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Reinstating memories' temporal context at encoding causes Sisyphus-like memory rejuvenation

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As memories age, their immediate retrievability decreases albeit, due to ongoing memory consolidation, their future rate of forgetting weakens. Here, we show in two experiments (*N* = 1.216 participants) that mentally traveling back in time to older memories' temporal context at encoding reverses the two effects and makes the memories similar again to how they were at an earlier point in time. Mental time travel increased both the memories' immediate retrievability and their future rate of forgetting when individuals attempted to reinstate context deliberately and actively and when they retrieved other memories sharing a similar temporal context. Intriguingly, the forgetting after mental time travel even followed the same trajectory as the forgetting after encoding. Attempts to reinstate memories' encoding context thus rejuvenated memories, although the degree of rejuvenation decreased as temporal lag between encoding and the reinstatement attempts increased, which was mediated by the fact that, with increasing lag, decreasing proportions of the encoded memories were reactivated and reconsolidated in response to participants' reinstatement attempts. Mentally traveling back in time creates rejuvenation cycles with enhanced retrievability followed by a restart of forgetting and consolidation processes. Recurring rejuvenation cycles may thus be key to maintain memories' retrievability over longer periods of time, painting the picture of Sisyphus-like memory resurrection.

memory | retrieval | forgetting | context reinstatement

Significance

Memories fade away with the passage of time but by mentally reinstating the temporal context that surrounded older memories at encoding the retrievability of the memories can be improved again. Here, we show that such mental time travel into the past has a rejuvenating function for the memories. Memories decrease in immediate retrievability and, due to ongoing memory consolidation, also decrease in future forgetting as they age, but mentally turning back time reverses the two effects and makes the memories similar again to how they were at an earlier point in time. Accordingly, the forgetting right upon encoding and the forgetting after a later reinstatement attempt share the same forgetting trajectory. The resurrection of memories is like a Sisyphus task.

The resurrection of memories apparently forgotten over time often feels like a Sisyphus task. To overcome the forgetting of a memory, one may arduously have tried to mentally reinstate the temporal context that surrounded the memory at encoding in order to facilitate retrieval of the memory, only to realize that the forgetting reemerges as time after the mental time travel passes and context changes again. People remember less and less of what they encoded into memory at a particular point in time as more and more time since encoding passes (1–5), but previous research has shown that mentally reinstating memories' temporal context at encoding can indeed overcome the forgetting and enhance the memories' retrievability again (6–10). However, it is unclear whether the effect of reinstatement attempts is limited to this possibly short-lived enhancement of memories' retrievability, or the reinstatement has a much broader effect on the memories, also influencing their future forgetting. Mentally traveling back to the time at encoding might rejuvenate the memories, making them again similar in immediate retrievability and future forgetting to how they were at an earlier point in time. Forgetting after encoding would thus share its trajectory with the reemerged forgetting and memory resurrection in fact resemble Sisyphean work. Alternatively, if the contextual change induced by reinstatement attempts was transient in character and the reinstatement effects vanished shortly after the attempts (11), then the memories' retrievability might quickly become indistinguishable from the retrievability when no previous reinstatement attempts took place.

The goal of the present study was to put the idea that attempts to reinstate older memories' encoding context rejuvenate the memories and cause Sisyphus-like memory resurrection to a test. A key characteristic of human forgetting is that memories' retrievability declines rapidly soon after encoding but due to ongoing memory consolidation, the rate of forgetting decreases with the passage of time (1–3, 12–14). Older memories therefore do not only show reduced immediate retrievability but also slowed forgetting over time relative to younger memories (14, 15). The rejuvenation hypothesis assumes that mentally traveling back to the time when the older memories were originally encoded reverses these effects: It enhances the memories' retrievability immediately after the mental time travel as well as their future rate of forgetting, effectively creating a copy of how the memories were at an earlier point in time (Fig. 1). More successful reinstatement attempts may thus lead to better retrievability directly after the mental time travel and a higher rate of future forgetting, compared to less successful reinstatement attempts. In particular, forgetting

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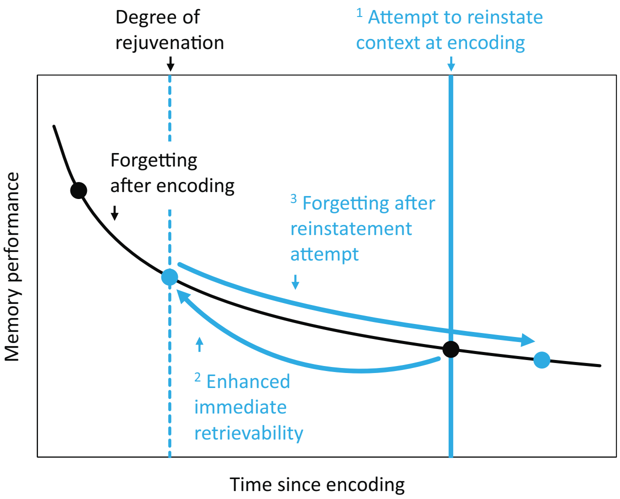

Fig. 1. The rejuvenation hypothesis. As time after the encoding of memories passes, forgetting arises. Attempts to reinstate the temporal context that surrounded memories at encoding (1) can rejuvenate the memories and enhance the immediate retrievability of the memories (2), before forgetting reemerges (3). The hypothesis assumes that forgetting after encoding and forgetting after reinstatement attempts share the same forgetting trajectory.

after mental time travel may follow the very same trajectory as forgetting after encoding, albeit possibly starting from a reduced retrievability level.

In memory research, methods to resurrect apparently forgotten memories have mostly been used to reveal the extent to which mental time travel can improve memories' immediate retrievability, and memory performance thus was measured at a single point in time after the mental time travel (6–10). Surprisingly, resurrection methods have seldom been applied to study forgetting after mental time travel by measuring memory performance at several time intervals after reinstatement attempts (16). We used such an approach to compare memories' immediate retrievability and subsequent forgetting directly after encoding to immediate retrievability and subsequent forgetting after mental time travel. In addition, we varied the temporal lag between encoding and reinstatement attempts, assuming that mental time travel becomes more difficult, and less successful, as temporal lag up to mental time travel increases (8, 9). On the basis of the rejuvenation hypothesis, a shorter temporal lag may therefore lead to higher immediate retrievability and a higher forgetting rate after the mental time travel than a longer temporal lag.

In this study, we employed two different methods to resurrect forgotten memories. The one method is based on individuals' deliberate active attempts to reinstate context by asking participants to mentally travel back to the time at encoding and remember some contextual detail they experienced at this particular point in time (6–8, 10). The other method relies on individuals' selective retrieval of a subset of the encoded material, which reactivates the temporal context that was present when this material was encoded and enhances recall of other material sharing a similar encoding context (16–19). The first experiment employed the selective retrieval method (Fig. 2). Then, 608 participants, who were divided into four groups, studied a list of unrelated words they were later tested on. The no-reinstatement group recalled the items without any previous reinstatement attempts 2.5, 12.5, 22.5, or 42.5 min after study. All items served as target items. Recall of the three reinstatement groups was preceded by a selective retrieval phase, which took place 4 h, 24 h, or 7 d after study. In this phase, participants remembered half of the list items, providing the items' unique word stems as retrieval cues. The other half of the list items served as target items and, at test, were recalled 2.5, 12.5, 22.5, or 42.5 min after selective retrieval. In all conditions, target items were recalled in the presence of the items' unique initial letters. To demonstrate target items' expected recall enhancement right after the selective retrieval, three subgroups of the no-reinstatement group were tested at exactly the same time since study as those participants of the three reinstatement groups who were tested 2.5 min after the selective retrieval. In a second experiment, 608 participants studied an educationally relevant prose passage on the sun. At test, parts of single sentences of the text were provided as retrieval cues and participants completed the sentences with the missing target word(s) from the text (16, 20). This time, participants engaged in deliberate active attempts to reinstate encoding context. Before being tested on the studied material, they took a few minutes to recall and write down some of their thoughts, feelings, and emotions prior to the beginning of the study phase and during the study phase itself. In all other aspects, the experiment was identical to the first experiment.

Results

Results were similar in the two experiments. Fig. 3 shows that, in the absence of any prior reinstatement attempts, target recall decreased from shortly after study to the six longer delay intervals of up to 7 d, revealing typical forgetting over time [first experiment: $F(6, 217) = 16.36$, $P < 0.001$; second experiment: $F(6, 217) = 12.83$, $P < 0.001$]. Fig. 3 *B*–*D* and *F*–*H* also shows that the attempts to reinstate context enhanced target recall shortly after the attempts when the attempts occurred 4 or 24 h after study [first experiment: 4-h lag $t(62) = 5.43$, $P < 0.001$; 24-h lag $t(62) = 3.82$, $P < 0.001$; second experiment: 4-h lag $t(62) = 2.28$, $P = 0.026$; 24-h lag $t(62) = 2.38$, $P = 0.020$], but not when they occurred 7 d after study [first experiment: $t(62) = 1.44$, $P = 0.155$; second experiment: $t(62) = 0.47$, $P = 0.641$]. To quantify the forgetting in the no-reinstatement and the three reinstatement conditions of an experiment, we fitted a power function of time, $r(t) = a(1 + t)^{-b}$, to the recall rates in each condition (2, 3, 14, 21). In this function, $r(t)$ represents target recall at time t, parameter b represents the forgetting rate as time passes, and parameter a represents target recall at $t = 0$, i.e., directly after study in the no-reinstatement condition and directly after the reinstatement attempts in the three reinstatement conditions. The function described the forgetting in each condition well (*SI Appendix*, Table S1), but in both experiments, the values of the function's parameters varied between conditions [first experiment: $\chi^2(6) = 96.77$, $P < 0.001$; second experiment: $\chi^2(6) = 355.69$, $P < 0.001$]. Both parameters were numerically higher in the no-reinstatement than the three reinstatement conditions and continued to decrease as the temporal lag between study and the reinstatement attempts increased. These results show that targets' immediate retrievability and future forgetting after reinstatement attempts remained below the levels shown directly after study and were higher after shorter than longer temporal lag, which fits the rejuvenation hypothesis.

We tested the rejuvenation hypothesis directly by examining whether an experiment's recall rates in the no-reinstatement and the three reinstatement conditions followed the same forgetting trajectory. If time t in all four conditions is indexed as time since study and recall rates in the four conditions follow the same forgetting trajectory, then the four sets of recall rates are horizontally parallel along this temporal axis. Rates in each reinstatement condition can

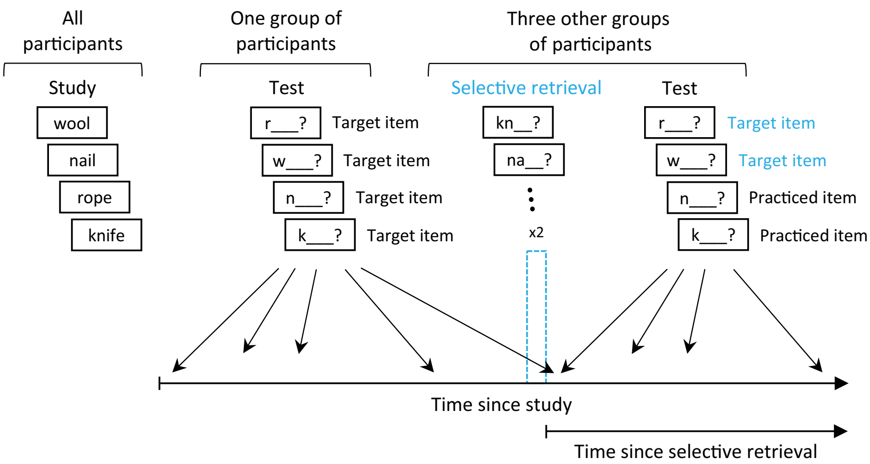

Fig. 2. Experimental design for experiment 1. Four groups of participants studied a list of words. Recall of one group was tested directly after study without preceding selective retrieval. Different subgroups were tested at different times since study. Recall of the three other groups was tested after selective retrieval, which took place 4 h, 24 h, or 7 d after study and created target and practiced items. Different subgroups of the groups were tested at different times since selective retrieval.

then be horizontally shifted toward the study phase such that the rates align with the forgetting trajectory in the no-reinstatement condition (22). The alignment leads to a new, effective age of the memories directly after the reinstatement attempts, replacing the memories' actual age of 4 h, 24 h, or 7 d in the single reinstatement conditions. The power function was enriched by parameter *c* to allow a horizontal shift of recall rates, and the resulting function, $r(t) = a(1 + c + t)^{-b}$, simultaneously fit to the recall rates of an experiment's no-reinstatement and three reinstatement conditions (*SI Appendix*). Parameter *c* marks the memories' effective age directly after the reinstatement attempts, and time *t* the time after study in the no-reinstatement condition respectively the time after the reinstatement attempts in the three reinstatement conditions. For the fitting, parameters *a* and *b* were restricted to be constant across conditions, whereas parameter *c* was free to vary between the three reinstatement conditions but set to 0 in the no-reinstatement condition (Fig. 4). The function described recall rates of each experiment well [first experiment: $\chi^2(3) = 1.24$, $P = 0.743$; second experiment:

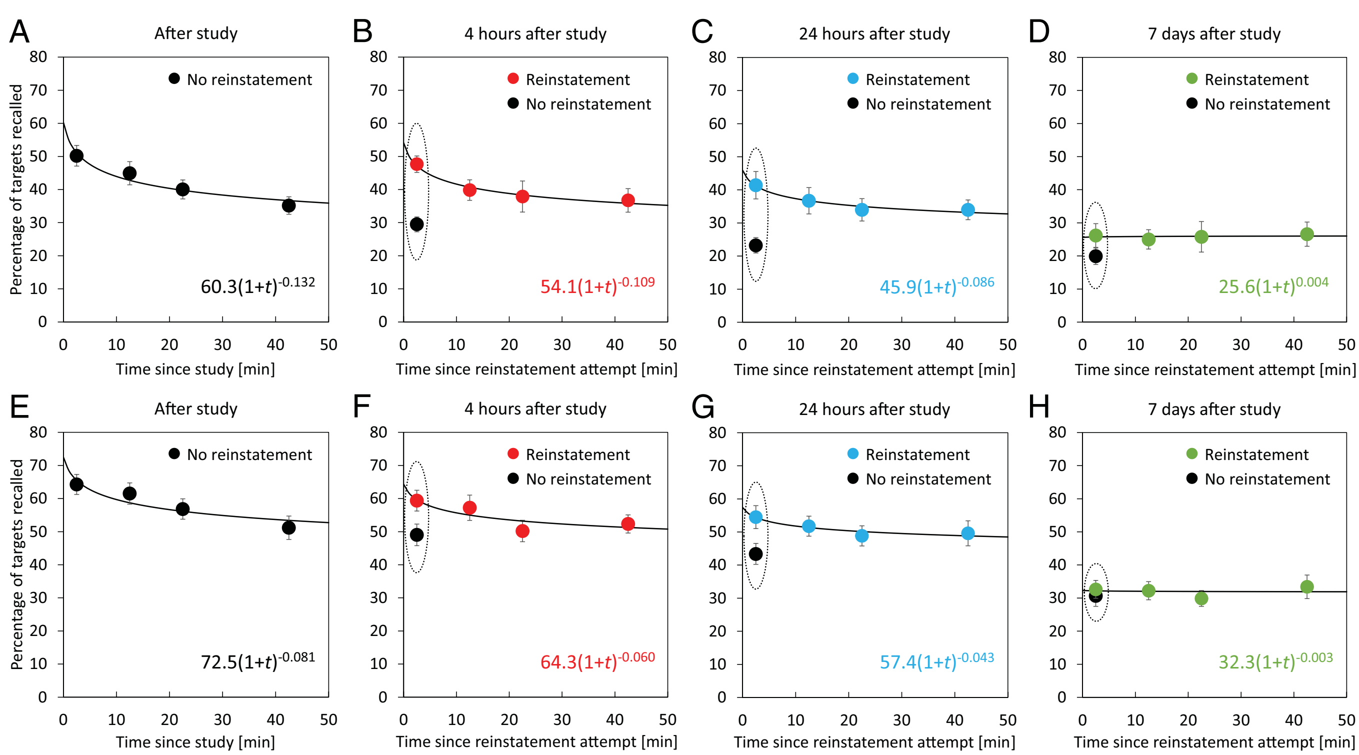

Fig. 3. Attempts to reinstate context at encoding influence memories' immediate retrievability and subsequent forgetting. Results of the first (*A*–*D*) and the second experiment (*E*–*H*) are shown. Each graph shows percentage of target items recalled at several time intervals directly after study without prior reinstatement attempts (*A* and *E*) or after reinstatement attempts 4 h, 24 h, or 7 d after study (*B*–*D* and *F*–*H*). (*B*–*D* and *F*–*H*) also show recall in a no-reinstatement condition matched in time since study with the reinstatement condition when recall was tested shortly after reinstatement attempts. Reinstatement attempts 4 or 24 h after study, but not attempts 7 d after study, enhanced recall relative to the no-reinstatement condition (highlighted by ovals). Forgetting over time was described by a power function of time. The function's estimated parameters indicate that both recall directly after reinstatement attempts and the forgetting rate after reinstatement attempts were numerically reduced relative to recall directly after study, and both measures decreased as the temporal lag between study and reinstatement attempts increased. Each data point within each graph represents the mean of *N* = 32 different participants. Error bars represent ± 1 SEM.

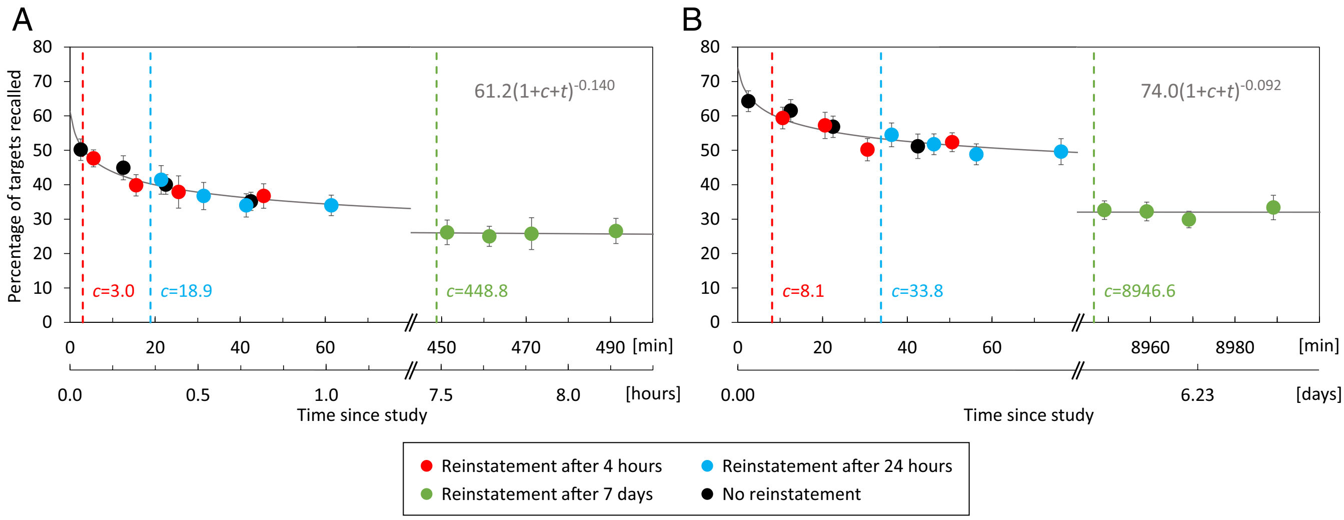

Fig. 4. A single trajectory describes forgetting. (*A* and *B*) show percentage of target items recalled in the no-reinstatement and the three reinstatement conditions of the first (*A*) and the second experiment (*B*). Recall rates in the three reinstatement conditions were horizontally shifted along the time axis such that recall rates in the four conditions were best described by a single, common power function of time. The function's shift parameter *c* was measured in min relative to the end of the study phase and, for each single reinstatement condition, represents target memories' effective age directly after the reinstatement attempts, replacing the memories' actual age of 4 h, 24 h, or 7 d. Results indicate a high degree of target memory rejuvenation when the reinstatement attempts occurred 4 or 24 h after study and moderate to low degrees when the reinstatement attempts occurred 7 d after study. Each data point within each of the two graphs represents the mean of $N = 32$ different participants. Error bars represent ± 1 SEM.

$\chi^2(3) = 1.62$, $P = 0.655$], with a high degree of target memory rejuvenation, i.e., a low *c* value, in the 4-h and 24-h lag conditions, and moderate (first experiment) to low (second experiment) degrees of rejuvenation, i.e., higher *c* values, in the 7-d lag condition. The forgetting after reinstatement attempts thus followed the same trajectory as the forgetting directly after study, albeit starting from a reduced recall level reflecting the memories' effective age directly after the reinstatement attempts.

The observed differences in degree of target memory rejuvenation across the single reinstatement conditions may reflect differences in what proportion of the target memories became reactivated and reconsolidated. Reinstatement attempts may reactivate some encoded memories only, bringing the reactivated memories' recall level back to the recall level observed directly after encoding and inducing a restart of forgetting and consolidation over time (13, 16, 23). By contrast, nonreactivated memories may remain unaffected and continue to follow the original forgetting trajectory (Fig. 5). Target recall in a certain reinstatement condition may thus be predictable from knowing the recall rates of reactivated and nonreactivated memories and aggregating them proportionately. The power function of time estimated for an experiment to describe forgetting directly after encoding carries the information on reactivated and nonreactivated memories' recall rates, and we used this information to predict in each reinstatement condition target memories' recall 2.5, 12.5, 22.5, and 42.5 min after the reinstatement attempts (*SI Appendix*). Proportionately aggregating the respective recall rates of reactivated and nonreactivated memories, with proportion of reactivated memories as a free parameter, described target recall in each single reinstatement condition well (*SI Appendix*, Table S2) and indicated that 84.2% (4-h lag), 68.2% (24-h lag), and 31.2% (7-d lag) of the target memories became reactivated and reconsolidated after mental time travel in the first experiment and 69.9% (4-h lag), 59.3% (24-h lag), and 0.0% (7-d lag) of the memories in the second experiment. Differences in proportions of reactivated and reconsolidated memories can thus explain the observed differences in degree of target memory rejuvenation across conditions.

The finding of the first experiment that selective retrieval of some list items (the practiced items) enhanced recall of the remaining (target) items suggests the possibility that a similar beneficial effect emerges if recall performance of list items is compared across items' serial testing positions, with higher recall for later than earlier tested items. Table 1 shows for all combinations of reinstatement and delay conditions, recall performance for the first and second eight items of the list and, for each set of eight items, also recall performance for the first and second half of the set. In the three reinstatement conditions, the first eight items reflect practiced items recalled in the first round of selective retrieval using the items' unique word stems as retrieval cues, and the list's second eight items reflect target items recalled at test in the presence of the items' unique initial letters; in the no-reinstatement condition, all list items reflect target items (see again Fig. 2). Statistical comparison of sets of items tested with the same cued recall format showed that there were no differences between recall of earlier and later tested item sets, in both the no-reinstatement and the three reinstatement conditions (*SI Appendix*, Table S4). The result is consistent with prior work, which indicated that effects of testing position on recall performance can be small and difficult to find in lists of a length as used here (16, 24). Effects of testing position, however, have repeatedly been reported with much longer item lists (25–27), and such longer lists may be critical for the beneficial effect of selective retrieval to also emerge in list items' serial testing positions.

Discussion

Mentally reinstating older memories' temporal context at encoding is a powerful way to rejuvenate memories. Here, we have shown that, while memories' immediate retrievability and future forgetting decrease as the memories age (14, 15), mentally traveling back in time to when the memories were encoded reverses these effects and enhances both the memories' immediate retrievability and future forgetting. The reversal made the memories similar again to how they were at an earlier point in time, with forgetting after mental time travel following the very same trajectory as forgetting after encoding. This picture of a Sisyphus-like resurrection of memories

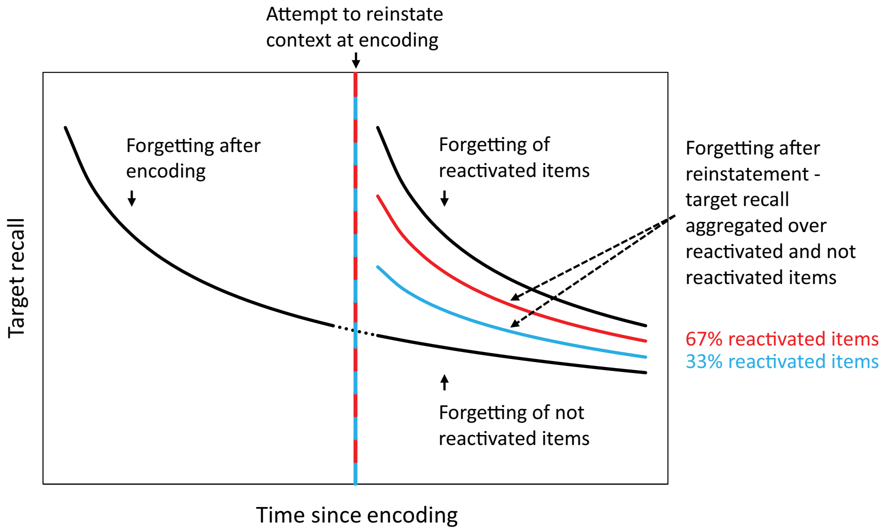

Fig. 5. Differences in degree of target memory rejuvenation may reflect differences in proportion of reactivated and reconsolidated memories. Attempts to reinstate context at encoding may lead to the reactivation and reconsolidation of some of the encoded target memories but not of others. If the reinstatement attempts bring the recall level of reactivated memories back to the level observed directly after encoding and induce a restart of forgetting and consolidation over time, then a higher proportion of reactivated memories in the set of target memories, e.g., 67% reactivated memories, leads to a higher degree of target memory rejuvenation with higher immediate retrievability and a higher forgetting rate than a lower proportion of reactivated memories, e.g., 33% reactivated memories, does.

contrasts with the idea that context reinstatement as induced by mental time travel is a transient contextual phenomenon. If transient in character, the induced enhancement effect should have vanished shortly after the reinstatement attempts, and the memories' retrievability quickly become indistinguishable from the retrievability when previous reinstatement attempts were missing.

Table 1. Percentage of recalled items as a function of items' testing position in the first experiment

	First eight items			Second eight items		
Reinstatement condition	All items	First half	Second half	All items	First half	Second half
No reinstatement						
2.5 min delay	54.3 (21.0)	57.0 (28.6)	51.6 (24.5)	46.1 (22.1)	46.9 (26.8)	45.3 (29.4)
12.5 min delay	48.0 (18.0)	47.7 (23.2)	48.4 (25.4)	41.8 (28.3)	42.2 (33.9)	41.4 (32.8)
22.5 min delay	36.7 (20.8)	34.4 (27.5)	39.1 (25.4)	43.4 (18.2)	45.3 (24.1)	41.4 (28.8)
42.5 min delay	35.2 (20.4)	33.6 (27.4)	36.7 (23.7)	35.2 (18.1)	34.4 (23.5)	35.9 (28.4)
4 h delay	30.5 (16.5)	30.5 (27.5)	30.5 (21.8)	28.1 (17.1)	23.4 (22.8)	32.8 (24.9)
24 h delay	24.2 (15.9)	26.6 (23.7)	21.9 (23.5)	22.3 (19.2)	22.7 (20.4)	21.9 (25.2)
7 d delay	21.9 (17.1)	21.1 (21.2)	22.7 (23.2)	18.0 (17.4)	14.8 (20.9)	21.1 (21.2)
After 4 h						
2.5 min delay	59.4 (20.1)	59.4 (26.8)	59.4 (31.6)	47.7 (14.0)	44.5 (25.2)	50.8 (24.2)
12.5 min delay	57.4 (18.5)	57.0 (26.4)	57.8 (23.3)	39.8 (17.5)	39.8 (26.1)	39.8 (26.1)
22.5 min delay	56.6 (19.0)	59.4 (24.4)	53.9 (24.7)	37.9 (26.5)	39.1 (29.1)	36.7 (33.0)
42.5 min delay	55.9 (17.1)	60.9 (22.8)	50.8 (27.3)	36.7 (20.1)	34.4 (25.2)	39.1 (27.6)
After 24 h						
2.5 min delay	58.6 (22.3)	56.3 (25.4)	60.9 (32.3)	41.4 (23.4)	40.6 (30.9)	42.2 (26.5)
12.5 min delay	56.3 (20.1)	58.6 (24.3)	53.9 (27.8)	36.7 (22.4)	43.0 (34.3)	30.5 (24.4)
22.5 min delay	54.3 (25.7)	56.3 (33.6)	52.3 (28.7)	34.0 (19.1)	31.3 (22.0)	36.7 (25.4)
42.5 min delay	52.3 (21.4)	53.9 (29.9)	50.8 (26.6)	34.0 (16.9)	38.3 (26.2)	29.7 (24.9)
After 7 d						
2.5 min delay	41.8 (20.2)	46.9 (27.5)	36.7 (26.2)	26.2 (20.2)	25.8 (24.2)	26.6 (25.4)
12.5 min delay	38.3 (17.4)	38.3 (22.0)	38.3 (27.7)	25.0 (16.5)	25.0 (23.8)	25.0 (19.1)
22.5 min delay	42.6 (25.6)	41.4 (28.8)	43.8 (33.6)	25.8 (26.2)	25.8 (31.4)	25.8 (28.0)
42.5 min delay	43.4 (22.9)	44.5 (29.6)	42.2 (25.7)	26.6 (20.8)	30.5 (30.3)	22.7 (21.4)

For all combinations of reinstatement and delay conditions, recall performance for the first and second eight list items are shown together with recall performance for the first and second halves of these items. SD are shown in brackets. In the no-reinstatement condition, all items reflect target items of the experiment, whereas in the three reinstatement conditions, the first eight items reflect practiced items recalled in the first round of selective retrieval and only the second eight items reflect target items. Target items were always tested in the presence of their unique initial letters, practiced items in the presence of their unique word stems.

Temporal context drifts with the passage of time (28–30) and also drifts during memory encoding, so that the single encoded memories can include slightly different contextual information (17, 18, 31). Critically, attempts to reinstate the encoding context can fail to reactivate all context features and thus can fail to reactivate and reconsolidate all target memories, leaving some of the memories unaffected and further follow the original forgetting trajectory. Memories' overall rejuvenation level may thus be driven by the proportion of reactivated and reconsolidated memories in the set of encoded memories. Indeed, if reactivated memories mimic memories right after encoding with their high immediate retrievability and high forgetting rate, then high proportions of these memories lead to higher immediate retrievability and a higher rate of forgetting after the mental time travel than low proportions of reactivated memories do and also cause a higher rejuvenation level. The present results support this view.

Memories' rejuvenation levels can be high if people's attempts to reinstate memories' encoding context follow encoding within few hours (16), but the present research shows that rejuvenation levels decrease as the time interval between memory encoding and reinstatement attempts further increases, and rejuvenation can even fail if the time interval is sufficiently prolonged. This holds both when the reinstatement attempts occur rather unintentionally and indirectly through selective retrieval of other information and when the reinstatement attempts are deliberate and participants actively memorize details about their internal state at encoding, which points to very different possible routes for similarly successful context reinstatement. We anticipate that similar effects will arise in situations of daily life, like educational settings, eyewitness testimony situations, or when people try to recall details about earlier phases of their lives. However, due to the often richer context representations, rejuvenation levels may be higher in daily life than with many laboratory settings, making mental context reinstatement an all the more useful method to revive older memories.

Memories can differ in forgetting rates (21, 32). Of particular relevance for applied situations is the finding that memories that were subject to a memory test immediately after encoding show a reduced forgetting rate compared to memories that were just restudied after encoding or not repeated at all (33–35), a finding that critically contributes to the so-called testing effect and the typical superiority of testing over restudy for later memory performance (36, 37). Multiple mechanisms have been identified as a possible cause for this effect, among them an enrichment of tested memories' context representation (34, 38, 39). Indeed, retrieval can cause context change (40, 41) and the retrieval induced through testing immediately after encoding may thus create a richer context representation for tested memories. The richer context representation may be beneficial when trying to remember the memories later, but it may also be beneficial when trying to mentally reinstate the memories' context at encoding. Differences in memories' context representation may therefore influence both memories' forgetting rate and rejuvenation level in response to mental context reinstatement.

Research shows that apparently forgotten memories may not be erased from memory but only access to the traces be impaired (40, 42–44). Attempts to mentally reinstate older memories' temporal context at encoding can resolve such inaccessibility by rejuvenating the memories. The rejuvenation creates a cycle of enhanced retrievability followed by a restart of forgetting and consolidation processes. Recurring rejuvenation cycles induced by recurring attempts to reinstate memories' encoding context may thus be key to maintain memories' retrievability over longer periods of time. The resurrection of memories is like a Sisyphus task, indeed.

Materials and Methods

Experiment 1.

Participants. A total of 608 participants of different German universities (mean age 23.94 y, range 18 to 35 y, 80.6% females, 0.2% divers) took part in the experiment. They were divided into four groups. The three reinstatement groups consisted of four subgroups each and the no-reinstatement group of seven subgroups ($n = 32$ per subgroup). Sample size was guided by prior work (16) as well as the results of a power analysis (45) with $\alpha = 0.05$, $\beta = 0.20$, and effect sizes of $d = 0.80$ for expected forgetting over time and expected effects of selective retrieval (16, 24, 46). All participants were tested individually in an online video conference hosted by the software Zoom (Zoom Video Communications). Instructions were given by the experimenter, who was present during the entire experiment.

Materials. A list of 16 unrelated concrete German nouns with unique initial letters (46) was employed as study material. In the no-reinstatement group, all items served as target items. In the reinstatement groups, half of the list items served as target items, whereas the other half served as practiced items recalled during selective retrieval. Within each subgroup of the three reinstatement groups, it was counterbalanced which half of the list items served as target items, so that each of the 16 items served as target item equally often.

Procedure. Prior to participation, each participant in this experiment–as well as in experiment 2–provided informed consent. The protocol employed in this study was deemed exempt by the ethical review board of Regensburg University. The experiments were carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. The same four delay intervals (2.5, 12.5, 22.5, and 42.5 min) were employed after study in the no-reinstatement group and after selective retrieval in the three reinstatement groups. Selective retrieval followed 4 h, 24 h, or 7 d after the initial study phase. In the no-reinstatement group, three additional delay intervals were employed matched in time since study with the three selective retrieval conditions when recall was tested 2.5 min after the selective retrieval. These intervals were included to potentially demonstrate for each selective retrieval condition, the recall enhancement of target items right after the selective retrieval relative to recall in the matched no-reinstatement condition. The shorter delay intervals of up to 42.5 min were filled with neutral distractor tasks (16, 24), whereas for the longer intervals of 4 h, 24 h, and 7 d, the participants were dismissed for this period of time and rejoined the experiment later. During study, the list items were presented individually in a random order for 6 s each on the computer screen. Selective retrieval consisted of two rounds of retrieval practice. Within each round, the participants were asked to recall the practiced items. The items' unique word stems served as retrieval cues, which were presented in a random order for 6 s each (16, 24, 46–48). Responses were given orally. At test, participants of all groups were asked to recall the target items. The items' unique initial letters served as retrieval cues and were presented for 6 s each in a random order. In the reinstatement groups, recall of the target items was followed by recall of the list's practiced items.

Experiment 2.

Participants. Another 608 participants (mean age 23.88 y, range 18 to 32 y, 80.6% females, 0.2% diverse) were divided into four groups. Again, the no-reinstatement group consisted of seven subgroups and the three reinstatement groups of four subgroups each ($n = 32$ per subgroup).

Materials. The text passage "The Sun" served as study material (33). The German version of the text consisted of 251 words. The text was divided into four segments and four sentences were selected from each segment to serve as target sentences at test. The target sentences included most of the idea units used in the prior work with this text. We employed both a rather strict scoring method, in which, to be scored correct, the recalled facts had to match with the wording in the text, and a more liberal scoring method, in which each single fact was already scored correct if the gist of the fact was remembered regardless of whether the wording matched. Recall rates were generally higher with liberal scoring, but the pattern of results did not differ between scoring methods. We report results for the liberal scoring method.

Procedure. In its core elements, the procedure was similar to experiment 1, but it differed from experiment 1 in detail: a) At the beginning of the experiment, participants rated pictures of food items for 3 min to facilitate later mental context reinstatement of reinstatement groups (10, 46); b) participants studied the text through two 5-min study cycles, separated in time through a 1-min neutral distractor task; c) instead of selective retrieval, participants conducted a mental context reinstatement task, in which they were asked to recall and write down their thoughts, feelings, and emotions while rating the food items at the beginning of the experiment and while studying the text passage (10, 46); d) at test, gapped versions of the 16 target sentences from the text were presented for 20 s each and the participants were asked to fill in the missing target information (e.g., "Once the sun has used up its energy, it will begin to _____." [Answer: shrink]) or "The sun may throw off huge amounts of _____ in violent eruptions." [Answer: gases] (16, 20); the 16 sentences were presented in the order they occurred in the text (see also *SI Appendix*, Fig. S1).

Data, Materials, and Software Availability. Data and materials availability: The study materials employed in the present experiments as well as the data from the single experiments are available on the Open Science Framework (https://osf.io/p9xuh/?view_only=963f49de241d4c1e9db845060b008b8b) (49). All experiments reported in this manuscript were implemented using the software PowerPoint 2019 (Microsoft Corporation) and the software Zoom (Zoom Video Communications). The software was run on standard desktop computers with the operating system Windows 10 (Microsoft, Redmond, WA). Data were analyzed using IBM SPSS Statistics for Windows, Version 29.0.1 (IBMCorp., Armonk, NY), G*Power 3.1 (45) as well as C program code that was used to fit power functions to target recall rates. The program code used to fit the single power functions is also available on the Open Science Framework.

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1. H. Ebbinghaus, *Über das Gedächtnis* (Duncker & Humblot, Leipzig, Germany, 1885).
2. J. T. Wixted, E. Ebbesen, On the form of forgetting. *Psychol. Sci.* **2**, 409–415 (1991).
3. D. C. Rubin, A. E. Wenzel, One hundred years of forgetting: A quantitative description of retention. *Psychol. Rev.* **103**, 734–760 (1996).
4. M. Meeter, J. M. J. Murre, S. M. J. Janssen, Remembering the news: A forgetting study with 14,000 participants. *Mem. Cogn.* **33**, 793–810 (2005).
5. H. P. Bahrick, P. O. Bahrick, R. P. Wittlinger, Fifty years of memory for names and faces: A cross-sectional approach. *J. Exp. Psychol. Gen.* **104**, 54–75 (1975).
6. S. M. Smith, Remembering in and out of context. *J. Exp. Psychol. Hum. Learn. Mem.* **5**, 460–471 (1979).
7. S. M. Smith, E. Vela, Environmental context-dependent memory: A review and meta-analysis. *Psychon. Bull. Rev.* **8**, 203–220 (2001).
8. A. Memon, C. A. Meissner, J. Fraser, The cognitive interview: A meta-analytic review and study space analysis of the past 25 years. *Psychol. Public Policy Law* **16**, 340–372 (2010).
9. W. A. Wagenaar, My memory: A study of autobiographical memory over six years. *Cogn. Psychol.* **18**, 225–252 (1986).
10. L. Sahakyan, C. M. Kelley, A contextual change account of the directed forgetting effect. *J. Exp. Psychol. Learn. Mem. Cogn.* **28**, 1064–1072 (2002).
11. S. Folkerts, U. Rutishauser, M. W. Howard, Human episodic memory retrieval is accompanied by a neural contiguity effect. *J. Neurosci.* **38**, 4200–4211 (2018).
12. G. E. Müller, A. Pilzecker, *Experimentelle Beiträge zur Lehre vom Gedächtnis [Experimental Contributions to the Science of Memory]* (Zeitschrift für Psychologie Ergänzungsband, J. A. Barth, Leipzig, Germany, 1900).
13. L. Nadel, M. Moscovitch, Memory consolidation, retrograde amnesia and the hippocampal complex. *Curr. Opin. Neurobiol.* **7**, 217–227 (1997).
14. J. T. Wixted, On common ground: Jost's (1897) law of forgetting and Ribot's (1881) law of retrograde amnesia. *Psychol. Rev.* **111**, 864–879 (2004).
15. A. Jost, Die Assoziationsfestigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen. [The strength of associations in their dependence on the distribution of repetitions]. *Z. Psychol. Physiol. Sinnesorg.* **16**, 436–472 (1897).
16. K.-H.T. Bäuml, L. Trißl, Selective memory retrieval can revive forgotten memories. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2114377119 (2022).
17. M. W. Howard, M. J. Kahana, A distributed representation of temporal context. *J. Math. Psychol.* **46**, 269–299 (2002).
18. S. M. Polyn, M. J. Kahana, Memory search and the neural representation of context. *Trends Cogn. Sci.* **12**, 24–30 (2008).
19. K.-H.T. Bäuml, Context retrieval as a critical component in selective memory retrieval. *Curr. Dir. Psychol. Sci.* **28**, 177–182 (2019).
20. J. C. K. Chan, K. B. McDermott, H. L. Roediger III, Retrieval-induced facilitation: Initially nontested material can benefit from prior testing of related material. *J. Exp. Psychol. Gen.* **135**, 553–571 (2006).
21. J. T. Wixted, Absolute vs. relative forgetting. *J. Exp. Psychol. Learn.* **48**, 1775–1786 (2022).
22. J.-C. Falmagne, Psychometric functions theory. *J. Math. Psychol.* **25**, 1–50 (1982).
23. Y. Dudai, The restless engram: Consolidations never end. *Annu. Rev. Neurosci.* **35**, 227–247 (2012).
24. V. M. Kriechbaum, K.-H.T. Bäuml, The critical importance of timing of retrieval practice for the fate of nonretrieved memories. *Sci. Rep.* **13**, 6128 (2023).
25. A. D. Smith, Output interference and organized recall from long-term memory. *J. Verbal Learn. Verbal Behav.* **10**, 400–408 (1971).
26. H. L. Roediger III, Recall as a self-limiting process. *Mem. Cogn.* **6**, 54–63 (1978).
27. A. H. Criss, K. J. Malmberg, R. M. Shiffrin, Output interference in recognition memory. *J. Mem. Lang.* **64**, 316–326 (2011).
28. W. K. Estes, Statistical theory of spontaneous recovery and regression. *Psychol. Rev.* **62**, 145–154 (1955).
29. G. H. Bower, "A selective review of organizational factors in memory" in *Organization of Memory*, E. Tulving, W. Donaldson, Eds. (Academic Press, New York, NY, 1972), pp. 93–137.
30. G. J. M. Mensink, J. G. W. Raaijmakers, A model for interference and forgetting. *Psychol. Rev.* **95**, 434–455 (1988).
31. M. Lehman, K. J. Malmberg, A buffer model of memory encoding and temporal correlations in retrieval. *Psychol. Rev.* **120**, 155–189 (2013).
32. A. Nickl, K.-H.T. Bäuml, To-be-forgotten information shows more relative forgetting over time than to-be-remembered information. *Psychon. B. Rev.* **31**, 156–165 (2024).
33. H. L. Roediger III, J. D. Karpicke, Test-enhanced learning: Taking memory tests improves long-term retention. *Psychol. Sci.* **17**, 249–255 (2006).
34. N. Kornell, R. A. Bjork, M. A. Garcia, Why tests appear to prevent forgetting: A distribution-based bifurcation model. *J. Mem. Lang.* **65**, 85–97 (2011).
35. S. K. Carpenter, H. Pashler, J. T. Wixted, E. Vul, The effects of tests on learning and forgetting. *Mem. Cognit.* **36**, 438–448 (2008).
36. H. L. Roediger III, A. C. Butler, The critical role of retrieval practice in long-term retention. *Trends Cogn. Sci.* **15**, 20–27 (2011).
37. P. K. Agarwal, L. D. Nunes, J. R. Blunt, Retrieval practice consistently benefits student learning: A systematic review of applied research in schools and classrooms. *Educ. Psychol. Rev.* **33**, 1409–1453 (2021).
38. M. A. Pyc, K. A. Rawson, Why testing improves memory: Mediator effectiveness hypothesis. *Science* **330**, 335 (2010).
39. J. D. Karpicke, M. Lehmann, W. R. Aue, "Retrieval-based learning" in *of Psychology of Learning and Motivation*, B. H. Ross, Ed. (Elsevier Academic Press, San Diego, CA, 2014), vol. 61, pp. 237–284.
40. R. M. Shiffrin, Forgetting: Trace erosions or retrieval failure? *Science* **168**, 1601–1603 (1970).
41. Y. Jang, D. E. Huber, Context retrieval and context change in free recall: Recalling from long-term memory drives list isolation. *J. Exp. Psychol. Learn. Mem. Cogn.* **34**, 112–127 (2008).
42. E. Tulving, D. M. Thompson, Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* **80**, 352–373 (1973).
43. D. R. Godden, A. D. Baddeley, Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* **66**, 325–331 (1975).
44. E. Eich, D. Macaulay, L. Ryan, Mood dependent memory for events of the personal past. *J. Exp. Psychol. Gen.* **123**, 201–215 (1994).
45. F. Faul, E. Erdfelder, A. G. Lang, A. Buchner, Gpower 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods.* **39**, 175–191 (2007).
46. L. Wallner, K.-H.T. Bäuml, Beneficial effects of selective item repetition on the recall of other items. *J. Mem. Lang.* **95**, 159–172 (2017).
47. M. C. Anderson, R. A. Bjork, E. L. Bjork, Remembering can cause forgetting: Retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn. Mem. Cogn.* **20**, 1063–1087 (1994).
48. M. C. Anderson, B. A. Spellman, On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychol. Rev.* **102**, 68–100 (1995).
49. K.-H.T. Bäuml, S. R. Meixensperger, M. L. Hirsch, Reinstating memories' temporal context at encoding causes Sisyphus-like memory rejuvenation. OSF. https://osf.io/p9xuh/?view_only=963f49de241d4c1e9db845060b008b8b. Accessed 23 January 2025.