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ABSTRACT
When cued to intentionally forget previously encoded memories, participants typically show reduced recall of the memories on a later recall test. We examined how such directed forgetting is affected by a brief period of wakeful resting between encoding and test. Encoding was followed by a "passive" wakeful resting period in which subjects heard emotionally neutral music or perceived neutral pictures, or it was followed by an "active" distraction period in which subjects were engaged in counting or calculation tasks. Whereas typical directed forgetting was present after active distraction, the forgetting was absent after wakeful resting. The findings indicate that the degree to which people can intentionally forget memories is influenced by the cognitive activity that people engage in shortly after learning takes place. The results provide first evidence on the interplay between wakeful resting and intentional forgetting.

Humans can intentionally forget outdated memories, like a friend's old home address, and make them less retrievable in order to enhance access to more current and relevant information, that is, the friend's current home address. Such updating processes in episodic memory have been examined in the laboratory using the list-method directed forgetting (LMDF) task (e.g., Bjork, 1970). In this task, participants study a list of items and, after study, receive a cue to either forget or continue to remember that list. After study of another list, participants are asked to recall the items on the first list, irrespective of original cuing. Typically, the forget cue impairs recall of the items, relative to the remember cue, reflecting goal-directed forgetting of the obsolete precue information (for a recent review of LMDF, see Sahakyan, Delaney, Foster, & Abushanab, 2013). [1]

The directed forgetting effect is mostly explained by a retrieval inhibition or context change. The retrieval inhibition account assumes that the forget cue leads to reduced accessibility of the precue items by active inhibition of the items' study context (Geiselman, Bjork, & Fishman, 1983). The context-change account assumes that the forget cue induces a change in participants' internal context and the resulting mismatch between the contexts at encoding and test causes forgetting of the first-list items (Sahakyan & Kelley, 2002). Although the processes underlying the forgetting effect thus are characterised as inhibitory by the one account and as noninhibitory by the other, both explain the forgetting by impaired access to the items' study context (see also Bäuml & Samenieh, 2012a, 2012b).

In line with the impaired context access explanation, several studies have shown that the memorial effects of the forget cue on the precue items can be reduced, or even be eliminated, when the study context of the items is reactivated at test. Sahakyan and Kelley (2002), for instance, used a mental context reinstatement technique and asked participants at test to think back and write down which thoughts and feelings they had immediately before and during learning of the precue items. Doing so, participants in the forget condition showed less directed forgetting than in the absence of such context reinstatement. Bäuml and Samenieh (2010) used a selective retrieval technique and asked participants to recall predefined target items of the first list at test, either with or without preceding (cued) recall of the list's remaining (nontarget) items. The preceding recall of nontarget items reduced the forgetting of the target items, suggesting that retrieval of a some precue items can reactivate the items' study context and thus facilitate access to the remaining list items (see also Bäuml & Samenieh, 2012b; Bjork & Bjork, 1996).

Whereas this line of work shows that a deactivated study episode can be reactivated by effortful mental context reinstatement or active retrieval of some of the episode's items, other research areas suggest that reactivation can also occur more passively, such as during sleep or wakeful resting. Indeed, numerous studies reported evidence that regular nocturnal sleep after encoding improves memory performance relative to a wake interval of the same duration (e.g., Diekelmann, Wilhelm, & Born,

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2009; Stickgold & Walker, 2013). Similarly, some studies found increased recall when encoding was followed by a short period of wakeful resting compared to when it was followed by a period during which participants actively engaged in a distractor task, like a psychometric test or a spot-the-difference game (e.g., Cowan, Beschin, & Della Sala, 2004; Dewar, Alber, Butler, Cowan, & Della Sala, 2012). The proposal is that both sleep and wakeful resting can cause reactivation of the study episode and thus promote consolidation and later recall of the memory contents (Dewar et al., 2012; Rasch & Born, 2013). Imaging studies support the proposal, reporting that the beneficial effects of both sleep and wakeful resting are associated with hippocampal replay of study-related neural activity (Rasch, Büchel, Gais, & Born, 2007; Tambini, Ketz, & Davachi, 2010).

If reactivation of the precue items' study context can reduce directed forgetting of these items (Sahakyan & Kelley, 2002) and sleep after study reactivates the study episode (e.g., Rasch et al., 2007), then sleep may also reduce directed forgetting. Corresponding evidence was reported in a recent study by Abel and Bäuml (2013). Employing the LMDF task, these researchers let participants study the two lists either in the morning at 9 a.m. (wake condition) or in the evening at 9 p.m. (sleep condition). Participants in the wake condition stayed awake and took the final test at 9 p.m. in the evening of the same day. In contrast, in the sleep condition, participants were tested the following morning at 9 a.m. after a night including normal nocturnal sleep. Whereas in the wake condition, directed forgetting of the precue items was present after the 12 h retention interval, no forgetting arose in the sleep condition.

The goal of the present study was to examine whether wakeful resting can also reduce directed forgetting. Indeed, if reactivation of the study context can reduce items' directed forgetting, and wakeful resting after study can reactivate the study context (Dewar et al., 2012; Tambini et al., 2010), then wakeful resting may also reduce directed forgetting. To date, the results of numerous studies support the view of reactivation processes during sleep, whereas studies indicating reactivation processes during wakeful resting are limited. In particular, no study has yet examined whether wakeful resting can reduce intentional forgetting. This study thus extends the prior work in important ways, providing first information on whether intentional forgetting can be affected by the cognitive activity people engage in briefly after new learning takes place.

A standard LMDF procedure was employed to address this issue. In each of two experimental blocks, participants studied a list of items and received a cue to either remember or forget the list. After study of the second list and a short retention interval, memory for the items on the first list was tested. We manipulated the level of cognitive activity during the retention interval by employing two types of distractor tasks. We employed counting

backwards and calculation tasks as common "active" distractor tasks, which require participants to perform cognitive operations (e.g., Nairne & Healy, 1983) and in previous LMDF studies were found to induce directed forgetting (e.g., Geiselman et al., 1983; Sahakyan & Kelley, 2002; see also Discussion). In contrast, we used hearing neutral music and perceiving neutral pictures as "passive" distractor tasks, which do not require any demanding cognitive operations and thus can induce wakeful resting. Following the view that wakeful resting can induce reactivation and consolidation of newly acquired memories (Diba & Buzsáki, 2007; Tambini et al., 2010), we hypothesised that wakeful resting may reduce directed forgetting.

Method

Participants. Ninety-six undergraduate students (67 female) of Regensburg University participated ($M = 22.9$ years, SD = 3.2). They were tested individually, with 24 participants in each experimental condition.

Materials. Four study lists were constructed, each consisting of 15 unrelated concrete German nouns (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Two lists were used as List 1, and for each of the two lists, 5 items were defined as target items. Within these lists, each item had a unique initial letter. The other two lists were used as List 2.

In one of the four distractor task conditions, participants were presented with two emotionally neutral instrumental pieces of music (*Aerial Boundaries* by Michael Hedges and *Neptune, the Mystic* by Gustav Holst; e.g., Richell & Anderson, 2004; Wood, Saltzberg, & Goldsamt, 1990). In another condition, we used two sets of 10 pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999). Emotional valence of the pictures was neutral ($M = 4.8$) and did not differ between the sets, $t(18) < 1$. Ratings for emotional arousal showed moderate values ($M = 3.6$) and did also not differ between the sets, $t(18) < 1$.

Design. The experiment had a 2×4 mixed factorial design. CUE (remember, forget) was manipulated within participants, and DISTRACTOR TASK (counting, calculations, music, and pictures) between participants. In the remember condition, study of List 1 was followed by a cue to remember the list for an upcoming memory test, whereas in the forget condition, it was followed by a cue to forget the list. After study of List 2, participants counted backwards by threes, solved simple math calculations, listened to a short piece of music, or watched a set of pictures. Order of cue conditions, as well as assignment of lists to conditions, were counterbalanced.

Procedure. The procedure is shown in Figure 1(a).

Study Phase. In each experimental condition, list items were exposed individually at a 4 s rate in a random order. Presentation of List-1 items was followed by a cue to remember the items for an upcoming test, or a software
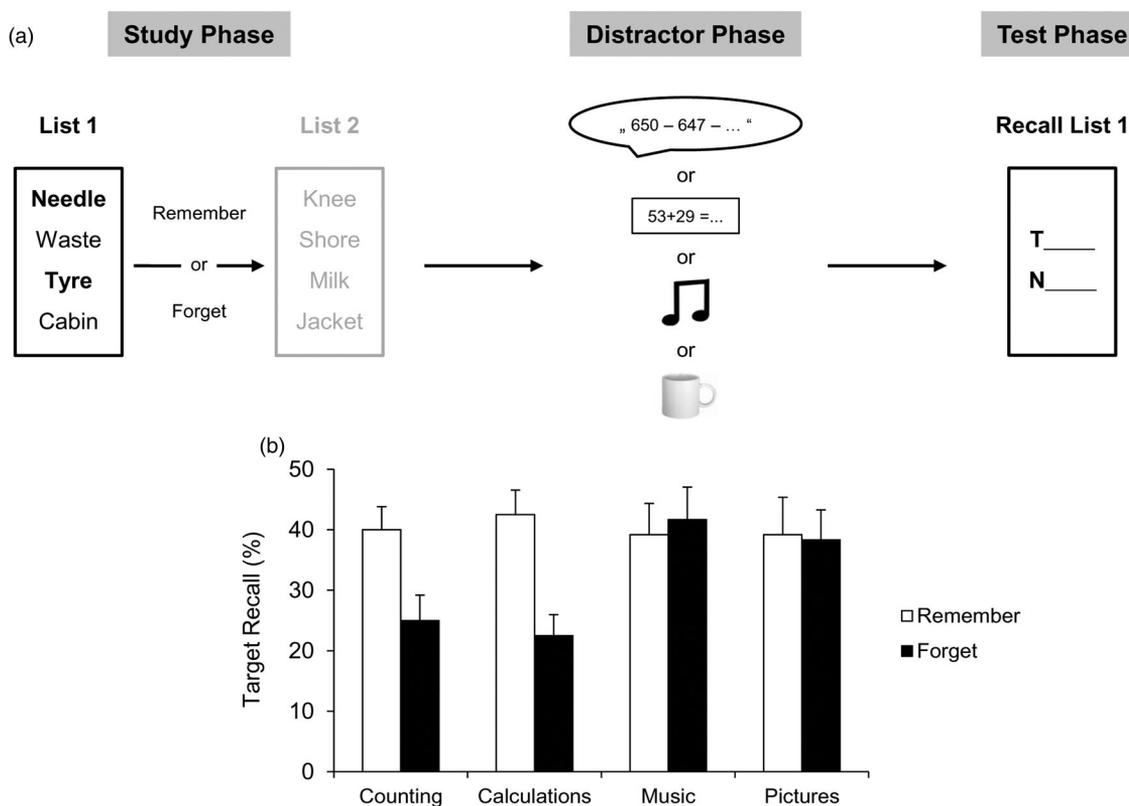
Figure 1. (a) Overview of the experimental procedure. In the study phase, participants studied two word lists. After study of List 1, participants received a cue to either forget or continue to remember that list. In the distractor phase, participants either counted backwards by threes, solved simple math calculations, listened to emotionally neutral music, or watched emotionally neutral pictures. In the test phase, participants were asked to recall predefined target words (boldface type) from List 1 (e.g., Needle, Tyre). (b) Mean target recall as a function of cue (remember vs. forget) and distractor task (counting vs. calculations vs. music vs. pictures). The error bars represent standard errors.

crash was simulated and participants were asked to forget the list and try remembering the upcoming list instead (e.g. Abel & Bäuml, 2013). List-2 presentation was always followed by a cue to remember the list.

Distractor Phase. The subsequent retention interval lasted 72 s. Participants in the counting condition were asked to count backwards by threes from a three digit number (e.g., 650, 647, …). In the calculations condition, they were asked to solve as many simple math calculations as possible (e.g., 53 + 29 = …) on a sheet of paper. In the music condition, participants were told to relax and listen to a short piece of music; then they were presented with the first 72 s of one of the two instrumental pieces. Participants in the picture condition were also told to relax and were asked to contemplate 10 pictures for 6 s each, with a prestimulus interval of 2 s and an interstimulus interval of 1 s.

Test Phase. After the retention interval, participants were asked to recall the first-list items. Target items were tested first and they were cued with their unique initial letter. The item cues were exposed successively, for 6 s each, and followed a random order. Participants gave their responses orally. Because the forget cue predominantly affects List-1 items probed early at test (e.g., Bäuml & Samenieh, 2010, 2012a), analysis of List-1 recall focused on the target items (see also Abel & Bäuml, 2013). The remaining

List-1 and the List-2 items were tested afterwards. The List-2 items were cued with their unique initial letter, the remaining List-1 items with their word stems.

After a 5-min break, participants completed the second experimental block in the other cue condition. That is, if they had received a remember cue after List-1 in the first experimental block, they received a forget cue in the second experimental block, and vice versa (e.g., Barnier et al., 2007; Conway & Fthenaki, 2003; Zellner & Bäuml, 2006). Participants in the counting condition started counting backwards from a different three digit number, and in the calculations condition, individuals solved different calculations. Participants in the music condition were presented with the other instrumental piece, and in the picture condition, individuals contemplated the other set of pictures.

Results

Recall of list-1 target items

Recall rates for target items are shown in Figure 1(b). A 2 (cue: remember, forget) x 4 (distractor task: counting, calculations, music, pictures) analysis of variance (ANOVA) revealed a significant main effect of cue, $F(1,92) = 9.95$, $MSE = 0.033$, $p = .002$, partial $\eta^2 = .10$, reflecting overall

directed forgetting, that is, lower recall in the forget than in the remember condition (31.9% vs. 40.2%), but no significant main effect of distractor task, $F(3,92) = 1.11$, $MSE = 0.074$, $p = .35$, partial $\eta^2 = .04$. Most important, a significant interaction between the two factors arose, $F(3,92) = 4.23$, $MSE = 0.033$, $p = .008$, partial $\eta^2 = .12$, signifying that the forget cue affected recall differently depending on distractor task condition. Whereas directed forgetting was present in the counting condition (25.0% vs. 40.0%), $t(23) = 3.09$, $p = .005$, $d = 0.76$, and in the calculations condition (22.5% vs. 42.5%), $t(23) = 4.29$, $p < .001$, $d = 1.08$, the forget cue did not affect recall in the music condition (41.7% vs. 39.2%), $t(23) < 1$, and the pictures condition (38.3% vs. 39.2%), $t(23) < 1$. Recall of to-be-remembered target items was unaffected by distractor task condition, $F(3,92) < 1$.

Regarding intrusions, no subject falsely recalled any second-list item when asked to recall first-list items. Cases of extra-list intrusions, that is, unstudied items which were falsely recalled during recall of the first-list items were rare ($M = 0.8$, $SD = 1.3$) and there were no differences between distractor task or cue conditions, $ps > .130$.

In this experiment, one half of the participants completed the remember condition first, and the other half completed the forget condition first. Cue order did not affect target recall, as is indicated by a $2 \times 4 \times 2$ ANOVA with the additional factor of *cue order* (remember first, forget first). Such analysis showed no main effect of cue order, $F(1,88) = 2.52$, $MSE = 0.074$, $p = .116$, partial $\eta^2 = .03$, no interaction between cue and cue order, $F(1,88) = 2.53$,

$MSE = 0.033$, $p = .115$, partial $\eta^2 = .03$, no interaction between distractor task and cue order, $F(3,88) < 1$, and particularly no significant three-way-interaction, $F(3,88) < 1$.

Recall of list-2 items

Regarding recall performance for the List-2 items in the remember and forget conditions, results showed recall rates of 43.1% ($SE = 5.2$) and 48.1% ($SE = 5.1$) in the counting condition, 55.6% ($SE = 4.7$) and 49.2% ($SE = 3.8$) in the calculation condition, 53.1% ($SE = 5.4$) and 60.0% ($SE = 5.4$) in the music condition, and 48.1% ($SE = 6.0$) and 56.7% ($SE = 5.9$) in the picture condition. A 2 (cue: remember, forget) $\times$ 4 (distractor task: counting, calculations, music, pictures) ANOVA revealed no significant effects, all $ps > .110$. These results are consistent with prior work, showing that preceding recall of first-list items often eliminates possible effects of the forget cue on recall of second-list items (e.g., Golding & Gottlob, 2005; Pastötter, Kliegl, & Bäuml, 2012). [2]

Discussion

The results show that the level of cognitive activity that subjects engage in shortly after new learning takes place influences directed forgetting. When subjects engage in "active" distractor tasks, like backward counting or math calculations, the forget cue reduces memory for to-be-forgotten items and directed forgetting arises. In contrast, when "passive" wakeful resting is induced during the

Table 1. Studies along with type of distractor task, duration of distractor task, percentage of list 1 forgetting and effect size of list 1 forgetting.

Studies included in the meta-analysis	Distractor task	Duration	$\%_F$	d_F	$S(d_F)$
Aslan, Zellner, and Bäuml (2010, Experiment 1)	Counting	90 s	9	0.577	0.174
Pastötter and Bäuml (2007)	Counting	30 s	10	0.751	0.199
Pastötter and Bäuml (2010, Experiment 1, 15 item conditions)	Counting	30 s	16	1.225	0.272
Pastötter and Bäuml (2010, Experiment 2, 15 item conditions)	Counting	30 s	12	0.967	0.176
Pastötter and Bäuml (2010, Experiment 3, 15 item conditions)	Counting	30 s	18	0.849	0.246
Sahakyan, Delaney, and Goodmon (2008, Experiment 1)	Counting	60 s	~15[a]	1.090	0.268
Sahakyan et al. (2008, Experiment 2)	Counting	60 s	~11[a]	0.908	0.263
Sahakyan and Goodmon (2007, Experiment 1, unrelated conditions)	Counting	90 s	12	0.987	0.306
Sahakyan and Goodmon (2007, Experiment 2, unrelated conditions)	Counting	90 s	10	0.968	0.216
Sterzer, Schabus, Bäuml, and Kerschbaum (2015)	Counting	30 s	22	1.321	0.494
Zou, Zhang, Huang, and Weng (2011, Experiment 2, healthy controls)	Counting	180 s	12	0.513	0.371
Delaney and Sahakyan (2007, Experiment 1)	Calculations	90 s	20	1.121	0.229
Hupbach and Sahakyan (2014, matching conditions)	Calculations	60 s	11	0.801	0.300
Lehman and Malmberg (2009, Experiment 1)	Calculations	30 s	7	0.548	0.222
Lehman and Malmberg (2011, unrelated items)	Calculations	30 s	~7[a]	0.622	0.229
Minnema and Knowlton (2008, Experiment 1, neutral words)	Calculations	60 s	~5[a]	0.452	0.261
Mulji and Bodner (2010, Experiment 1)	Calculations	90 s	9	0.727	0.286
Racsmány et al. (2008, Experiment 1)	Calculations	300 s	18	0.813	0.380
Sahakyan and Kelley (2002, Experiment 1, standard conditions)	Calculations	90 s	11	0.542	0.217
Sahakyan and Kelley (2002, Experiment 2, not reinstated conditions)	Calculations	90 s	20	1.183	0.271
Whetstone, Cross, and Whetstone (1996)	Calculations	120 s	~16[a]	0.900	0.309
Zellner and Bäuml (2006, Experiment 1)	Calculations	120 s	16	0.833	0.363
Foster and Sahakyan (2011, overt conditions)	None	–	9	0.469	0.227
Golding and Gottlob (2005, Experiment 2)	Drawing	120 s	12	0.722	0.337
Kimball and Bjork (2002, Experiment 1)	None	–	12	0.630	0.187
Spillers and Unsworth (2011)	Ordering	30 s	~12[a]	0.839	0.295
Wessel and Merckelbach (2006, neutral conditions)	Concentration	180 s	18	1.095	0.287

Note: Duration = duration of the distractor task; $\%_F$ = percentage of List 1 forgetting; d_F = effect size of List 1 forgetting; $S(d_F)$ = estimated standard deviation of d_F.
[a] = estimated from figure

retention interval, as was the case in the present music condition and the pictures condition, the forget cue does not affect memory and no directed forgetting arises.

In LMDF, the forgetting of the precue items is often attributed to some form of contextual forgetting, assuming that the presentation of the forget cue impairs access to the items' study context (e.g., Bäuml & Samenieh, 2010; Geiselman et al., 1983; Kimball & Bjork, 2002; Sahakyan & Kelley, 2002). On the basis of such view, wakeful resting immediately after encoding may attenuate the forgetting, because wakeful resting can reactivate the study episode (Dewar, Alber, Cowan, & Della Sala, 2014; Tambini et al., 2010). Indeed, if reactivation of the study episode was more beneficial for the (previously deactivated) to-be-forgotten items than the (still activated) to-be-remembered items, then wakeful resting may improve mainly recall of the to-be-forgotten items, thus reducing directed forgetting. The results show exactly this pattern.

Instead of attributing the present results to reactivation processes, alternatively one may like to explain the results by context-change processes that may have been induced by the present music and picture presentations during the resting period. For instance, according to the context-change account of LMDF, which assumes that the forget cue enhances the difference between the two list contexts, and the view that mental context fluctuates over time (e.g., Estes, 1955; McGeoch, 1932), a music- or pictures-induced context change may shift the context sufficiently far away from the list contexts, so that the difference between the two list contexts may become relatively small and List-1 recall may no longer depend much on the originally induced mental context change, that is, the forgetting of List-1 items disappears (Divis & Benjamin, 2014; Mensink & Raaijmakers, 1988). Such proposal, however, does not only predict that List-1 forgetting should disappear when music or pictures are provided during the retention interval, but does also predict that List-1 recall in the remember condition should be impaired in the music and pictures conditions, relative to the counting and calculation conditions. While the first prediction is confirmed by the present results, the second prediction is not, which rules out a context-change explanation of the present resting finding.

An alternative to explain the present results may be rehearsal processes. The assumption would be that participants engage in intentional rehearsal of the to-be-forgotten items during resting and thus create recall improvement for these items on the later memory test. However, Dewar et al. (2014) reported that even (unrehearsable) nonwords (e.g., *toijcunn*) are better remembered after a period of wakeful resting than after an active distractor task, suggesting that wakeful resting can promote recall improvement even without intentional rehearsal of the study material. Moreover, it has been argued that, if rehearsal occurred during a retention interval, it should maintain or even enhance the forgetting effect (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). The view

is that participants in the remember condition may rehearse List-2 and List-1 items, whereas participants in the forget condition selectively rehearse the List-2 items, anticipating that only those items will be tested later. The present results thus appear more easily explainable by attributing them to reactivation processes rather than attributing them to context-change or rehearsal processes. Of course, such proposal must remain speculative at this point, and further work is required to examine in more detail exactly which mechanism(s) mediate(s) the effect of brief wakeful resting on directed forgetting.

Previous studies showed that the effects of the forget cue can be reduced with a number of context reactivation techniques. Such techniques include many active processes, such as mental reinstatement of the precue study context (Sahakyan & Kelley, 2002) or selective retrieval of some of the precue items (Bäuml & Samenieh, 2010). Against this background, the recent finding that nocturnal sleep can eliminate directed forgetting (Abel & Bäuml, 2013) provided first evidence that the effects of the forget cue can also be counteracted when memory processing is not subject to conscious control. The present results extend these findings even further by demonstrating that even a brief period of wakeful resting after encoding can be sufficient to attenuate the forgetting. Critically, sleep effects have been shown to emerge primarily if sleep follows closely upon encoding (e.g., Benson & Feinberg, 1977; Gais, Lucas, & Born, 2006; Talamini, Nieuwenhuis, Takashima, & Jensen, 2008). Similarly, resting effects may presuppose that resting follows closely upon encoding. The present finding thus is not in conflict with Abel and Bäuml (2013) result that List-1 forgetting can persist for 12 hours of being awake. Although, in general, such long delay will include some wakeful resting, often the resting will not occur immediately after encoding.

Motivated by prior LMDF work, in which there was typically a short active distractor of 30–180 s between encoding and test (e.g., Geiselman et al., 1983; Pastötter & Bäuml, 2010; Sahakyan & Kelley, 2002), this study employed a resting period of 72 s after encoding, which was thus shorter than the 10-min period used in several previous resting studies (e.g., Dewar et al., 2012, 2014). On the one hand, the briefness of the present resting period provides an outstanding demonstration of the possible influence of even very short resting periods on memory performance. On the other hand, it may also be responsible for why there was no beneficial effect of resting on to-be-remembered items at all. If wakeful resting provides conditions of minimal interference during which the study episode can be replayed, then longer periods of resting may increase the number of such automatic replays, strengthening the memory traces to a larger extent than shorter periods (e.g., Dewar et al., 2014). If so, longer periods of resting may improve recall in LMDF even more than was observed in the present study, and also to-be-remembered items may profit from resting, though to a lesser extent than the (previously deactivated) to-be-forgotten items.

Such finding would mimic the results of Abel and Bäuml (2013) sleep study.

The results of this study arrive at a time when LMDF research has typically been conducted using a very restrictive set of distractor tasks between study and test. Indeed, when taking a look at LMDF studies of the past 20 years, it turns out that most of the studies used either a variant of backward counting or a variant of performing calculations as distractor task (see Table 1). The mean effect size of List-1 forgetting was similar between the two types of tasks (0.92 vs. 0.78; $\chi^2(1) = 1.28$, $p = .260$) and is similar to the effect size observed in the counting and calculations conditions of the present study (0.76 vs. 1.08). In particular, in all this prior research there is not a single case in which the retention interval was filled with any form of "passive" wakeful resting. The present study thus opens a new field for LMDF research, which may take a closer look at the role of distractor task for List-1 forgetting and examine the effects of "active" distractor tasks other than counting and calculations, and "passive" distractor tasks other than providing music and pictures. The findings from such work may provide new insights into the possible role of distractor task and resting in LMDF.

In brief, this is the first study to show that a brief period of wakeful resting can eliminate intentional forgetting. People were able to forget supposedly irrelevant material in the absence of a resting period shortly after study, whereas they were not able to do so in its presence. The findings demonstrate that the degree to which people can intentionally forget memories can be influenced by the cognitive activity that people engage in shortly after learning takes place.

Notes

1. Typically, the forget cue does not only reduce recall of the first list but does also improve recall of the second list (e.g., Geiselman et al., 1983). Because in this study the focus is exclusively on first-list recall, however, this effect is ignored here.
2. Regarding recall performance for the remaining List-1 items in the remember and forget conditions, results showed recall rates of 92.9% (*SE* = 1.5) and 90.4% (*SE* = 2.7) in the counting group, 93.3% (*SE* = 1.4) and 90.4% (*SE* = 2.0) in the calculation group, 92.5% (*SE* = 2.5) and 93.8% (*SE* = 2.1) in the music condition, and 95.0% (*SE* = 1.7) and 90.0% (*SE* = 2.5) in the pictures condition. Analysis of variance revealed no significant effects, all *ps* > .080. These results replicate prior work, showing that effects of the forget cue on List 1 recall are largely absent if the items' word stems are provided as retrieval cues at test (e.g., Bäuml & Samenieh, 2010, 2012a).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Studies included in the meta-analysis (see Table 1) are marked with an asterisk (*).

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