directed toward deviant stimulus features. This may have caused RT prolongations on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials, as in Experiment 1. To exclude this possibility, we repeated the ANOVA exclusively for the first ongoing-task-only block (i.e., Block 2) and found confirming evidence that participants responded significantly more slowly on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials (M = 728 ms, SD = 255 ms) than on oddball trials (M = 655 ms, SD = 214 ms), $F(1, 11) = 7.47$, $p = .019$, $\eta^2 = .40$.

An additional ANOVA revealed that the observed aftereffects of completed intentions were again larger in the first than the second half of the experimental block, $F(1, 11) = 7.60$, $p = .019$, $\eta^2 = .41$. Aftereffects were detected in the first half (M = 84 ms, SD = 71 ms; $\mathrm{PM}_{\mathrm{REPEATED}}$ trials: M = 696 ms, SD = 165 ms; oddball trials: M = 612 ms, SD = 148 ms), $t(11) = 4.14$, $p = .002$, d = 0.54, but were not significant in the second half of the experimental block (M = 15 ms, SD = 72 ms; $\mathrm{PM}_{\mathrm{REPEATED}}$ trials: M = 613 ms, SD = 143 ms; oddball trials: M = 598 ms, SD = 167 ms), $t(11) = 0.71$, $p = .495$, $d = 0.10$.

To test whether cognitive resources were required for performing the PM task additionally to the ongoing task, we compared RTs on standard trials in ongoing-task-only blocks with those in PM-task blocks. For this analysis we excluded three trials following PM trials, $\mathrm{PM}_{\mathrm{REPEATED}}$ trials, and oddball trials to ensure that

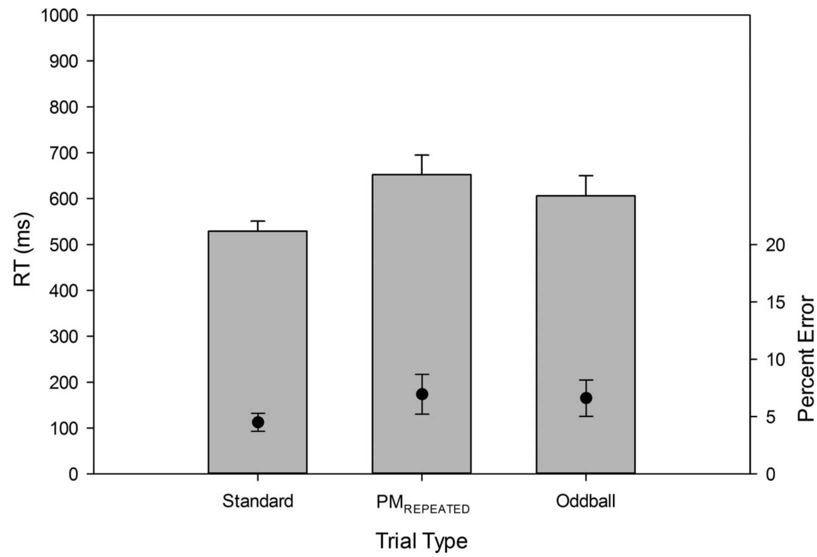

Figure 4. Mean response time (RT) and percent error of no-monitoring blocks (2, 4, 6, 8) as a function of trial type (standard, $PM_{REPEATED}$, oddball) in Experiment 3. Error bars represent standard errors. PM = prospective memory.

putative costs in the PM-task condition were not related to resources required for switching attention between the PM trials and standard trials (for a similar analysis, see Smith, 2010). RTs on standard trials were significantly increased in the PM-task condition (i.e., Blocks 3, 5, 7; $M = 564$ ms, $SD = 102$ ms) as compared to the ongoing-task-only condition (i.e., Blocks 2, 4, 6, 8; $M = 527$ ms, $SD = 75$ ms), $t(11) = 3.74$, $p = .003$, $d = 0.42$.

Errors. The ANOVA for error rates did not yield a reliable main effect of trial type ($F < 1$). Yet, $PM_{REPEATED}$ trials produced slightly more (1.1%) false alarms (i.e., erroneously executed PM responses) than did oddball trials (0%), $t(11) = 1.92$, $p = .042$ (one-sided), $d = 0.78$. Error rates to $PM_{REPEATED}$ trials were not different for the first and second halves of the experimental block, $F(1, 11) = 3.01$, $p = .111$, $\eta^2 = .21$.

Further, in addition to RT costs associated with the PM task we observed similar error rate costs. This was indicated by a higher error rate on standard trials in PM-task blocks ($M = 5.4\%$) than on ongoing-task-only blocks ($M = 4.5\%$), $t(11) = 3.24$, $p = .008$, $d = 0.34$.

Between-experiment comparison. We computed a 2 × 2 repeated-measurements ANOVA on RTs with experiment (Experiment 1, Experiment 3, ongoing-task-only blocks) as between-subjects factor and trial type ($PM_{REPEATED}$, oddball) as within-subject factor. The ANOVA yielded a significant main effect of experiment, $F(1, 22) = 7.35$, $p = .013$, $\eta^2 = .25$, and of trial type, $F(1, 22) = 45.59$, $p < .001$, $\eta^2 = .67$. Most important, the Experiment × Trial Type interaction was significant, $F(1, 22) = 9.37$, $p = .006$, $\eta^2 = .30$, which indicates that the difference between $PM_{REPEATED}$ trials and oddball trials was smaller in Experiment 3 (47 ms) than in Experiment 1 (126 ms). A similar ANOVA for error rates did not reveal differences in error rates between experiments (Fs < 1).[2]

Furthermore, we tested whether the decline of aftereffects across experimental blocks differed between conditions including a new PM task to be performed (Experiment 1) and conditions without an additional PM task (Experiment 3). Results showed that the decline between differences between the first three encounters and the last three encounters of $PM_{REPEATED}$ trials and oddball trials, respectively, did not vary between Experiment 1 (88 ms) and Experiment 3 (70 ms), $t(22) = 0.51$, $p = .618$, $d = 0.21$.

Discussion

The findings of Experiment 3 replicated and extended those of Experiments 1 and 2. Most important, the observation of slowed responses on $PM_{REPEATED}$ trials compared to oddball trials in blocks without the intention to respond to any deviant stimuli suggests that this effect cannot entirely be attributed to the continuing presence of the PM task and, thus, a general intention to direct attention to deviant stimulus features. However, at the same time, the aftereffect of the completed intention was significantly smaller in ongoing-task-only conditions (Experiment 3) than in PM-task conditions (Experiment 1). Nevertheless, completed intentions seem to maintain a state of heightened activation even when deviant items become completely irrelevant for task processing. This state of heightened activation, however, was much larger in the first than the second half of the experimental block. The fact that the reduction of aftereffects from the first to the second half of the block did not differ between Experiment 3 and Experiment 1 suggests that a superordinate PM intention does not modulate the

[2] One might argue, though, that different aftereffects in Experiments 1 and 3 might have been at least partly due to faster RTs on oddball trials in Experiment 3 than in Experiment 1. In order to rule out that the different aftereffects were due to the lower baseline in Experiment 3, we conducted a more conservative test. An additional t test on the RT ratio between $PM_{REPEATED}$ trials and oddball trials in Experiment 1 and 3 (ongoing-task-only blocks) yielded significance, $t(22) = 2.31$, $p = .031$, $d = 0.94$, and therefore confirmed that aftereffects were increased in Experiment 1 as compared to Experiment 3.

time course of the persistence but more so the initial level of activation after intention completion (for further discussion, see the General Discussion).

With conservative testing (Smith, 2010), results of Experiment 3 revealed also a higher RT level (and error rates) for standard trials when an additional PM task was included than with mere ongoing task performance without an additional PM task. Thus, the obtained performance costs on the ongoing task due to the additional PM task may be interpreted in line with the PAM theory and assumptions of a resource-demanding process associated with PM cue retrieval (see Smith, 2010; Smith et al., 2007). At the same time, though, it should be mentioned that our study did not focus on a systematic investigation of costs specifically associated with the retrieval of PM cues. Therefore, it seems inappropriate to refute spontaneous (resource-independent) retrieval mechanisms as proposed by the multiprocess view, because, for example, our data do not allow us to specify whether the observed costs are directly related to PM-cue retrieval or whether they reflect unspecific multitasking coordination costs (for a critical review of ongoing-task costs as indicators of preparatory attentional processing, see Einstein & McDaniel, 2010).

Experiment 4

A central feature of our PM task paradigm is that participants are required to detect prespecified stimulus features and to perform a designated action in response to the occurrence of those features. In the subsequent block the repetition of those (then irrelevant) features led to a substantial RT slowing, which we interpreted as evidence for residual activation of completed intentions. However, one could argue that the observed effects do not provide evidence for a failure to immediately deactivate completed intentions but instead may reflect the acquisition of direct stimulus–response (S-R) links between specific PM cues and the PM task response. Given that each response to a PM cue results in sensorimotor learning and the integration of stimulus and response features into a shared episode or S-R link (e.g., Abrams & Greenwald, 2000; Hommel, 1998; Hommel & Colzato, 2004; Kiesel, Wendt, & Peters, 2007; Logan, 1988; Neumann & Klotz, 1994; Wendt & Kiesel, 2008), the presentation of a PM cue after intention completion may lead to the automatic retrieval of the S-R episode and thus primes previously associated responses (Waszak & Hommel, 2007). This should lead to increased RTs in the ongoing task, even if the corresponding intention has already been deactivated.

In order to eliminate the possibility that our finding of increased RTs on $\text{PM}_{\text{REPEATED}}$ trials merely reflects an effect of acquired associations between specific stimulus features and the PM response (rather than persisting intention activation), we included in Experiment 4 an additional set of PM cues, for which the formation of specific S-R links appears unlikely. In odd-numbered blocks, participants were required to perform the PM task on instances of an abstract stimulus *category* as PM cues (e.g., rotated digits). Importantly, only one of two possible category members (e.g., rotated to the left) actually appeared as a PM cue. Performing the PM task might result in the formation of a direct S-R link between this specific stimulus feature and the associated motor response. As participants, however, never performed the PM response to the second category member (e.g., digits rotated to the right), we can exclude that they formed S-R links between the never presented stimulus feature and the PM response. The intention induced by the PM instruction does, however, include both category instances as PM cues. In the subsequent (even-numbered) block, participants were instructed to respond to specific PM cues as in Experiments 1 and 2, and the repeated PM cue consisted of the PM category member that had not been presented in the previous odd-numbered block. This repeated PM cue matched the intention but had never been associated with the PM response ($\text{PM}_{\text{REPEATED-CATEGORY}}$ trials).

If increased RTs on $\text{PM}_{\text{REPEATED}}$ trials compared to oddball trials in Experiments 1, 2, and 3 were not due to residual activation levels but instead reflected automatic retrieval of acquired S-R links, $\text{PM}_{\text{REPEATED-CATEGORY}}$ trials should cause at best an orientation reaction, indicated by similar RTs as on oddball trials. To the contrary, if prolonged RTs on $\text{PM}_{\text{REPEATED}}$ trials compared to oddball trials in the previous experiments were due to residual activation of completed intentions, RTs on $\text{PM}_{\text{REPEATED-CATEGORY}}$ trials should significantly exceed RTs on oddball trials.

Method

Participants. A new sample of 12 students of the Technische Universität Dresden took part in Experiment 4. Because one participant did not comply with the instructions, data were replaced by retesting an additional person (final sample: 5 male; age M = 22.83 years, SD = 3.33, range 19–28 years). All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. The methods of Experiment 4 were the same as those of Experiment 1 except from the following changes. As categorical PM instructions were used in half of the trial blocks, pairs of exemplar PM cues were selected that represented members of a category. Categorical PM cues were displayed in a font color differing from black (green vs. red), rotated (to the left vs. to the right), in different font sizes (40 pixels vs. 120 pixels), or in different font types (Algerian vs. Tempus Sans ITC). For the remaining PM trials, $\text{PM}_{\text{REPEATED}}$ trials, and oddball trials we used stimuli from the stimulus set described in Experiment 1.

Procedure and design. In contrast to Experiment 1, for Blocks 1, 3, 5, and 7 participants received a categorical PM task instruction, which required them to press the space bar in response to a particular stimulus category (i.e., rotated digits, digits in different font colors, font sizes, or typeface). The PM cue category changed from block to block. No PM cue was shown as an example during the category PM task instruction. Importantly, in each block only one exemplar stimulus from the given PM cue category actually appeared as the PM cue (e.g., digits rotated to the left).

In the even-numbered blocks, 2, 4, 6, and 8, an exemplar instruction was given for the PM task, as in Experiments 1 and 2. In these blocks, the exemplar stimulus feature of the previous PM cue category that had not been presented in the previous block (e.g., digits rotated to the right) now served as the repeated category PM cue ($\text{PM}_{\text{REPEATED-CATEGORY}}$ trials). We counterbalanced across participants which of both exemplar stimulus features of a particular stimulus category was shown as PM cues and as $\text{PM}_{\text{REPEATED-CATEGORY}}$ cues.

The experiment consisted of eight experimental blocks each comprising 208 trials. The first block contained 202 standard trials and six PM trials. Blocks 2, 4, 6, and 8 contained 190 standard trials, six PM trials, six $PM_{REPEATED\text{-}CATEGORY}$ trials, and six oddball trials. Blocks 3, 5, and 7 contained 190 standard trials, six PM trials, six $PM_{REPEATED}$ trials, and six oddball trials.

Results

We focus on the results from the even-numbered blocks to assess the aftereffects of completed intentions on $PM_{REPEATED\text{-}CATEGORY}$ trials. Error trials (4.4%) as well as RTs that exceeded the outlier criterion (+/−2.5 *SD* per participant and condition mean; 2.9%) were excluded from the RT analyses. A repeated-measurements ANOVA with the factor trial type (standard, $PM_{REPEATED\text{-}CATEGORY}$, oddball) was conducted on RTs and error data of the ongoing task. Results of the even-numbered blocks are presented in Figure 5.

RTs. The ANOVA yielded a highly reliable effect of the trial type, $F(2, 22) = 77.06$, $p < .001$, $\eta^2 = .88$. Planned contrasts revealed that participants' RTs were faster on standard trials (M = 552 ms, SD = 96 ms) than on oddball trials (M = 722 ms, SD = 139 ms), $F(1, 11) = 54.41$, $p < .001$, $\eta^2 = .83$. Most important, responses to $PM_{REPEATED\text{-}CATEGORY}$ trials (M = 793 ms, SD = 130 ms) were significantly slower than responses to oddball trials, $F(1, 11) = 14.67$, $p = .003$, $\eta^2 = .57$.

As in Experiment 3, aftereffects of completed intentions were observed only in the first half of the experimental block (M = 110 ms, SD = 141 ms; $PM_{REPEATED}$ trials: M = 868 ms, SD = 162 ms; oddball trials: M = 758 ms, SD = 177 ms), $t(11) = 2.71$, p = .020, d = 0.64, and not in the second half (M = −7 ms, SD = 60 ms; $PM_{REPEATED}$ trials: M = 683 ms, SD = 118 ms; oddball trials: M = 690 ms, SD = 115 ms), $t(11) = -0.42$, p = .680, d = −0.07, resulting in a significant Trial Type × Position interaction, $F(1, 11) = 6.38$, $p = .028$, $\eta^2 = .37$.

Aftereffects on $PM_{REPEATED\text{-}CATEGORY}$ vs. $PM_{REPEATED}$ trials. To compare aftereffects of completed intentions on $PM_{REPEATED\text{-}CATEGORY}$ trials in even-numbered blocks with $PM_{REPEATED}$ trials in odd-numbered blocks, we computed a 2 × 2 repeated-measurements ANOVA on RTs with the factors block (even-numbered, odd-numbered) and trial type ($PM_{REPEATED\text{-}CATEGORY}$/$PM_{REPEATED}$, oddballs).

Most important, the slowing for repeated PM trials compared to oddball trials was similar for $PM_{REPEATED\text{-}CATEGORY}$ cues (71 ms) and $PM_{REPEATED}$ cues (67 ms), as the Block × Trial Type interaction was far from significance ($F < 1$). Further, responses were slightly faster on even-numbered blocks ($PM_{REPEATED\text{-}CATEGORY}$ trials) than on odd-numbered blocks ($PM_{REPEATED}$ trials), which was indicated by a main effect of blocks that slightly missed significance, $F(1, 11) = 4.79$, $p = .051$, $\eta^2 = .30$.

Errors. The ANOVA for error rates did not yield a reliable main effect of trial type ($F < 1$). Error rates to $PM_{REPEATED}$ trials were not different for the first and second halves of the experimental block, $F(1, 11) = 1.15$, $p = .306$, $\eta^2 = .09$.

Discussion

The findings of Experiment 4 replicated those of Experiments 1 to 3. Although we used a categorical PM instruction in half of the blocks, $PM_{REPEATED\text{-}CATEGORY}$ trials that matched the intention but had never been associated with the execution of a specific PM response nevertheless produced significantly larger RTs than oddball trials. These aftereffects on $PM_{REPEATED\text{-}CATEGORY}$ trials did not differ from aftereffects on $PM_{REPEATED}$ trials. Consequently, the RT increase on $PM_{REPEATED}$ trials found in previous experiments cannot be accounted for exclusively by the stimulus-

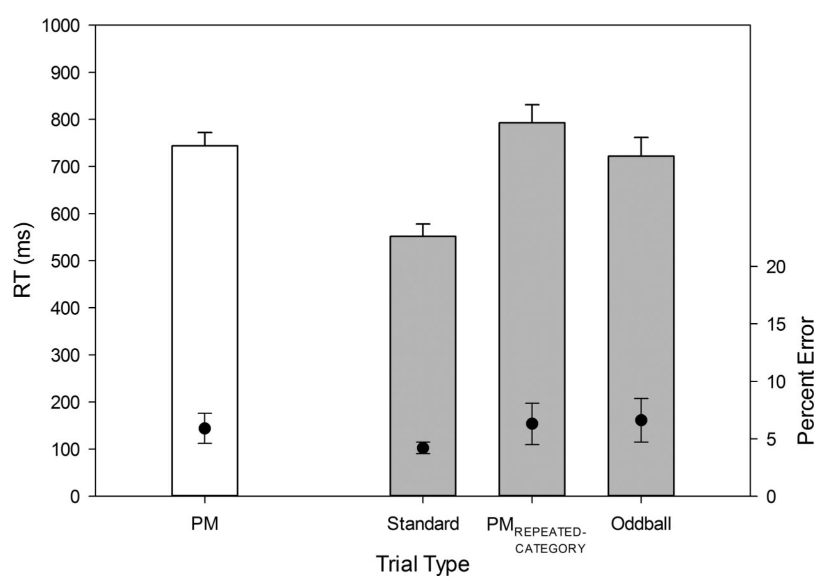

Figure 5. Mean response time (RT) and percent error of blocks with categorical repeated PM cues (i.e., Blocks 2, 4, 6, 8) as a function of trial type (prospective memory [PM], standard, $PM_{REPEATED\text{-}CATEGORY}$, oddball) in Experiment 4. Error bars represent standard errors.

triggered retrieval of specific S-R links that were formed during intention execution (see the General Discussion for a more detailed discussion of this point).

General Discussion

Our aim in the present study was to investigate aftereffects of completed intentions on subsequent performance in a task context that required the maintenance and execution of new intentions. Therefore we developed a novel experimental paradigm, which we termed the repeated PM cue paradigm, that allowed us to assess aftereffects of completed intentions by comparing RTs on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials with baseline RTs on oddball trials. We hypothesized that completed intentions might be inhibited, might be deactivated, or might remain in a state of heightened activation, which would result in performance benefits, equal performance, or performance costs on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials compared to oddball trials, respectively.

Across four experiments, the results were clear cut in demonstrating increased RTs on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials compared to oddball trials. The presentation of cues associated with completed intentions triggered the (now incorrect) PM response, which interfered with the execution of the correct ongoing task response. We interpret these performance costs as a failure of deactivation of completed intentions. That is, even after completion, previous intentions may remain in a residual heightened activation (but see below for alternative conceptions).

Several alternative explanations for the repeated PM cue effect could be rejected. First, in Experiment 2 we ruled out that increased RTs on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials were due to a familiarity-based increased orientation reaction to $\mathrm{PM}_{\mathrm{REPEATED}}$ trials compared to oddball trials. Second, in Experiment 3 we investigated aftereffects of completed intentions in a condition without a new PM task. Although deviant stimulus features were irrelevant for performing the ongoing-task-only condition, participants nevertheless responded significantly more slowly on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials than on oddball trials. Third, in Experiment 4 we showed that increased RTs on $\mathrm{PM}_{\mathrm{REPEATED}}$ trials did not merely reflect the acquisition of visuomotor S-R links between specific PM cues and the PM response. Instead, RTs were reliably increased when exemplars of an abstract PM cue category related to a completed intention were presented, even if the specific exemplar stimuli had never been associated with the execution of the PM response (Fischer, Plessow, & Kiesel, 2011). This shows that the RT increase elicited by repeated PM cues was not due to episodic retrieval of specific S-R links but most likely reflected the residual activation of the completed intention at a more abstract level of representation.

Our findings extend previous knowledge by showing that not only the retrospective component of PM (Cohen et al., 2005; Penningroth, 2011) but also the prospective component of PM may remain activated immediately after intention completion. That is, our study was based on the same logic as previous studies focusing on the prospective component of PM (Einstein et al., 2005; Knight et al., 2011; Scullin et al., 2009, 2011; West et al., 2007). Participants responded to specific PM cues and, after the PM task had been completed, canceled, or suspended, these PM cues were interleaved in an ongoing task. Prolonged RTs on trials containing irrelevant PM cues were interpreted as evidence for residual activation or spontaneous retrieval of the PM response. Yet, in contrast to our study, Scullin et al. (2009) did not find increased RTs to repeated PM cues in the completed intention condition, which raises the question of the nature of these seemingly conflicting outcomes. Several possibilities are conceivable.

First, the finding of decreasing aftereffects within the experimental block indicates that aftereffects of completed intentions might be sensitive to the delay between PM task and the measurement of aftereffects. That is, aftereffects of completed intentions might be easier to detect in short intervals (e.g., West et al., 2007) than in longer intervals (Scullin et al., 2009, 2011; see below for further discussion).

Second, the extent in which completed intentions reveal aftereffects might directly depend on the activation level of the intention in the preceding PM task. It thus seems plausible that the stronger the intention (and/or its activation), the more pronounced the aftereffects in the subsequent task. Such a view is consistent with the influential PAM theory, which assumes that PM retrieval is realized by a resource-demanding preparatory attentional process (Smith, 2003; Smith et al., 2007). In this context, a strong engagement in a preparatory attentional process to perform the PM task might, as a direct consequence, result in aftereffects. In the PAM theory, the preparatory attentional process is measured as performance costs in the ongoing task due to an additional PM task (as compared to performance in an ongoing task without a PM task). To our knowledge, Scullin et al. (2009, 2011) did not report evidence of an attentional process in the PM task and did not find aftereffects of completed intentions. In our study, however, Experiment 3 allowed us to test for PM-related performance costs. Despite rather salient cues (which generally favor automatic PM retrieval), the additional PM task decreased performance in the primary ongoing task, as reflected in higher RTs and error rates.[3] Thus, it is conceivable that the involvement of the preparatory attentional process is directly linked to the subsequent observation of aftereffects of completed intentions. A strong engagement in monitoring, for example, may deepen the link between PM cue features and the associated intention. Therefore, the stronger the monitoring, the larger the subsequent aftereffects for completed intentions that are linked to repeated (irrelevant) PM cue features. At the present state, PAM does not say by which mechanisms aftereffects of completed intentions may arise. Also, our study did not contain a sufficient sample size and was not designed to pursue this question in full detail. Therefore, subsequent research is clearly needed to elaborate on the relationship between the engagement of a preparatory attentional process and subsequent aftereffects of completed intentions.

[3] These findings may be due to methodological differences. In the Scullin et al. (2009, 2011) studies, participants were not forced to monitor for the occurrence of PM cues, because they did not receive negative feedback when they missed a PM cue. In contrast, in the present study participants received error feedback when performing the ongoing task response on PM trials. This might have caused them to constantly monitor for the occurrence of relevant PM cues. We thank Mark McDaniel for highlighting this point.

Aftereffect of Completed Intentions: Residual Activation or Cue-Based Reactivation

So far, the evidence of aftereffects of completed intentions in the present study has been consistently interpreted as a measure of residual heightened activation of the completed intention. We argued that a complete deactivation of a finished intention should not reveal aftereffects in subsequent performance. Slowed responses to repeated and irrelevant PM cues, on the other hand, demonstrate that at least some aspects of the completed intention are still active and interfere with performance in the ongoing task. The heightened activation of the intention to respond with the PM response (i.e., space bar) to the irrelevant repeated PM cue results in the activation of two competing responses: the incorrect former PM response and the correct current ongoing task response. The assumption of residual heightened activation of the former intention is supported by the finding that aftereffects were more pronounced in the first half of the experimental block and were reduced or even diminished in the second half of the experimental block. Therefore, it is tempting to take this result as evidence for a rather passive decay of residual activation that fades out with increasing temporal distance to the time point of former intention completion. This decay assumption may also explain the differences from Scullin et al. (2009), where aftereffects were not found in similar conditions. Thus, it is conceivable that even the short-delay condition in the Scullin et al. (2009, 2011) studies was too long to catch any aftereffects. To the contrary, the delay in the West et al. (2007) study might have been short enough to reveal an effect similar to that found in the present study. However, in their “forget” condition West et al. presented only one canceled PM cue, which interfered with the ongoing task. Adding more PM cues might have yielded a decline pattern similar to that observed in our study.

It should be noted, however, that our preferred assumption of residual activation of completed intentions is by no means the only explanation of our findings. The influential multiprocess view of PM performance (McDaniel & Einstein, 2000, 2007), for example, would not assume that a completed intention necessarily remains in a state of heightened activation. Instead, aftereffects of completed intentions are assumed to reflect spontaneous repeated PM cue-based reactivation of the former intention associated with the repeated PM cue stimulus. The multiprocess view proposes two mechanisms enabling spontaneous retrieval of features and intentions that are associated (McDaniel & Einstein, 2007). A noticing plus search process assumes that when a deviant stimulus is encountered, processing fluency will be interrupted and will automatically trigger a search in memory for the relevance or irrelevance of that stimulus. Indeed, the salient features of oddballs and repeated PM trials might trigger this orienting response (attentional capture) and thus increase RTs compared to standard trials. A second, reflexive associative process triggers the automatic retrieval of associated features of the encountered stimulus. That is, in case of the repeated PM cue, the formerly relevant associated PM response might be reflexively reactivated and thus slow performance even further. No such reflexive associative process would be active during oddball trials.

In Experiment 4, the finding of aftereffects of completed intentions (despite the absence of stimulus exemplars linked with the previous PM response) excludes an explanation of aftereffects based on stimulus-triggered retrieval of *specific* S-R links that were established during previous intention execution. In terms of multiprocess theory, however, it is still possible that the specific exemplar of a repeated PM cue, which has no direct S-R links to the previous intention ($\text{PM}_{\text{REPEATED-CATEGORY}}$), may nevertheless trigger automatic retrieval processes with respect to a more generic target event (e.g., activating the category to which the exemplar belongs).

Results of Experiment 1–4 suggest, however, that this cue-triggered activation is contingent upon the number of encounters in the new situation as the aftereffects of completed intentions decreased throughout the block. Therefore, in terms of multiprocess theory, decreasing aftereffects of completed intentions throughout the block of testing might result from cue effectiveness washing out with increasing number of cue encounters. In different words, the repeated exposure of $\text{PM}_{\text{REPEATED}}$ trials along with the absence of performing the related PM response may extinguish the aftereffects. In this respect, future research may manipulate the time line between PM task performance and measurement of aftereffects to potentially differentiate between residual activation of completed intention and cue effectiveness upon encounter, respectively.

Cue effectiveness may also depend on the context similarity between PM task performance and measurement of aftereffects of completed intentions. That is, arguing against cue-based retrieval, a lack of aftereffects in Scullin et al. (2009, 2011) might be caused by task-context changes between PM task and measurement of aftereffects, which may render cues less effective in triggering retrieval processes.

Although the outlined mechanism as proposed in the multiprocess theory may also account for the present findings, it is, at least in our opinion, an open question whether these mechanisms necessarily refute the claim of residual heightened activation of the completed intention. On speculative terms, one could go further and ask whether the heightened level of residual activation of an intention may increase the likelihood and efficiency of the cue-triggered retrieval of the intention representation. For example, it remains unclear whether decreasing aftereffects of completed intentions throughout the block of testing are cue related (e.g., reduced cue effectiveness with increasing number of cue encounters). Alternatively, cue effectiveness may remain intact, but the former intention (or intention-related features) may be harder to activate because the residual activation level of the former intention is subject to decay after intention completion. Pushing this argument even further, the automatic memory retrieval process triggered by the cue stimulus may be contingent upon a residually heightened activation level of the former intention. Such assumptions of contingent “automaticity” are not new and can be found in other research fields, such as visual search (e.g., Folk & Remington, 1999; Folk, Remington, & Johnston, 1992) and nonconscious information processing (Kunde, Kiesel, & Hoffmann, 2003; Neumann & Klotz, 1994). This issue cannot be resolved at the present state but clearly calls for further research along these lines.

Interference of Subsequent Intentions on Aftereffects of Completed Intentions

In real-world situations we rarely perform only one intention in isolation but instead are required to constantly form, maintain, retrieve, and execute several intentions in parallel. A novel aspect of the present study is, therefore, that our repeated PM cue paradigm allowed us to investigate aftereffects of completed intentions while participants had to perform new intentions. This feature extends paradigms that exclusively measure intention deactivation in the absence of the requirement to maintain and execute novel intentions. We aimed to mirror situations in which old and new intentions overlap strongly, as often found in everyday situations. For example, after having invited a friend to your birthday party, you might form the new intention to invite another friend. While holding this intention in PM, you run into the first friend on the street. This encounter might result in a commission error in terms of erroneously inviting the first friend again to your birthday party. Put differently, although the intention to respond to the old prespecified PM cue is completed and now irrelevant, it nevertheless shares the response that is required for the new intention targeted at the new prespecified PM stimulus (i.e., pressing the space bar as response to the currently relevant PM cue). Therefore, it is important to note that in the present study, conclusions with respect to the influence of aftereffects of completed intentions can be validly drawn only with the restriction to the present experimental design of the high degree of intention overlap.

Previous research suggested that aftereffects of completed intentions may in fact depend on whether a new intention has or has not to be performed in parallel and how much elements (PM cues, actions, goals) of completed and to-be-executed intentions do or do not overlap. Several authors noted, for example, that inhibition of completed intentions is functional, as it reduces proactive interference in subsequent tasks (e.g., Förster et al., 2005; Liberman et al., 2007; Mayr & Keele, 2000). However, although this suggests that completed intentions should be inhibited even more strongly when participants are required to execute a new PM task, we found aftereffects of completed intentions not only in conditions that did not require performing a new PM task (Experiment 3) but also when participants had to execute new intentions (Experiments 1, 2, 4).

In fact, aftereffects of completed intentions were even more pronounced in conditions of new PM tasks to be performed (Experiments 1 and 2) than in conditions of the ongoing number categorization task alone (Experiment 3). Thus, it seems that completed intentions are harder to deactivate whenever the subsequent task requires a further monitoring process. Stronger aftereffects in conditions of additional new intention pursuit (Experiment 1 and 2) than in conditions without additional PM task (Experiment 3) might thus be explained, in that the further monitoring in the new intention condition (e.g., preparatory attentional processes) may involve heightened attention to deviant stimuli in general and thus also include now irrelevant repeated PM cues. It is possible that effects of the exogenous alerting property of the deviant stimulus combine with effects of the attentional monitoring process, which in sum result in larger aftereffects than in conditions in which no monitoring process is involved. In particular, in the ongoing-task-only condition of Experiment 3 no preparatory attentional processes were present. Thus, deactivation of the completed intention should be much easier, as reflected in smaller aftereffects by irrelevant repeated PM cues. These aftereffects might reflect more spontaneous retrieval processes elicited by the cue.

From a more general theoretical perspective, in situations in which intentions overlap with respect to their execution conditions or their content, individuals face a dilemma between goal shielding and monitoring (Goschke, in press; Goschke & Dreisbach, 2008). On the one hand they are required to monitor for PM cues signaling that the intended action must be executed. On the other hand, they must shield the current intention from environmental cues that are irrelevant for performing the intended action and may cause interference or trigger unwanted actions. In our repeated PM cue paradigm, participants thus had to balance a trade-off between shielding intentions from task irrelevant information (i.e., cues associated with a completed intention) and at the same time monitoring for relevant information (i.e., PM cues pertaining to the new intention). Therefore, a complete deactivation or inhibition of old PM cues might not have been functional in Experiments 1, 2, and 4, as it might have impaired the detection of PM cues associated with the new intention. A specific prediction that derives from this interpretation is that the likelihood of intention deactivation failures should depend critically on the degree to which completed and novel intentions overlap and require monitoring similar environmental cues. Accordingly, we assume that intention deactivation failures are a relatively direct indication of how individuals balance the trade-off between monitoring and shielding depending on the current task context (Goschke & Dreisbach, 2008).

Our study might inspire future research to study systematically how the deactivation of completed intentions—with respect both to the retrospective and the prospective component—is affected by the requirement to perform new intentions. In particular, investigating how intention deactivation is influenced by the overlap between completed and to-be-performed intentions and how such influences are moderated by individual differences (e.g., with respect to dispositions toward rumination and perseveration) should provide new insights into how the balance between goal shielding and monitoring is regulated.

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