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# Adaptive memory: The influence of sleep and wake delay on the survival-processing effect

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Processing items in terms of their survival value leads to superior memory relative to many deep (semantic) processing tasks. To date, such survival processing has been investigated with short delay intervals only, ignoring possible effects of longer wake and sleep delay. In this study, subjects performed orienting tasks that induced survival or deep (semantic) processing of single items. A surprise memory test was administered after a short delay or a delay of 12 hours that included either sleep or wake; a cued-recall test was conducted in Experiment 1, and an item-recognition test in Experiment 2. Survival-processing effects were present regardless of delay, and their size was not influenced by delay interval. While wake delay reduced memory for both item types, sleep compared to wake enhanced their memory. These results suggest that the survival-processing effect is fully maintained across longer delay, regardless of whether the interval is filled with wake or sleep.

**Keywords:** Survival processing; Deep processing; Delay; Sleep; Forgetting.

One is bound to state the obvious when pointing out that memory decreases as time passes and increases with improved encoding, since both findings (originally reported by Ebbinghaus, 1885) have been widely integrated into general knowledge by now. Indeed, the results of many experiments have demonstrated the critical role of both initial encoding and delay between study and test for memory performance. In contrast, it is much less clear whether the effects of encoding and delay interact with each other, and whether initial encoding influences the amount of delay-induced forgetting. Experimental research on the topic has produced mixed results, showing that some manipulations of initial encoding affect delay-induced forgetting, whereas others do not.<sup>1</sup>

Research investigating the influence of degree of learning on subsequent forgetting suggests that initial encoding may not affect delay-induced

forgetting. Manipulating the number of study trials during acquisition, Slamecka and McElree (1983), for instance, showed that a higher number of study trials leads to higher recall immediately after study, but does not affect the amount of delay-induced forgetting. In contrast, research focusing on the learning activities in which individuals engage during acquisition suggests

<sup>1</sup>There has been some debate in the literature about how to measure delay-induced forgetting. While some have argued that delay-induced forgetting is adequately assessed by looking at absolute forgetting scores, others have suggested that it should be evaluated assessing relative forgetting scores. In this study, we followed Wixted's (1990) point of view, according to which the focus of the investigation at hand should be decisive for which approach is chosen: when mainly interested in the empirical principle of forgetting and less in testing a specific model of memory, which is the case in the present study, amounts of delay-induced forgetting should be compared by analysing absolute difference scores.

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that the exact study conditions can influence how much information is forgotten over time. Roediger and Karpicke (2006), for instance, compared the effects of retrieval practice during study with restudy opportunities on later memory of the studied material. While after a short delay between study and test, memory performance was superior in the restudy condition, after prolonged delays of up to one week, it was superior in the retrieval-practice condition, indicating that retrieval practice during initial encoding can reduce delay-induced forgetting. These results suggest that while quantitative variations in degree of learning may not influence the amount of forgetting, qualitatively different forms of encoding may well do.

However, variations in initial encoding can not only be induced with intentional learning, as is done in degree-of-learning and retrieval-practice studies, but can also be induced with incidental learning using different orienting tasks. Employing the levels-of-processing framework, for instance, it has been shown that when subjects make judgements on single items involving deep semantic processing versus shallow visual processing, memory is better in the deep- than the shallow-processing condition (e.g., Craik & Tulving, 1975). Also, employing the more recent survival-processing framework, it has been shown that when subjects initially rate items' relevance in an imagined survival scenario, such survival processing typically leads to superior retention compared to both classic and newly adapted deep-processing tasks (e.g., Nairne, Thompson, & Pandeirada, 2007). Although deep processing is regarded as a superior form of encoding and survival processing as "one of the best encoding procedures yet identified in human memory research" (Nairne & Pandeirada, 2008, p. 242), not much is yet known about the interplay of these forms of encoding and delay-induced forgetting. Indeed, to date, classic levels-of-processing effects have mostly been investigated with delays of up to one hour (e.g., Gardiner, 1988; Rajaram, 1993; for exceptions, see McDaniel & Masson, 1977; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994), and survival-processing effects with delays of a few minutes only (e.g., Aslan & Bäuml, 2012; Nairne et al., 2007; but see Raymaekers, Otgaar, & Smeets, 2013).

When investigating delay-induced forgetting, prior work often employed delay intervals of 24 hours up to several days, which typically include both longer wake and longer sleep inter-

vals (e.g., McDaniel & Masson, 1977; Roediger & Karpicke, 2006; Slamecka & McElree, 1983; Tulving et al., 1994). Guided by the theoretical idea that sleep may influence memory consolidation, however, more recent work contrasted delay intervals filled with wakefulness with delay intervals in which sleep follows shortly upon encoding (e.g., Payne, Stickgold, Swanberg, & Kensinger, 2008; Scullin & McDaniel, 2010). Employing such delay intervals, results from numerous studies have shown that sleep in comparison to wakefulness can aid memory performance. Such beneficial effects of sleep on memory were found over a wide range of experimental tasks, and they are generally attributed to the reactivation of memory contents during certain sleep stages, which is assumed to stabilise and consolidate the memories (for a review, see Diekelmann & Born, 2010).

Importantly, sleep does not necessarily influence all memory contents equally. For instance, sleep has been found to be more beneficial for emotional than neutral memories (Payne et al., 2008), and to have different effects on relevant and irrelevant memory contents (Wilhelm et al., 2011). While benefits of sleep have been observed with incidentally encoded memories before (e.g., Payne et al., 2008), not much is yet known about the interplay of sleep and different forms of incidental item encoding. In particular, to the best of our knowledge, there is no previous study in which survival-processing effects were directly compared across wake and sleep delay. This study addresses the issue.

The results of two experiments are reported, designed to examine how sleep and wake delay between encoding and test affect memory for items encoded in a survival-processing task and a deep-processing task. In each experiment, two orienting tasks were employed and subjects rated single items with regard to their potential relevance in a survival situation (survival processing) and their perceived pleasantness (deep processing). A surprise memory test was administered after either a short delay or a delay of 12 hours that included either sleep or wake; a cued-recall test was conducted in Experiment 1, and an item-recognition test in Experiment 2. The results of the two experiments will provide first evidence on (a) the interplay of incidental survival and deep processing and memory after wake delay, and (b) the role of sleep for the two forms of incidental encoding.

## EXPERIMENT 1

### Method

#### Participants

A total of 96 subjects participated in return for a compensatory amount of money. Mean age was 22.3 years (range 18–32 years). All subjects were fluent in German and reported regular sleep–wake cycles; none of the participants reported psychiatric or neurological disorders. Participants were equally distributed across the three delay conditions.

#### Material

A total of 40 unrelated, common, and concrete nouns were drawn from different semantic categories (Van Overschelde, Rawson, & Dunlosky, 2004), and were randomly clustered into two lists of 20 items each. Item lists were counterbalanced across orienting tasks.

#### Design

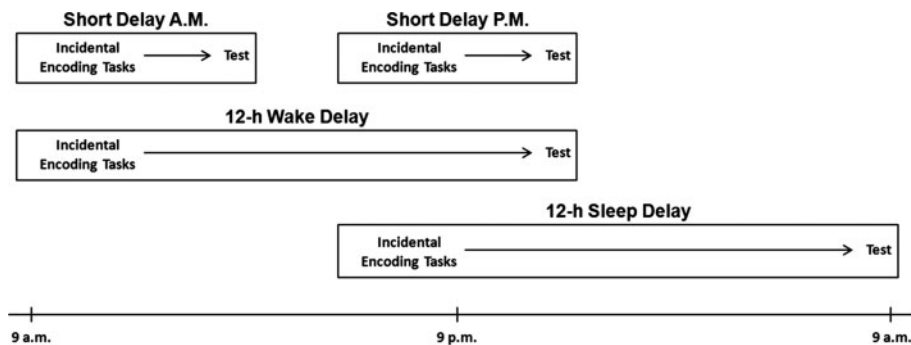
The experiment had a 2 × 3 mixed design with the within-participants factor of *encoding* (survival, pleasantness) and the between-participants factor of *delay* (short, 12-h wake, 12-h sleep). Initially, subjects rated items on two separate lists; the rating instructions varied across lists and successively triggered survival and pleasantness ratings of the list items. In the short-delay condition, all subjects were unexpectedly tested on the initially rated material after a delay of about 6 minutes. Subjects in the 12-h wake condition started the experiment at 9 a.m., and were tested

on the same material after a delay of 12 hours that included daytime wakefulness; in contrast, subjects in the 12-h sleep condition started the experiment at 9 p.m., and were tested after a delay of 12 hours that included nighttime sleep. Because sessions took place at different times of day in the 12-h delay conditions, subjects in the short-delay condition completed the whole experiment at either 9 a.m. (a.m. condition), or 9 p.m. (p.m. condition), which allows for the examination of potential circadian effects on memory performance (see Figure 1 for an illustration of conditions; for similar designs, see Abel & Bäuml, 2013; Payne et al., 2008; Scullin & McDaniel, 2010).

#### Procedure

*Rating phase.* Initially, subjects were asked to rate item material with respect to two different criteria, supposedly in order to compile the material for another experiment based on their ratings. The rating instructions for the two orienting tasks were as follows:

- **Survival Rating Task** (Nairne et al., 2007): In this task, we would like you to imagine that you are stranded in the grasslands of a foreign land, without any basic survival materials. Over the next few months, you will need to find steady supplies of food and water and protect yourself from predators. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in this survival situation. Some of the words may be relevant and others may not—it’s up to you to decide.



**Figure 1.** Illustration of conditions in the two experiments. In the short-delay conditions, participants completed the whole experiment at either 9 a.m. (short delay a.m.) or 9 p.m. (short delay p.m.); participants rated items on two different orienting tasks and were tested on the incidentally encoded material after a short delay. In the 12-h delay conditions, memory was tested after a delay of 12 hours; participants either performed the orienting tasks at 9 a.m. and were tested after daytime wakefulness (12-h wake condition), or rated the material at 9 p.m. and were tested after nighttime sleep (12-h sleep condition).

- **Pleasantness Rating Task:** In this task, we are going to show you a list of words, and we would like you to rate the pleasantness of each word. Some of the words may be pleasant to you and others may not—it's up to you to decide.

For each task, subjects rated 20 items on a five-point rating scale (1 = very irrelevant/unpleasant; 5 = very relevant/pleasant). Sequence of orienting tasks was counterbalanced across subjects. After subjects had completed both orienting tasks, they worked on unrelated decision tasks for about 6 minutes. Subjects in the long-delay conditions then left the laboratory and returned after 12 hours; subjects in the short-delay conditions stayed and their memory for the incidentally encoded material was immediately tested.

### Test phase

Memory performance was assessed using a cued-recall test. Subjects were debriefed about the actual purpose of the experiment and were asked to try to recall the items they had pre-

viously rated. Separate tests were conducted for the two orienting tasks, and the rating instructions were presented as retrieval cues. In each condition, subjects had 3 minutes to recall the 20 previously rated items, with sequence of conditions being counterbalanced across subjects.

## Results and Discussion

Table 1 shows mean recall performance in the short-delay condition. A  $2 \times 2$  ANOVA with the factors of *encoding* (survival, pleasantness) and *time of day* (a.m., p.m.) revealed a significant main effect of *encoding*, ( $F(1, 30) = 37.57$ ,  $MSE = 95.83$ ,  $p < .001$ ,  $\eta^2 = .57$ ), reflecting higher recall after the survival than after the pleasantness orienting task (38.1% vs. 23.1%). No other significant effects arose ( $F_s < 1.0$ ), indicating that memory performance was unaffected by *time of day*. For all further analyses, we therefore pooled the two short-delay conditions (a.m., p.m.) to a single short-delay condition.

Figure 2a shows mean recall performance as a function of encoding and delay conditions. A  $2 \times 3$

TABLE 1

Mean memory performance in the short-delay condition as a function of experiment (Experiment 1, Experiment 2), encoding (survival, pleasantness), and time of day (a.m., p.m.)

	Experiment 1			Experiment 2		
	A.M.	P.M.	Combined	A.M.	P.M.	Combined
Survival rating	38.1 (3.5)	38.1 (2.3)	38.1 (2.1)	96.9 (1.1)	96.6 (1.2)	96.7 (0.8)
Pleasantness rating	24.4 (3.4)	21.9 (2.5)	23.1 (2.1)	92.2 (1.4)	93.1 (1.5)	92.7 (1.0)

Standard errors are displayed in parentheses. Experiment 1: percentage of recalled items; Experiment 2: percentage of recognition hits.

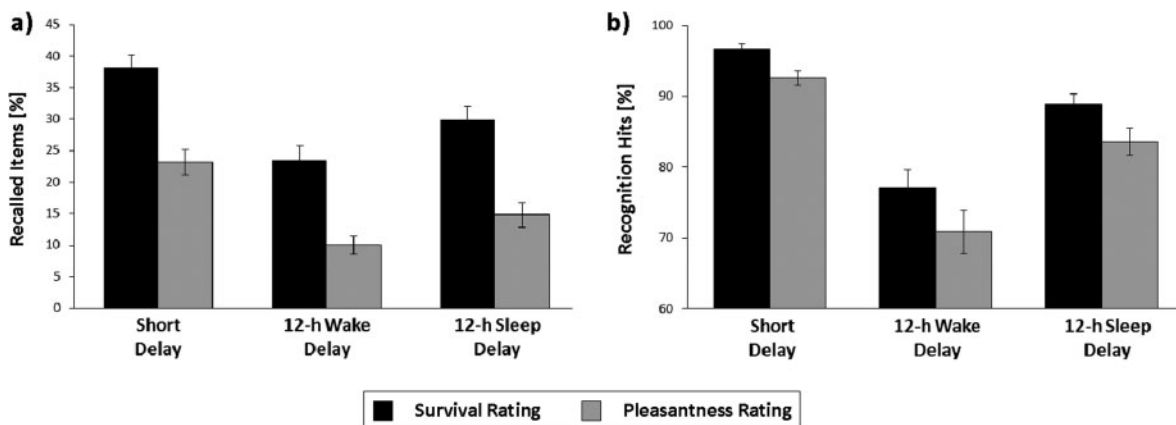


Figure 2. Mean memory performance as a function of delay (short, 12-h sleep, 12-h wake) and encoding (survival, pleasantness). (a) Experiment 1: Cued-recall test; (b) Experiment 2: Recognition test. Error bars represent standard errors.

ANOVA with the factors of *encoding* (survival, pleasantness) and *delay* (short, 12-h wake, 12-h sleep) revealed a significant main effect of *encoding* ( $F(1, 93) = 101.06$ ,  $MSE = 99.58$ ,  $p < .001$ ,  $\eta^2 = .52$ ) and a significant main effect of *delay* ( $F(2, 93) = 18.99$ ,  $MSE = 164.89$ ,  $p < .001$ ,  $\eta^2 = .29$ ), but no significant interaction of the two factors ( $F(2, 93) < 1.0$ ). The main effect of *encoding* indicates that memory performance was overall better after survival than pleasantness rating tasks (30.5% vs. 16.0%), the main effect of *delay* suggests that memory performance differed across delay conditions. Consistently, mean memory performance was better after the short than the 12-h sleep delay (30.6% vs. 22.3%; ( $F(1, 62) = 11.46$ ,  $MSE = 191.51$ ,  $p = .001$ ,  $\eta^2 = .16$ ) and better after the 12-h sleep than the 12-h wake delay (22.3% vs. 16.7%; ( $F(1, 62) = 6.43$ ,  $MSE = 157.41$ ,  $p = .014$ ,  $\eta^2 = .10$ ).<sup>2</sup>

The results in the short-delay condition replicate prior work by showing the typical survival-processing effect (e.g., Nairne et al., 2007). They also suggest that recall was unaffected by circadian factors.<sup>3</sup> The results in the 12-h delay conditions extend the prior work by showing that the survival-processing effect was maintained after a longer wake delay. The size of the effect was unaffected by delay interval, indicating that type of encoding did not influence the amount of delay-induced forgetting. Finally, the results show beneficial effects of sleep on memory performance that were similar in size across the two orienting tasks. To the best of our knowledge, this is the first demonstration that items incidentally encoded in survival-processing and pleasantness-rating tasks show comparable delay-induced forgetting and show comparable beneficial effects after sleep. The goal of Experiment 2 was to replicate these results using item recognition rather than cued recall as the memory task.

<sup>2</sup> We also analysed the number of intrusions. After the 12-h delays, more intrusions occurred after survival ( $M = .94$ ,  $SD = 1.05$ ) than pleasantness ratings ( $M = .33$ ,  $SD = .62$ ;  $p < .001$ ), which is in line with previous work (Howe & Derbish, 2010; Otgaar & Smeets, 2010). No difference arose after the short delay (survival:  $M = .06$ ,  $SD = .25$ ; pleasantness:  $M = .16$ ,  $SD = .45$ ;  $p = .263$ ).

<sup>3</sup> While short-delay control conditions are frequently used to check for potential time-of-day confounds, there have been other studies in research on sleep-associated memory consolidation that kept the time of day constant across conditions and still observed benefits of sleep (for a review, see Diekelmann & Born, 2010). Together, the results converge on the view that potential time-of-day confounds do not explain the beneficial effect of sleep on memory.

## EXPERIMENT 2

### Method

#### Participants

A new sample of 96 healthy subjects participated in the experiment; mean age was 22.5 years (range 19–35 years). All subjects were fluent in German and reported regular sleep–wake cycles. Subjects were again equally distributed across the three delay conditions.

#### Material

The item material consisted of the material employed in Experiment 1 and an additional set of 40 further unrelated and concrete nouns. There was counterbalancing for which of the two sets was used as study material during encoding and which was used as new item material (lures) during the recognition test.

#### Design

The experiment had the same  $2 \times 3$  design as Experiment 1; the factor of *encoding* (survival, pleasantness) was again manipulated within-subjects, the factor of *delay* (short delay, 12-h wake delay, 12-h sleep delay) between-subjects.

#### Procedure

The general procedure was identical to that of Experiment 1, with the only exception being that a recognition test was applied to assess memory. At test, subjects received a randomised list of 80 words, comprising the 40 originally rated items and 40 new items. They were asked to decide for each single item whether it was presented during the study phase (old item) or not (new item).

## Results and Discussion

Mean percentage of recognition hits in the short-delay condition is displayed in Table 1. A  $2 \times 2$  ANOVA with the factors of *encoding* (survival, pleasantness) and *time of day* (a.m., p.m.) revealed a significant main effect of *encoding* ( $F(1, 30) = 17.42$ ,  $MSE = 15.16$ ,  $p < .001$ ,  $\eta^2 = .37$ ), reflecting better recognition after survival than pleasantness-orienting tasks (96.7% vs. 92.7%). No other significant effects emerged ( $F_s < 1.0$ ), indicating that recognition was not

affected by *time of day*. For all further analyses, we therefore collapsed the two short-delay conditions (a.m., p.m.).

Figure 2b shows mean hit rates as a function of encoding and delay conditions. A  $2 \times 3$  ANOVA with the factors of *encoding* (survival, pleasantness) and *delay* (short, 12-h wake, 12-h sleep) revealed a significant main effect of *encoding* ( $F(1, 93) = 18.12$ ,  $MSE = 71.88$ ,  $p < .001$ ,  $\eta^2 = .16$ ) and a significant main effect of *delay* ( $F(2, 93) = 40.34$ ,  $MSE = 170.57$ ,  $p < .001$ ,  $\eta^2 = .47$ ), but no significant interaction of the two factors ( $F(2, 93) < 1.0$ ). The main effect of *encoding* reflects the fact that recognition was better after survival than pleasantness ratings (87.6% vs. 82.4%), and the main effect of *delay* reflects the fact that recognition was better after the short than the 12-h sleep delay (94.7% vs. 86.3%;  $F(1, 62) = 28.57$ ,  $MSE = 79.74$ ,  $p < .001$ ,  $\eta^2 = .32$ ) and better after the sleep than the wake delay (86.3% vs. 74.1%;  $F(1, 62) = 20.12$ ,  $MSE = 236.19$ ,  $p < .001$ ,  $\eta^2 = .25$ ).

Because no separate recognition tests were conducted for the two encoding conditions, false alarm rates can only be compared across delay conditions. Significantly fewer false alarms were made after the short delay (1.3%,  $SD = 1.8$ ) compared to both 12-h delay conditions ( $t(62) \geq 4.27$ ,  $ps < .001$ ), whereas false alarm rates did not differ between the 12-h wake and sleep conditions (wake: 10.5%,  $SD = 10.9$ ; sleep: 9.5%,  $SD = 10.7$ ;  $t(62) < 1.0$ ). Consistent with this false alarm rate analysis and the above hit rate analysis, a  $d'$  analysis showed that recognition performance was indeed higher after the 12-h sleep compared to the 12-h wake delay (sleep:  $d' = 2.61$ ,  $SD = 0.84$ ; wake:  $d' = 2.07$ ,  $SD = 0.72$ ;  $t(62) = 2.78$ ,  $p = .007$ ), and was highest in the short delay condition ( $d' = 3.67$ ,  $SD = 0.47$ ;  $t(62) \geq 6.25$ ,  $ps < .001$ ).<sup>4</sup>

The results of Experiment 2 replicate those of Experiment 1. After the short delay, the different orienting tasks resulted in the typical survival-

processing effect. The same pattern was also present in the 12-h wake delay condition, with the size of the encoding effect being unaffected by the delay interval. Also, as with Experiment 1, sleep improved memory performance, showing comparable beneficial effects for both orienting tasks. The results were not affected by circadian factors.

## GENERAL DISCUSSION

The present results show superior memory for items subject to survival compared to deep processing, as operationalised by a pleasantness rating task (e.g., Nairne et al., 2007). To date this survival effect was mostly investigated with delay intervals of a few minutes only (e.g., Nairne & Pandeirada, 2008) and the size of the effect was not compared across delay intervals. The present results show that the survival-processing effect is present after short and long delays, and that the size of the effect is not influenced by the delay interval. Moreover, sleep was beneficial in both the survival- and the pleasantness-encoding conditions, improving memory for the two encoding types to about the same extent. Together, these results suggest that survival-processing effects are maintained across longer delays, regardless of whether the delay includes wake or sleep. This pattern is consistent with the results of a very recent study in which survival-processing effects were observed after delays of 24 and 48 hours (Raymaekers et al., 2013). The present study, however, goes beyond this recent work by separately analysing the influence of wake and sleep delay on the survival-processing effect.

The currently dominant account of the survival-processing effect is based on a functional-evolutionary perspective, assuming that human memory, as a product of evolution, is specifically “tuned” for processing and retaining fitness-related information (e.g., Nairne et al., 2007). Other accounts of the effect focus instead on proximate mechanisms—for instance, suggesting more emotionality or arousal (e.g., Nairne et al., 2007), a higher degree of item-specific processing (e.g., Burns, Hart, Griffith, & Burns, 2012), or richer encoding (e.g., Kroneisen, Erdfelder, & Buchner, 2013) in survival compared to control conditions. While for most of the accounts, the present results do not bear any direct implications, the results may provide a challenge for at least some of the current accounts. For instance,

<sup>4</sup> Concerning the rating data obtained on the two orienting tasks, a  $2 \times 3 \times 2$  ANOVA with the factors of *encoding* (survival, pleasantness), *delay* (short, 12-h wake, 12-h sleep), and *experiment* (Experiment 1, Experiment 2) revealed a significant main effect of *encoding* ( $F(1, 186) = 53.36$ ,  $MSE = .16$ ,  $ps < .001$ ,  $\eta^2 = .22$ ), but no other significant effects or interactions (all  $F_s \leq 1.94$ , all  $ps \geq .166$ ). Items were rated higher in the pleasantness than in the survival condition ( $M = 3.03$  vs.  $M = 2.74$ ;  $t(191) = 7.33$ ,  $p < .001$ ). Although no analysis on item level was carried out, the finding replicates previous results by Nairne and colleagues (Nairne et al., 2007; Nairne & Pandeirada, 2008), indicating that congruity between material and survival-processing task may not have been crucial for the superior retention observed in the present experiments.

the results speak against an emotionality-based explanation of the survival-processing effect, because emotionality is known to become more important for memory with delay (e.g., Kleinsmith & Kaplan, 1963; Payne et al., 2008), whereas the survival-processing effect was not enhanced with delay in the present study (see also Nairne et al., 2007; Otgaar, Smeets, & Van Bergen, 2010; Raymaekers et al., 2013). The results also challenge the view of a higher degree of item-specific processing in the survival-processing condition, because such processing is assumed to produce superior retrieval cues that should be particularly beneficial after longer delay, which is again in contrast with the present findings. Of course, to bolster these arguments, future work must show that the present results generalise to other deep-orienting tasks and to significantly longer delay intervals.

Prior work on the interplay of encoding and memory after delay employed intentional learning, either manipulating the initial degree of learning or introducing retrieval-practice cycles during study. These studies found no effect of degree of learning (e.g., Slamecka & McElree, 1983), but an effect of retrieval practice (e.g., Roediger & Karpicke, 2006) on delay-induced forgetting. Using incidental learning with different orienting tasks, the present results mimic the results from the degree-of-learning studies and contrast with the results from the retrieval-practice studies. Because both the present experiments and the degree-of-learning studies did not include any retrieval cycles during study, the present and previous results may indicate that, in the absence of retrieval cycles, variations in initial encoding have only a minor influence on delay-induced forgetting, if at all.

On their own, the present results on the role of sleep for memory performance are consistent with the classic view that sleep passively protects memories from interference. According to this view, new learning experiences may occur during wake, but scarcely during sleep, thus reducing performance in wake compared to sleep conditions due to arising interference (e.g., Wixted, 2004). Because, in the present study, all memories were forgotten to a similar degree across wake, and profited about equally from sleep, the present results are well compatible with such a view. However, other results from the literature strongly indicate that sleep can actively stabilise memories—for instance, by reactivating and redistributing them during specific sleep stages

(e.g., Diekelmann & Born, 2010). In fact, several previous studies provided behavioural evidence for an active contribution of sleep to memory consolidation (e.g., Abel & Bäuml, 2013; Scullin & McDaniel, 2010), and the present results are compatible with such an account as well.

In sum, this is the first study to examine the effects of sleep and wake delay on items incidentally encoded in a survival-processing task and a deep-processing task. The results show that the survival-processing effect is not restricted to short delays between encoding and test, but is equally present after delays of 12 hours. This pattern arose regardless of whether the delay was filled with wake or sleep, indicating that sleep is about equally beneficial for the single forms of item encoding. The findings provide new insights into the interplay of encoding and memory after wake and sleep delay.

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