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Time-Related Decay or Interference-Based Forgetting in Working Memory?

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The time-based resource-sharing model of working memory assumes that memory traces suffer from a time-related decay when attention is occupied by concurrent activities. Using complex continuous span tasks in which temporal parameters are carefully controlled, P. Barrouillet, S. Bernardin, S. Portrat, E. Vergauwe, & V. Camos (2007) recently provided evidence that any increase in time of the processing component of these tasks results in lower recall performance. However, K. Oberauer and R. Kliegl (2006) pointed out that, in this paradigm, increased processing times are accompanied by a corollary decrease of the remaining time during which attention is available to refresh memory traces. As a consequence, the main determinant of recall performance in complex span tasks would not be the duration of attentional capture inducing time-related decay, as Barrouillet et al. (2007) claimed, but the time available to repair memory traces, and thus would be compatible with an interference account of forgetting. The authors demonstrate here that even when the time available to refresh memory traces is kept constant, increasing the processing time still results in poorer recall, confirming that time-related decay is the source of forgetting within working memory.

Keywords: working memory, forgetting, memory decay, interference

Among the different models of working memory (WM), two alternative hypotheses have been put forward to account for the forgetting of stored information, namely the time-related decay and the interference-based hypotheses. We recently proposed a model of WM called the time-based resource-sharing (TBRS) model in which forgetting is time related (Barrouillet, Bernardin, & Camos, 2004). Most of the evidence we provided to support the TBRS model and its temporal decay hypothesis relies on a complex span task paradigm by which we have demonstrated that variations in the duration of the attentional capture induced by processing affect recall performance (e.g., Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007). However, Oberauer and Kliegl (2006) noted that this paradigm leads to a confound between the duration of processing and the duration of the remaining time during which attention is available to refresh memory traces. According to these authors, this latter duration would be the main determinant of the effects we observed on recall by constraining the amount of refreshing activities that could repair the degradation of memory traces resulting from representation-based interference. If this alternative hypothesis proved to be correct, all the evidence sustaining the TBRS model would have to be drastically reassessed. The aim of the present report is to assess Oberauer and Kliegl's proposal by removing the confound they identified.

One of the main assumptions of the TBRS model is that the activation of memory traces suffers from a time-related decay as soon as attention is switched away. Because processing and maintenance of information within WM rely on the same limited attentional resource, the memory traces of the items to be maintained fade away when attention is occupied by processing. The refreshing of these items before their complete disappearance requires their reactivation by attentional focusing. Thus, attention must be shared between processing and maintenance through a rapid switching occurring in the short free pauses that can be available during processing. According to the TBRS model, the cognitive load a given task involves corresponds to the proportion of time during which attention is captured by this task, thus impeding the refreshing of decaying memory traces of the to-be-maintained items.

When the total time allowed to perform the processing component of a WM span task is kept constant, the TBRS model predicts that any increase in the duration of the attentional capture induced by this processing should lead to an increase in cognitive load and hence to lower recall performance. Accordingly, we have recently shown that increasing the duration of the processing component has a detrimental effect on concurrent memory performance (Barrouillet

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et al., 2007). For example, in Barrouillet et al.'s (2007) Experiment 2, participants had to judge the location (up or down) of series of squares appearing successively on-screen while maintaining letters for further recall. By manipulating the discriminability of the two locations, which were either close or distant, we manipulated processing times that were longer in the close condition. We reasoned that longer processing times reveal an increase in the duration of attentional capture during which memory traces fade away and, therefore, should result in poorer recall in the close condition. As the TBRS model predicted, the recall was indeed weaker when the location task took longer.

Though this result provides evidence for the TBRS model, Oberauer and Kliegl (2006) have put forward an alternative explanation. They noted that, because the interval between two successive items to be recalled is usually kept constant in our paradigm, any increase in the duration of the processing component results inevitably in a related decrease in the time available to refresh memory traces. Thus, the weaker recall performance observed by Barrouillet et al. (2007) in the close condition could be due to this reduction of the time available for refreshing activities. Interference could then be equally the source of forgetting and not the time-related decay induced by a prolonged capture of attention.

Oberauer and Kliegl (2001, 2006) proposed a formal model of WM in which there is no time-related decay, with forgetting being exclusively due to representation-based interference. In this model, each item is represented by the simultaneous activation of a set of features. Because the number of features is limited, the same features could be required to encode different items. Thus, two items sharing some features would compete for them, and one of these items would lose these features through a feature-overwriting mechanism (Nairne, 1990; Neath, 2000), resulting in degraded memory traces. When attention is available, it can be used to repair partially degraded traces (Lewandowsky, 1999; Schweickert, 1993). A redintegration mechanism or an elaborative rehearsal could restore the representations by enriching them with more features or by recoding items with fewer feature overlaps. According to this account, in Barrouillet et al.'s (2007) Experiment 2, the close condition reduced the time available to restore memory traces, inducing the observed reduction in recall performance. Thus, because the processing time and the time available for refreshing covaried in Experiment 2, the time-based decay and the interference hypotheses could not be disentangled.

The present experiment aimed at determining the locus of forgetting in WM by manipulating processing time while keeping constant the time available for refreshing activities. To this end, we used the same continuous span task as in Experiment 2 of Barrouillet et al. (2007). In this previous experiment, a square was displayed on-screen every second in both conditions. Thus, the time available for refreshing was reduced when the processing time increased. By contrast, in the present experiment, the response to each square was followed by a constant delay of 650 ms before the appearance of the next square. Therefore, although the two conditions (i.e., close and distant squares) differed on the processing time, the time available for refreshing was kept constant. The two hypotheses of forgetting in WM led then to opposite predictions. If interference is the key of WM forgetting, recall should not differ between the two conditions because the time available to repair partially degraded memory traces is equated. By contrast, if a time-related decay is responsible for the loss of information in WM, the close condition that induces longer periods of time during which attention is diverted from maintenance should result in poorer recall. According to the TBRS model, recall performance is a function of the cognitive load induced by the processing component that is the proportion of time during which attention is captured. If *PT* is the processing time and *FT* the time available for refreshing in the distant condition, the cognitive load in the distant condition can be approximated by the ratio $PT/(PT + FT)$. Increasing *PT* by a value Δpt while keeping *FT* constant, as in the close condition of the present experiment, leads to a greater ratio $(PT + \Delta pt)/(PT + \Delta pt + FT)$. Thus, even when equating the time available for refreshing, the close condition still involves a greater cognitive load and should induce lower recall performance.

Method

Participants

Twenty-four undergraduate women students at the Université de Bourgogne received a partial course credit for participating. Their mean age was 19.5 years ($SD = 1.0$).

Material and Procedure

Participants were seated about 60 cm from the computer screen and presented with a series of three to eight consonants to be remembered. Each consonant was followed by a series of eight stimuli successively displayed on-screen. These stimuli were the same as those used in Experiment 2 of Barrouillet et al. (2007). They consisted of a black square (side = 18 mm subtending 2° in visual angle) centered on one of two possible locations, either in the upper or the lower part of the screen. In each condition and each series, squares were randomly displayed in both locations with the same frequency. In the distant condition, the two locations were 68 mm apart (6.5° in visual angle), whereas in the close condition this distance was reduced to 5 mm (0.5° in visual angle). For each length, 3 series of consonants were associated with each condition of discriminability in the location task, resulting in a total of 36 series of consonants to be remembered that were presented to each participant according to two fixed random orders of presentation.

Each series began by a first screen indicating during 2,000 ms the number of letters to be remembered (e.g., "5 items to be memorized") and the discriminability condition ("close stimuli" or "distant stimuli"). After a white screen of 500 ms, a ready signal (an asterisk) centered on-screen for 750 ms was followed by a 500-ms delay. Then the first letter appeared for 1,500 ms, followed by a 500-ms delay. After this postletter delay, eight successive squares were displayed on-screen for 666 ms each. The participants' response on keyboard for each square triggered a constant delay lasting 650 ms[1] before the next square or letter appeared and was available for refreshing. However, the participants' response did not trigger the disappearance of the current square, which was always displayed for 666 ms to prevent participants from strategically controlling the progress of the experiment. Figures 1A and 1B depict the design of this experiment for the distant and the close conditions respectively.

[1] The duration of the constant delay was set to 650 ms because it was the mean observed refreshing time across conditions in Barrouillet et al.'s (2007) Experiment 2.

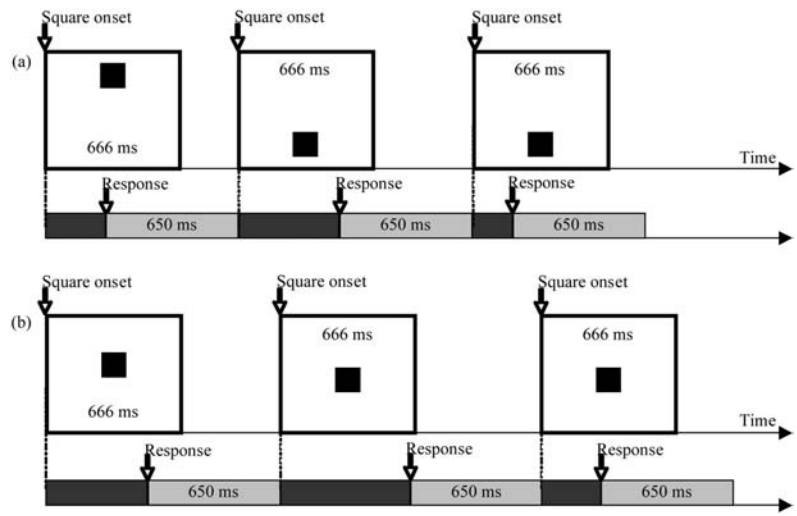

Figure 1. Time course of the successive events with processing time (black bars) and time available for refreshing (grey bars) between two successive stimuli of the location judgment task for the distant (A) and close (B) conditions.

Participants were asked to read aloud each letter when it appeared and to judge the location of each square as fast as possible without sacrificing accuracy by pressing either a left- or a right-handed key for the lower and the upper locations, respectively. At the end of each series, the word "rappel" (recall) was displayed on-screen, and the participants were asked to write down the letters in correct order by filling out frames containing the appropriate number of boxes. Besides the letters recalled, reaction times and accuracy during the location task were recorded. A training phase familiarized participants with the location task on 144 squares distributed on nine series of each discriminability condition randomly presented. In this training phase, squares appeared during 666 ms, followed by a constant delay of 334 ms. This computer-paced procedure was favored to prevent participants from developing any strategy. In this training phase, participants heard a beep if they made a mistake or if they were too slow in responding (i.e., more than 1 s). If they did not reach 80% of correct responses, they were asked to perform again the same series of squares with a maximum of three training phases. Before the testing phase itself, they performed three series of the WM task as examples.

Results

All the participants succeeded the location task training. The 24 participants reached a high rate of correct responses that were nonetheless more frequent in the distant than in the close condition (99% and 87%, respectively), $t(23) = 13.77$, $p < .001$.

We first verified that the processing time was indeed higher in the close than in the distant condition, as observed in Barrouillet et al.'s (2007) experiment, and that the time available to refresh memory traces was actually constant across conditions. Then we reported the results concerning recall performance.

Response Time Analyses

As previously observed by Barrouillet et al. (2007), the mean response time to judge the location of squares was longer in the close than in the distant condition (415 ms, $SD = 52$, and 345 ms, $SD = 40$, respectively), $t(23) = 17.13$, $p < .001$. Although these participants were slower than those in Barrouillet et al.'s Experiment 2 (377 ms and 314 ms for the close and the distant condition, respectively), the difference between the two conditions remained approximately the same (70 ms vs. 63 ms), $t(46) = 1.04$, $p = .30$.

The delay between the responses and the onset of the following square was controlled by the timer of Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Nevertheless, we verified the actual duration of this delay in each condition by subtracting the response time for each square to the difference between the onset of the current square and the following one. Although the mean duration of the delay was slightly higher than the 650 ms planned, this duration was exactly the same in both conditions (657 ms). Thus, as the test of our hypothesis required, the close condition did induce longer processing time, but the time available for refreshing memory traces did not differ between conditions.

Recall Performance Analyses

In line with the time-based decay hypothesis, the percentage of letters recalled in correct order was lower in the close condition (78%, $SD = 11$) than in the distant condition (82%, $SD = 9$), $t(23) = 2.59$, $p < .05$. Even when the order was not taken into account, the same effect was observed (88%, $SD = 9$, and 93%, $SD = 5$, respectively), $t(23) = 3.43$, $p < .01$. For sake of comparison, Barrouillet et al. (2007) reported 75% and 83% of letters recalled in correct order for the close and the distant condition, respectively (86% and 92%, respectively, when order was not taken into account). The 4% effect observed on recall in the present experiment did not differ from the 8% in Barrouillet et al.'s experiment, $t(46) = 1.12$, $p = .27$. The same pattern was observed when order was not taken into account; the 5% effect observed here did not differ from the 6% effect in Barrouillet et al.'s experiment ($t < 1$).

The difference in recall observed between the close and the distant condition in the present experiment cannot be due to a

trade-off between accuracy in the secondary task and maintenance of memory items because the close condition elicited both the lower recall performance and the higher rate of error in the location judgment task. More errors in the close condition could reflect less attention paid to the intervening task and thus more attention available to maintain memory items, which would run counter to our hypothesis.

Discussion

The present findings demonstrate that, contrary to Oberauer and Kliegl's (2006) hypothesis, the time available for refreshing memory traces is not the main determinant of forgetting in complex span tasks. Even when this time is kept constant, recall performance decreases as the time during which processing occupies attention increases, lending strong support to the TBRS model, which assumes that recall performance is an inverse function of time during which attention is engaged in processing, impeding the refreshing of memory traces.

The fact that increasing processing time has a damaging effect on memory maintenance even when refreshing periods are similar cannot be explained by the interference phenomenon as described by Oberauer and Kliegl (2006). According to this representation-based interference hypothesis, each processing step generates an amount of interference that depends on the degree of overlap between the memory items and the representations involved in the processing component of the task. It is worth noting that, according to Oberauer and Kliegl's account, time would not play any role in the process of interference itself except in the possibility to repair the damaging effects of these interferences through refreshing activities. As a consequence, when the time available to refresh memory traces is constant, recall performance should no longer vary between conditions. Moreover, it cannot be imagined that subtle differences in spatial location of black squares (a change of only 3 cm of location on-screen) would induce such differences in the amount of representation-based interference with verbal material, that we would observe significant and replicable differences in recall performance.

In our view, the easiest way to account for the observed phenomena is to assume a time-based decay of memory traces. The simple hypothesis that the activation of memory traces suffers from a passive time-related decay when attention is switched away is sufficient to understand that longer attention-demanding processing episodes result in lower memory performance when all other things are kept constant. Of course, as suggested by Oberauer and Kliegl (2006), the time available for refreshing mechanisms also plays a major role, as suggested by the reduced, although not significant, effect observed in the present experiment when compared with the experiment in Barrouillet et al. (2007). In this latter experiment, both longer processing times and shorter refreshing times converged to reduce recall performance in the close condition (8% of letter recall in correct order). The present experiment revealed a smaller effect (4%) because the time available for refreshing was equated across conditions that differed only in processing time. However, there is overwhelming evidence that recall performance depends on the ratio between these two times (Barrouillet et al., 2004, 2007; Barrouillet & Camos, 2007; Lépine, Bernardin, & Barrouillet, 2005). This cannot be understood without assuming that the integrity of the memory traces maintained in WM is affected by the sheer passage of time, as many models of short-term memory and WM have assumed (Baddeley, 1986; Cowan, 2005; Page & Norris, 1998).

Assuming a time decay mechanism within WM does not exclude any representation-based interference corrupting memory traces. As we already discussed in Barrouillet et al. (2007), these two forgetting mechanisms could even be related. As suggested by Posner and Konick (1966) in their acid-bath theory, stored items would tend to lose precision of information over time. The activation of their features and the bonds between them would become weaker and weaker with time, thus increasing the probability of competition between representations for a given feature. As stressed by Posner and Konick (1966, p. 230), "such effects can be eliminated when full capacity is available for rehearsal." This last proposal is of course akin to Oberauer and Kliegl's (2006) suggestion, but the present results demonstrate that forgetting in WM cannot be properly understood without assuming a time-based decay mechanism, as suggested by the TBRS model.

References

Baddeley, A. D. (1986). *Working memory*. Oxford, England: Clarendon Press.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General, 133,* 83–100.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 570–585.

Barrouillet, P., & Camos, V. (2007). The time-based resource-sharing model of working memory. In N. Osaka, R. Logie, & M. D'Esposito (Eds.), *The cognitive neuroscience of working memory* (pp. 59–80). Oxford, England: Oxford University Press.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). Psyscope: A new graphic interactive environment for designing psychology experiments. *Behavior Research Methods, Instruments, & Computers, 25,* 257–271.

Cowan, N. (2005). *Working memory capacity*. Hove, England: Psychology Press.

Lépine, R., Bernardin, S., & Barrouillet, P. (2005). Attention switching and working memory spans. *European Journal of Cognitive Psychology, 17,* 329–345.

Lewandowsky, S. (1999). Redintegration and response suppression in serial recall: A dynamic network model. *International Journal of Psychology, 34,* 434–446.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition, 18,* 251–269.

Neath, I. (2000). Modeling the effects of irrelevant speech on memory. *Psychonomic Bulletin & Review, 7,* 403–423.

Oberauer, K., & Kliegl, R. (2001). Beyond resources: Formal models of complexity effects and age differences in working memory. *European Journal of Cognitive Psychology, 13,* 187–215.

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language, 55,* 601–626.

Page, M. P. A., & Norris, D. (1998). The primacy model: A new model of immediate serial recall. *Psychological Review, 105,* 761–781.

Posner, M. I., & Konick, A. W. (1966). On the role of interference in short-term retention. *Journal of Experimental Psychology, 72,* 221–231.

Schweickert, R. (1993). A multimodal processing tree model for degradation and redintegration in immediate recall. *Memory & Cognition, 21,* 168–173.

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