Ranschburg Unrepeated

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Open Science statement:

The study was not pre-registered.

All the data and codes have been made available on the Open Science Framework: https://osf.io/u4fpr/

Abstract

In verbal working memory (WM), the second occurrence of an item in a memory list generally leads to impaired recall performance, a phenomenon called the "inhibitory Ranschburg effect". Current WM models explain this inhibitory effect via response suppression, a mechanism by which an item is removed from the set of retrieval candidates once recalled. Hence, according to this theoretical explanation, the inhibitory effect depends on the order in which the repeated item is recalled. It therefore follows that the inhibitory effect should be observed for the first occurrence of an item when items are recalled backward. The purpose of the present study was twofold. First, we aimed at determining the generality of the inhibitory effect by extending it to the visuospatial domain. Second, we tested the response suppression assumption using a forward/backward recall procedure. After a first unsuccessful attempt to replicate the inhibitory Ranschburg effect using visuospatial stimuli, we sought to replicate the original effect using verbal materials. An additional series of six experiments failed to consistently replicate the inhibitory Ranschburg effect. Simulations show that if the inhibitory Ranschburg effect exists, it is unlikely to be explained by response suppression. The present study questions the importance of the Ranschburg effect for models of WM.

Keywords: Working Memory; Ranschburg effect; Serial recall

Introduction

Working memory (WM) is the ability to hold task-related information in mind and is of limited capacity (Baddeley, 1992). One of the factors appearing to influence WM capacity is the presence of repetitions in lists of items to be remembered (Henson, 1998a; Jahnke, 1969b; Kahana & Jacobs, 2000; Logan, 2021; Wickelgren, 1965), a phenomenon known as the *Ranschburg effect*. When two repeated items are presented directly next to each other, immediate recall performance increases for these items, producing a facilitatory effect. In contrast, when two repeated items are presented further apart from each other, recall performance for the second occurrence of the same item decreases, producing an inhibitory effect. One way to explain the inhibitory aspect of the Ranschburg effect is through response suppression, by which items are removed from WM after being recalled (Henson, 1998a; Lewandowsky, 1999). So far, the inhibitory effect has only been observed in the verbal domain (Oberauer et al., 2018) and remains unexplored in other domains. The aim of this study was twofold: First, we explored whether the inhibitory effect extends to the visuospatial domain. Second, we aimed to test a core prediction from the response suppression account, according to which the inhibitory effect depends on the direction in which items are retrieved, as opposed to the direction in which they are encoded.

The Ranschburg effect was initially observed by Ranschburg (1902). In his original study, he used an immediate serial recall task involving participants encoding short lists of stimuli (digits or letters) that they had to repeat back in their presentation order. Ranschburg showed that when a list included repetitions of the same items (e.g. ABCBD, ABBCD), the repeated items were more poorly recalled as compared to non-repeated items in equivalent control list positions (e.g. ABCDE, ABCDE). Contrary to the initial results found by Ranschburg, subsequent studies (Henson, 1998a; Jahnke, 1969b; Logan, 2021; Wickelgren, 1965) found that immediate repetitions (i.e. ABBCD) improved memory performance (*facilitation effect*), while repetitions impaired performance only when occurring over more distant positions (i.e. ABCBD) (*inhibitory effect*).

The facilitation effect occurring when two items are presented next to each other is generally explained by a form of grouping mechanism, in which participants detect the repetition and use it to reduce the load they carry in WM (Crowder, 1968; Henson, 1998a; Wickelgren, 1965). The repetition inhibitory effect is more controversial, early explanations suggesting that it occurs through a failure to detect repetitions at encoding (Crowder & Melton, 1965; Jahnke, 1969b). It has also been suggested that during recall, participants might forget that the list contains a repetition, despite its successful encoding (Jahnke, 1969b). An alternative explanation for the Ranschburg effect is that people are more likely to recall an item that has not already been recalled (Greene, 1991). A further hypothesis proposed by Jahnke (1969b) is that participants no longer remember which item is being repeated. Henson (1998a) tested this hypothesis by asking participants to note cases where they were uncertain of their answer. Contradicting Jahnke's hypothesis, the inhibitory effect remained after eliminating uncertain responses.

Henson (1998a) explained the inhibitory effect via *response suppression*, whereby an item, once recalled, is inhibited or removed from WM. For instance, recalling "A" in the list "ABCD" removes the letter "A" from the set of retrieval candidates, which renders "A" unavailable for subsequent retrieval attempts. In standard immediate serial recall tasks, people rarely repeat the same item twice (Henson et al., 1996), as repetition errors typically constitute only about 5% of the total number of errors. In computational models of WM, an excessive rate of repetition errors is typically prevented by implementing response suppression (Burgess & Hitch, 1999;

Henson, 1998b; Oberauer et al., 2012; Page & Norris, 1998). Most models of WM can therefore explain the inhibitory aspect of the Ranschburg effect via response suppression.

Other results seemingly contradict the response suppression hypothesis. The study by Kahana and Jacobs (2000) used a backward recall procedure in lists containing repeated items. In their study, participants were asked to successively learn 36 different lists of consonants with a learning criterion of three consecutive successful recalls. Once participants had successfully completed the three consecutive recalls for a given list, they were asked to recall the same list in backward order (e.g., recalling “DCBA” instead of “ABCD”). Contrary to what the response suppression hypothesis would have predicted, recall performance for the second occurrence of repeated items did not decrease in backward recall compared to items in the same position in a control list. The study by Kahana and Jacobs is however difficult to take as evidence against the response suppression account given that their task likely tapped recall from long-term memory rather than WM.

The present study

This study focuses on the inhibitory aspect of the Ranschburg effect. This repetition-induced inhibitory effect is potentially important from a theoretical perspective, as it might be indicative of a general response suppression mechanism during WM recall. As already noted, many computational models of verbal WM incorporate such a mechanism (Henson, 1998b; Hurlstone & Hitch, 2015; Lewandowsky, 1999; Oberauer et al., 2012; Oberauer & Lewandowsky, 2011). We may therefore expect that this effect could also appear in other WM domains, such as the visuospatial one.

Despite numerous studies on the Ranschburg effect, the vast majority of them focused on verbal WM (Henson, 1998b; Jahnke, 1969b; Kahana & Jacobs, 2000; Wickelgren, 1965) with the exception of two studies using tactile stimuli (Johnson et al., 2019; Roe et al., 2017). Given the importance of response suppression for models of WM, it is critical to test the existence of a Ranschburg effect spanning beyond verbal WM. To the best of our knowledge, no study investigated whether a Ranschburg effect could also be observed in visuospatial WM. The present study addresses this gap by examining the occurrence of an inhibitory Ranschburg effect using spatial locations as memoranda. In addition to this, we test a core prediction which logically follows from the response suppression mechanism. Specifically, if response suppression explains the inhibitory Ranschburg effect, this means that the successful retrieval of an item should prevent subsequent recall of the same item. Indeed, after a first successful recall (e.g., recalling the letter “C” in “ABC”), response suppression should prevent subsequent repetitions of that same item (e.g., recalling a second time “C” in “ABCDC”), because that item is now discarded from the set of recall candidates. Therefore, it follows that the inhibitory Ranschburg effect should depend on the direction in which items are *recalled*, not the way they are *encoded*. We tested this prediction by orthogonalizing encoding and recall order using a forward-backward recall procedure, by which participants recall items in either the same or the reverse order relative to encoding order. If the inhibitory Ranschburg effect arises due to items being discarded from the set of plausible candidates once recalled on a first occasion, the effect should reverse in backward recall. Specifically, there should now be a recall disadvantage for the repeated item that *occurred first*, as it has to be recalled second in backward recall.

To foreshadow the results of this first experiment, we failed to show an inhibitory effect for visuospatial memoranda. This null result led us to drift from our initial research question, by testing if an inhibitory effect could be observed at all. To do this, we progressively moved from an elaborated investigation of the inhibitory Ranschburg effect to a replication attempt of the basic Ranschburg effect. Experiment 2 used an experimental paradigm closely matched to Experiment 1 using verbal stimuli as memoranda. Experiment 3 used a different recall procedure, and Experiment 4 dropped the backward recall direction. Experiment 5 replicated Experiment 4 using a faster presentation rate. Experiments 6 and 7 included adjacent repetition pattern and the manipulation of recall direction for the latter. Across these seven experiments, we failed to observe a consistent inhibitory Ranschburg effect. This failure to replicate the inhibitory aspect of the Ranschburg effect led us to estimate in a simulation work the magnitude of the Ranschburg effect that should have been observed if it had been explained by response suppression.

Experiment 1

In Experiment 1, we tested the presence of an inhibitory Ranschburg effect in the visuospatial WM domain. Participants memorized sequences of locations and reproduced them immediately after encoding. We included two types of retrieval directions: forward and backward. In forward recall, participants reproduced the sequences in their original order, while in backward recall, they reproduced them in *reverse* order. From this manipulation, we predicted two outcomes. First, if the inhibitory Ranschburg effect also characterizes the visuospatial domain, recall performance for the second occurrence of the same item should decrease in forward recall. Second, if response suppression explains the inhibitory Ranschburg effect, we should observe the opposite pattern in backward recall, where recall performance should decrease for the first occurrence of the repeated item.

Methods

Transparency and openness. All the data, codes and materials across all experiments have been made available on OSF: https://osf.io/u4fpr/. The study was not pre-registered.

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. (https://prolific.co/). We used a sequential sampling approach, by stopping data collection when the criterion of a $BF_{01} > 5$ or a $BF_{10} > 10$ for the effect of interest was reached (Schönbrodt & Wagenmakers, 2018). The effect of interest was the interaction between the recall direction and the repetition. We started with 30 participants, increasing by 10 until we reached the criterion. All participants were English native speakers, reported no history of neurological disorder or learning difficulties. All participants gave their electronic informed consent before starting the experiment. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

Material. The stimuli consisted of a 6x6 grid composed of grey squares on a white background (see **Figure 1**). Each location to be remembered was signaled by a square changing color from grey to black. For each sequence, there were six successive locations to be remembered.

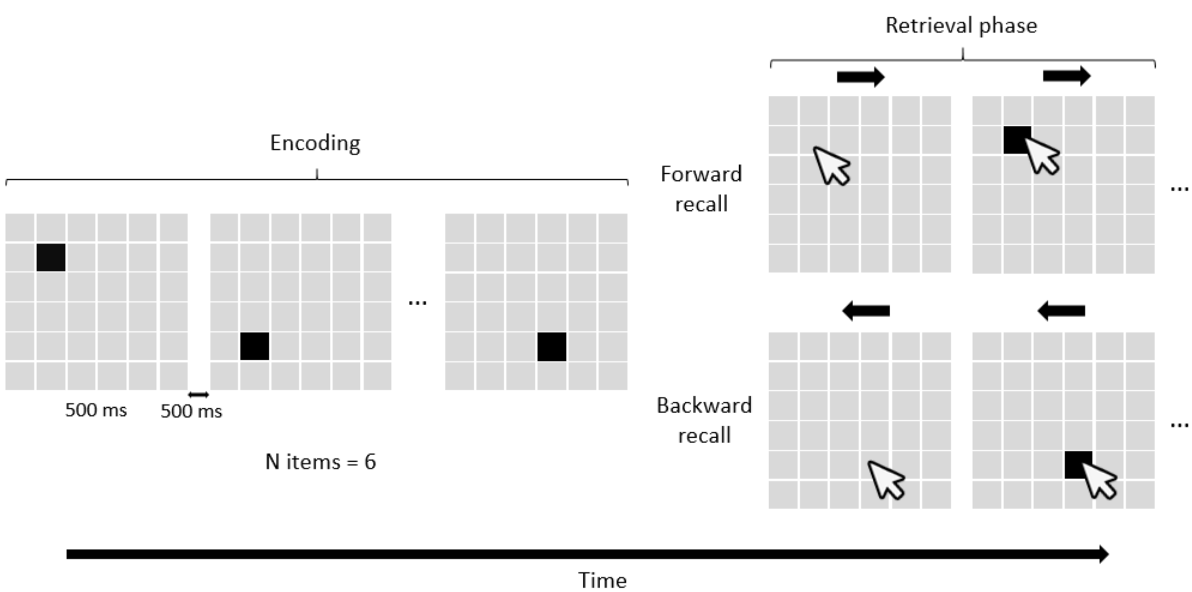
Sequences were constructed with the constraint that each location had a minimum Euclidean distance[1] of two from any other location within a given trial list. Corner locations were never included because we believed that they would be too salient and easy to remember. The number of border and inner side locations was equalized across all trials. The inhibitory Ranschburg sequences included repeated locations and were divided into seven repetition patterns:1-3, 1-4, 2-4,

[1]In our design, a Euclidean distance of 1 corresponds to the distance between two squares side by side.

2-5, 3-5, 3-6, 4-6, where each number corresponds to the serial positions at which the repeated items occurred. For example, in the sequence *ABCDEF*, the repetition pattern “1-3” would lead to *ABADEF*. No item was repeated in the control condition. There was a total of 112 experimental trials, resulting in 28 trials for each of the four conditions (backward/forward, repeated/non-repeated). We randomized the order in which the conditions were presented, with the constraint that a given condition could not appear more than five times consecutively.

Figure 1

Experiment 1 – Task setup



Note. Participants were presented with six successive locations and reproduced them in their original presentation order (forward recall) or in reverse order (backward recall).

Design. The present experiment is a 2 × 2 × 2 (repeated vs. non-repeated item, forward vs. backward recall, first vs. second occurrence) within-subject design. To simplify the design, we computed a difference score (see scoring procedure below) between the non-repeated and repeated conditions, and used it as depend variable.

Procedure. The task is illustrated in **Figure 1**. Each trial started with the successive presentation of six locations. The locations were presented at a rate of 1 second/location (500 ms on, 500 ms off). At retrieval, participants reproduced the sequence by clicking on the corresponding squares. The direction of recall was indicated by an arrow pointing to the left or to the right for the forward and backward recall directions, respectively. Once participants had reproduced all six locations, the text "Next" was displayed in the center of the screen. Clicking on “Next” initiated the next trial. Participants were instructed to always indicate six locations, even if they forgot a particular location. During the presentation of the locations, the mouse cursor disappeared and re-appeared only during the recall phase, which discouraged participants from using the mouse cursor as an aid to encode the locations. The recall direction was always post-cued, which means that participants did not know prior to the retrieval phase in which direction they had to recall a given sequence. Online task presentation and timing were controlled by a program coded in JavaScript, HTML5 and CSS. The stimuli had been generated using Python 3.8 (https://www.python.org).

Scoring procedure. Performance was measured using the Euclidean distance between the target and the response. A correct response corresponds to a score of 0, while a Euclidean distance of 1 corresponds to the distance between two squares side by side. Hence, lower values indicate higher memory performance. In the repeated condition, we computed the Euclidean distance between targets and responses for the two repeated locations, and averaged those values across all repetition patterns. In the non-repeated condition, we iteratively computed the Euclidean distance between targets and responses for the locations corresponding to each repetition patterns (1_3, 1_4, 2_4, 2_5, 3_5, 3_6, 4_6). This means that we used all non-repeated trials 7 times: once for each repetition pattern. For instance, given the sequence “ABCDEF”, and the repetition pattern “1-3”, we computed the Euclidean distance between targets and responses for items 1 and 3 for each trial in the no-repeated condition. We then repeated this process for the repetition pattern “1_4”, and so on. When then averaged those values across all repetition patterns. After computing the Euclidean distance between targets and responses for both conditions, we computed an difference score, which is the difference between the no-repeated and repeated conditions in equivalent serial positions, a negative score indicating an inhibitory effect.

Statistical analysis. We conducted Bayesian analyses using the BayesFactor package (Morey & Rouder, 2012) implemented in R[2]. We used the classification of strength of evidence proposed by Jeffreys (1998): a BF of 1 provides no evidence, 1 < BF < 3 provides anecdotal evidence, 3 < BF < 10 provides moderate evidence, 10 < BF < 30 provides strong evidence, 30 < BF < 100 provides very strong evidence and 100 < BF provides extreme/decisive evidence. For Bayesian ANOVAs, we used a top-down approach by comparing the most complex model (i.e., including all possible main effect and interaction effect) with a model that does not include our effect of interest. For all analysis, we set the number of Monte Carlo simulation to n = 100,000 in order to minimize the error in model estimation. The effect size was calculated with frequentist statistics using the ez package (Michael A. Lawrence , 2009).

[2] We first ran more complex mixed models using the brms package. Due to unsolvable convergence problems, we decided to run ANOVAs instead.

Result

We assessed the presence of an inhibitory effect as a function of occurrence (first, second) and recall direction (forward, backward) using Bayesian repeated measures ANOVAs on the difference score. We found anecdotal evidence against the interaction term (BF_{01} = 2.786, η^2_p = 0.007). We also found moderate evidence against the presence of a recall direction effect (BF_{01} = 4.76, η^2_p = 0.008) and moderate evidence against an occurrence effect (BF_{01} = 5.168, η^2_p = 0.027). Despite the absence of interaction and main effects, we had strong hypotheses relative to the locus of a potential inhibitory effect. We therefore conducted exploratory Bayesian one-sample t-tests, by examining whether the difference score deviated from 0 in any condition.

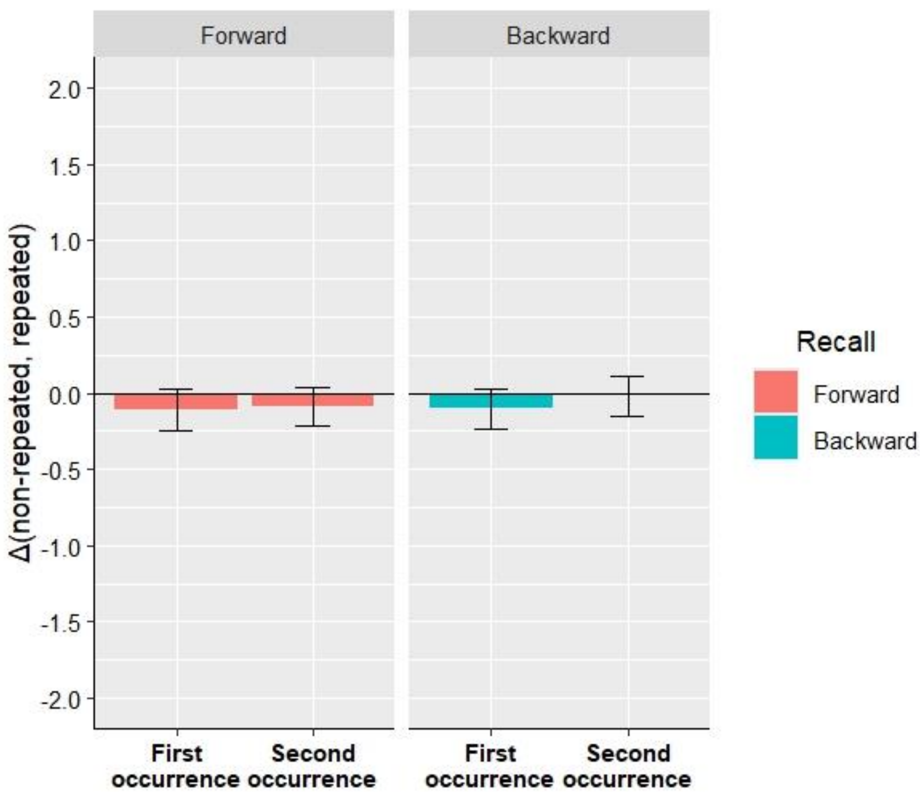
In forward recall, the inhibitory Ranschburg effect should typically lead to an inhibitory effect (i.e. a negative difference score) for the second occurrence of the repeated item, while no inhibitory effect should be observed for its first occurrence. A Bayesian one-sample t-test over the first occurrence of the repeated item led to anecdotal evidence against an inhibitory effect (BF_{01} = 1.659, d = 0.263). This was similarly observed for the second occurrence, with anecdotal evidence against an inhibitory effect (BF_{01} = 2.373, d = 0.221). These results are illustrated in **Figure 2**, left panel**.**

Next, we ran the same Bayesian one-sample t-tests in the backward recall direction. If response suppression is the main cause of the inhibitory Ranschburg effect, we expect to observe an inhibitory effect (i.e., a negative difference score) for the first occurrence of the repeated item (which in backward recall has been recalled second). This was not observed (see also **Figure 2**, right panel), as the Bayesian one-sample t-test led to anecdotal evidence against an inhibitory effect for the first occurrence of the repeated item (BF_{01} = 1.914, d = 0.247). Similarly, we found moderate evidence against an inhibitory effect for the second occurrence (BF_{01} = 5.643, d = 0.044).

Serial position curves are reported in **Figure 3**. In forward recall, primacy and recency effects are observed, as typically found in immediate serial recall experiments. In backward recall, this pattern reversed, reflecting the influence of output interference (see also Cowan et al., 2002; Oberauer, 2003).

Figure 2

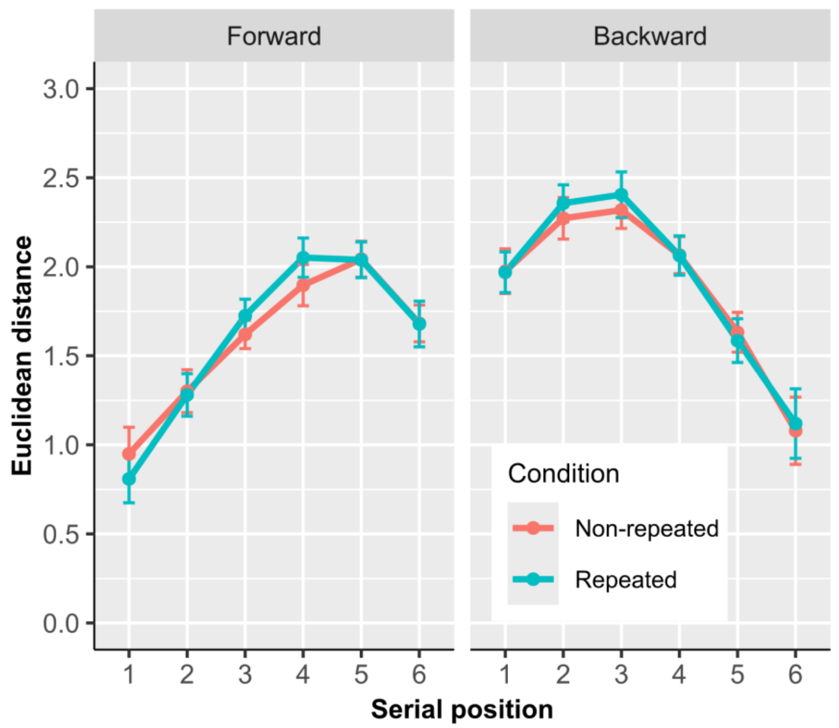
Experiment 1 – Difference score as a function of recall direction and occurrence condition.



Note. The y axis represents the difference between the non-repeated and repeated (Ranschburg) conditions. A negative score indicates an inhibitory effect. Left panel: Forward recall direction. Right panel: Backward recall direction. First occurrence: The first occurrence of the repeated item relative to the encoding direction (e.g., the first appearance of “C” in “ABCDC”). Second occurrence: The second occurrence of the repeated item relative to the encoding direction (e.g., the second appearance of “C” in “ABCDC”). Error bars represent 95% confidence intervals.

Figure 3

Experiment 1 – Mean Euclidean distance as function of recall direction and repetition condition for each serial position.



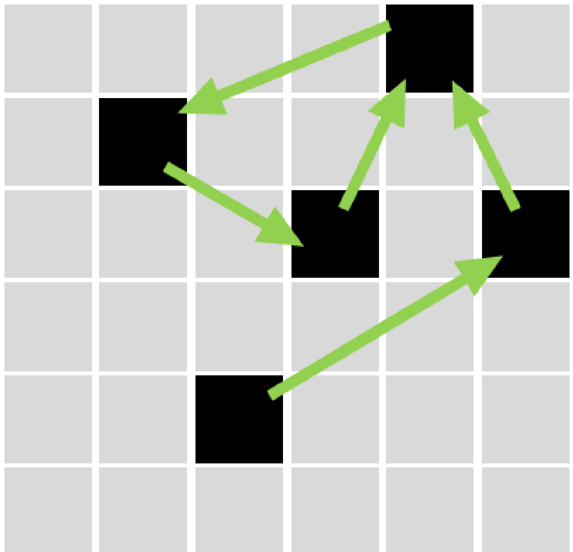
Note. Mean Euclidean distance as a function of recall direction (left panel: forward recall, right panel: backward recall) and repetition condition (repeated, non-repeated) for each serial position. Error bars represent 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Contrary to what has previously been observed the verbal domain (Henson, 1998a; Jahnke, 1969b; Wickelgren, 1965), we did not find an inhibitory Ranschburg effect using visuospatial stimuli as memoranda. One possible explanation for this null effect is the fact that, in the visuospatial domain, items might be represented as paths between locations, rather than as isolated locations. Between-item transition properties, such as path crossing (Parmentier & Andrés, 2006) and path length (Parmentier et al., 2005) are indeed known to affect performance in visuospatial WM paradigms. As illustrated in **Figure 4**, even if a location appears twice in a list, the path itself would necessarily be different. Therefore, the nature of the visuospatial stimuli may have prevented the observation of a Ranschburg effect, because the repeated locations are identified as being distinct, contrary to what happens in the verbal domain. Another possibility is that the inhibitory Ranschburg effect is not as robust as previously thought. Therefore, rather than running a second experiment with visuospatial stimuli that would avoid the formation of visual paths during encoding, we decided to test the robustness of the inhibitory Ranschburg effect in the verbal domain first. The next experiment was thus an attempt at replicating the inhibitory Ranschburg effect by using letters as memoranda.

Figure 4

Schematic representation of paths in an inhibitory Ranschburg sequence.



Note. Green arrows represent successive paths between locations. Even when the third location repeats, transitions between locations remain unique.

Experiment 2

The purpose of Experiment 2 was to test the robustness of the inhibitory Ranschburg effect using verbal stimuli as memoranda. We used an experimental setup similar to Experiment 1, replacing locations by letters. We also increased the set size to 7 given that verbal stimuli, such as letters or digits, typically lead to higher WM recall performance than locations (e.g., Kessels et al., 2008). Similarly to Experiment 1, we included a backward recall procedure to test the response suppression account of the inhibitory Ranschburg effect.

Methods

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethic committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

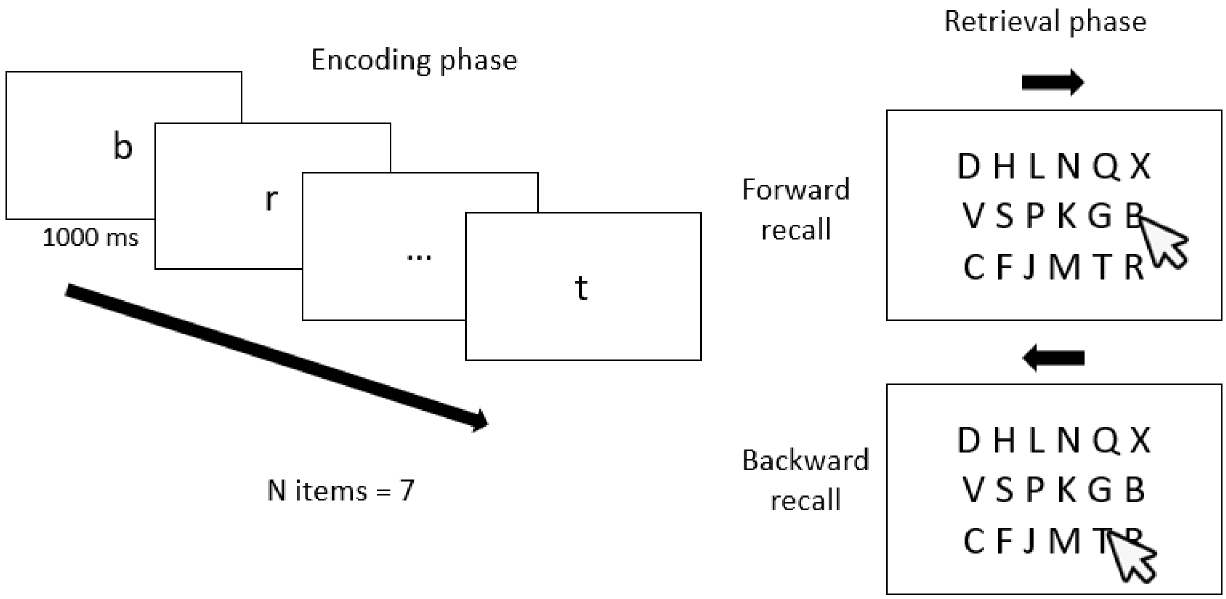
Material. We generated lists of 7 letters from a set of 18 consonants (B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, X). When creating the lists, we did not allow two phonologically similar letters (e.g., BD) and two adjacent letters from the alphabet (e.g., MN) to be presented at adjacent serial positions. Repetition patterns for the experimental sequences were: 2_4, 2_5, 3_5, 3_6, 4_6, where each number refers to the serial position of the repeated items. For example, in the sequence *ABCDEF*, the repetition pattern "2_4" would be *ABCBEFG*. There were 120 experimental trials, resulting in 30 trials for each of the four conditions (forward/backward, repeated/non-repeated). There were therefore 5 trials per repetition pattern in the repeated condition. The order in which the trials were presented was randomized with the constraint that an experimental condition could not appear more than four times consecutively. All sequences were generated using Python 3.8 (https://www.python.org/).

Design. The design was identical to Experiment 1.

Procedure. During the task, illustrated in **Figure 5**, participants performed four training trials before the main experiment. Each sequence started with the presentation of a sequence of 7 letters to be remembered in lowercase. Each letter was presented in the center of the screen at a pace of 1000 ms per item (500 ms on, 500 ms off). After the presentation of the memory list, the 18 consonants (see above) were displayed in uppercase across three rows in a random order. Participants were instructed to reproduce the sequence in correct order by clicking on each letter. As in Experiment 1, the direction of recall was indicated by an arrow (to the right for forward recall and to the left for reverse recall). A letter had to be selected for each of the seven positions.

Figure 5

Experiment 2 – Task setup



Note. Participants studied seven letters. At retrieval, all letters were presented on screen and participants clicked on them to reproduce the sequence in its original (forward recall) or reverse (backward recall) order.

Scoring procedure. The scoring procedure was identical to Experiment 1, except that we used a correct-in-position score, in which an item was scored as correct if it was selected in the correct serial position. After computing the proportion of correct responses in the repeated and non-repeated conditions, we computed again a difference score, this time computed using the difference between the repeated and non-repeated conditions such that a negative score indicates once again an inhibitory effect.

Statistical analysis. Statistical analyses were identical to Experiment 1.

Results

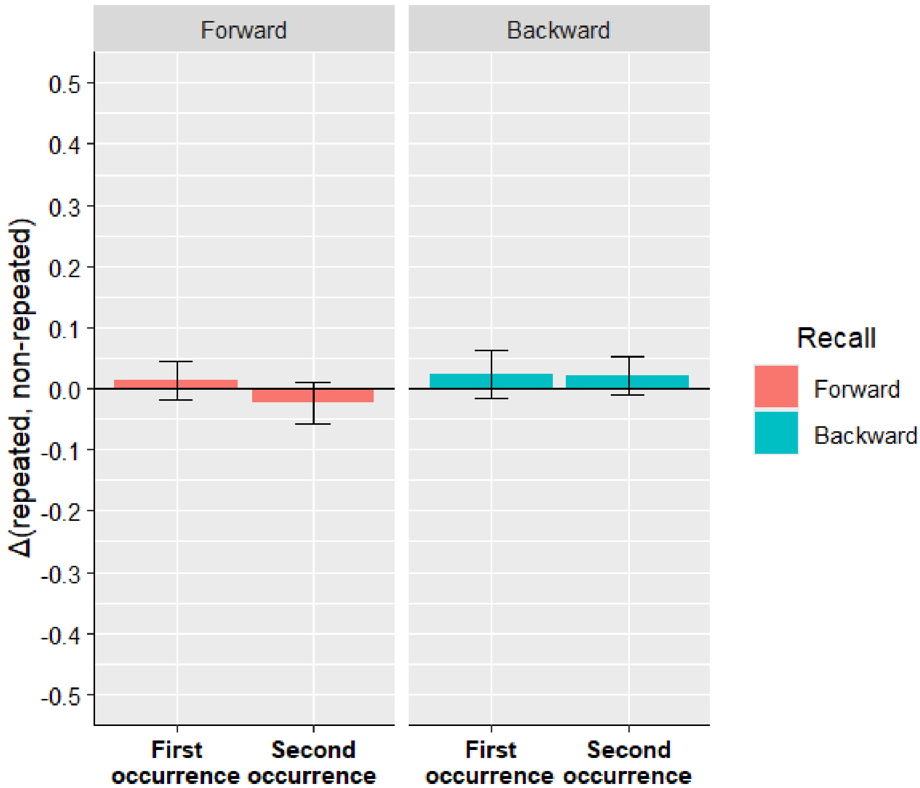
We assessed the presence of an inhibitory effect as a function of occurrence (first, second) and recall direction (forward, backward) using a Bayesian repeated measures ANOVA. We found anecdotal evidence against the interaction term ($BF_{01} = 2.290$, $\eta^2_p = 0.040$). We also found anecdotal evidence against the presence of a recall direction effect ($BF_{01} = 1.309$, $\eta^2_p = 0.057$) and anecdotal evidence against an occurrence effect ($BF_{01} = 2.508$, $\eta^2_p = 0.049$).

As in Experiment 1, we ran additional exploratory analyses using Bayesian one-sample t-tests. In the forward recall direction, the first occurrence of the repeated item led to moderate evidence against an inhibitory effect ($BF_{01} = 3.938$, $d = 0.146$). The second occurrence of the repeated item led to anecdotal evidence against an inhibitory effect ($BF_{01} = 2.436$, $d = 0.218$). These results are illustrated in **Figure 6**, left panel**.** Similar results were observed for the backward recall direction: Bayesian one-sample t-tests led to anecdotal evidence against an inhibitory effect for both occurrences of the repeated item. The first occurrence ($BF_{01} = 2.797$, $d = 0.200$), which was recalled second in backward recall and the second occurrence ($BF_{01} =2.457$, $d = 0.217$), which was recalled first. These results are illustrated in **Figure 6**, right panel**.**

Serial position curves are reported in **Figure 7**. In forward recall, primacy and recency effects are observed, as typically found in immediate serial recall experiments. In backward recall, this pattern reversed, reflecting once again the influence of output interference.

Figure 6

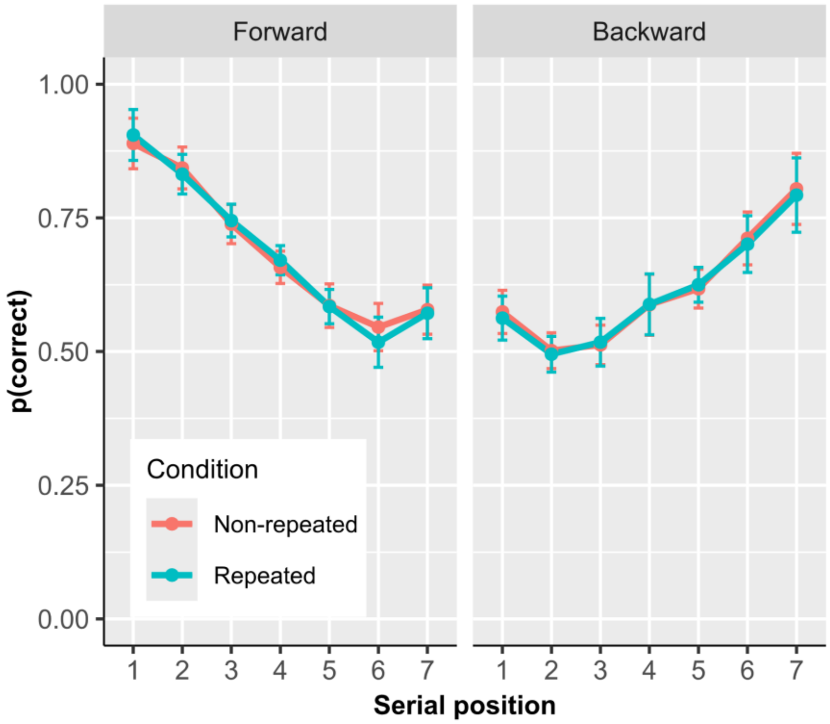
Experiment 2 – Difference score as a function of recall direction and occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Left panel: Forward recall. Right panel: Backward recall. Error bars indicate 95% confidence intervals.

Figure 7

Experiment 2 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis) and recall direction (forward, backward). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

This experiment tested the presence of an inhibitory Ranschburg effect using verbal stimuli as memoranda. We failed to find such an effect. One limitation of Experiment 2 is the fact that it used a procedure in which items were re-presented for serial reconstruction at retrieval, whereas the vast majority of studies in the literature used an immediate serial recall task. To determine whether the particular setup of the WM task could have led to the absence of an inhibitory Ranschburg effect, we ran a third experiment using an immediate serial recall task as in previous studies.

Experiment 3

The design of Experiment 3 was closer to previous studies which observed an inhibitory Ranschburg effect. We used an immediate serial recall task instead of the serial reconstruction procedure, thereby avoiding potential cuing of responses via the available letters on the screen which may have obscured the appearance of an inhibitory Ranschburg effect.

Methods

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

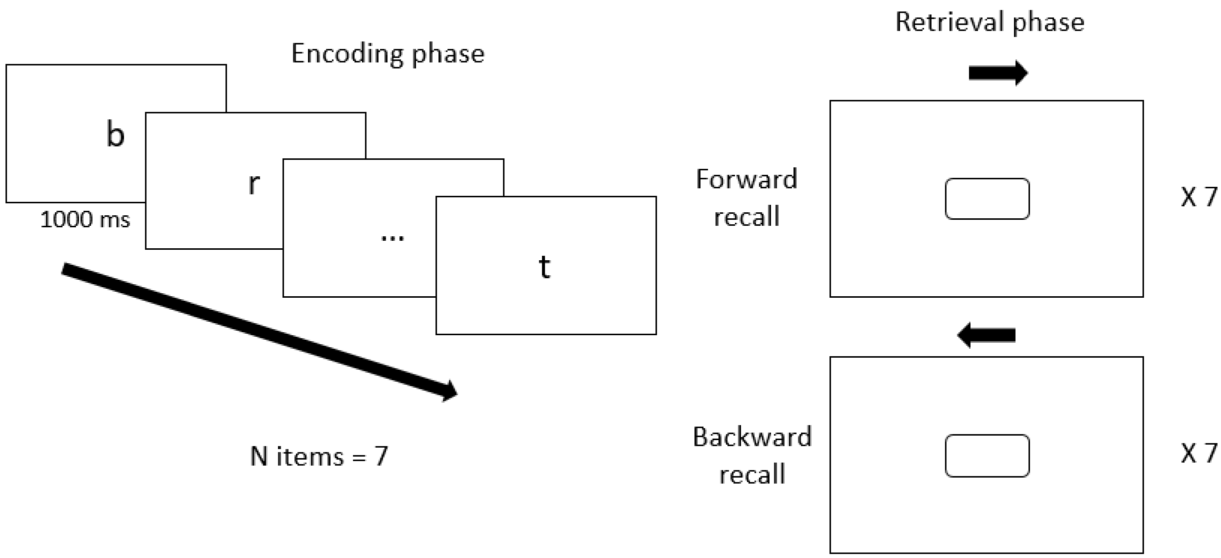
Material. All stimuli were identical to those of Experiment 2 except that there were 100 lists, resulting in 25 lists for each of the four conditions (forward/backward, repeated/non re-peated). There were therefore 5 trials per repetition pattern in the repeated condition.

Design. The design was identical to Experiment 2.

Procedure. The way the letters were encoded was identical to Experiment 2. At retrieval, a prompt box appeared on screen and participants recalled the sequence by typing the letters one by one using their computer keyboard. Once a letter had been typed, participants pressed the "Return" key, followed by the next letter, and so on. As in Experiment 1, the direction of re-trieval was indicated by an arrow pointing to the left or right, prompting participants to recall the sequence in forward or backward order, respectively. Participants performed four training trials before beginning the main experiment. The order of presentation of the different trials followed the same procedure as for the previous experiments. The task is illustrated in **Figure 8**.

Figure 8

Experiment 3 – Task setup



Note. Participants studied seven letters. At retrieval, participants typed the letters successively a prompt box presented in the center of the screen. The arrow indicated the recall direction.

Scoring procedure. The scoring procedure was identical to Experiment 2.

Statistical analysis. Statistical analyses were identical to Experiment 2.

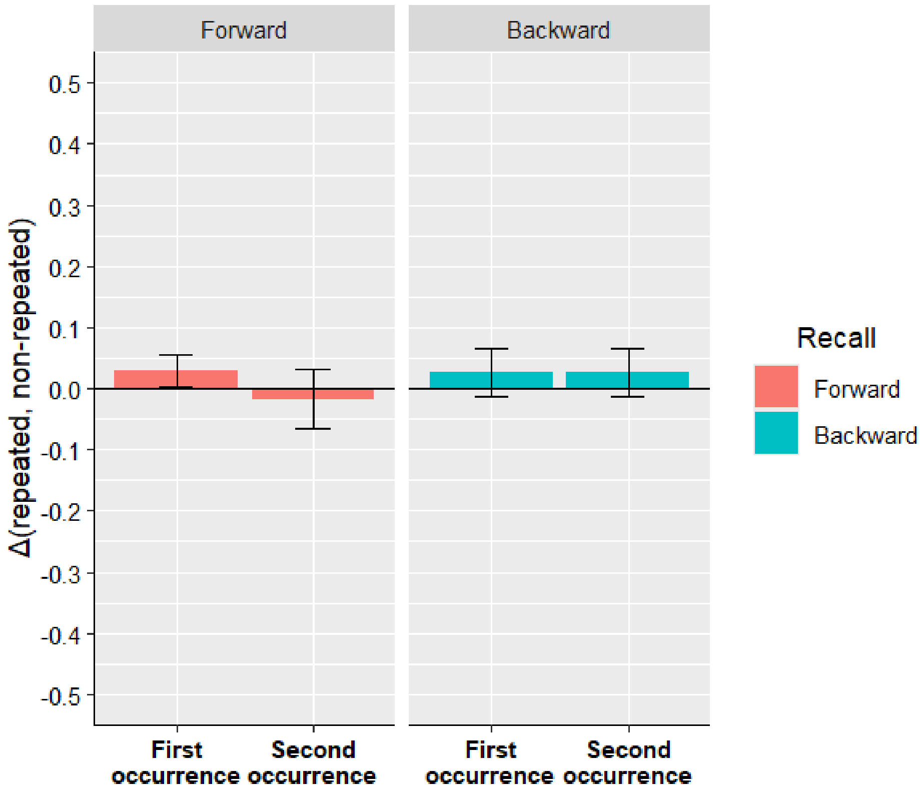
Results

We assessed the presence of an inhibitory effect as a function of occurrence (first, second) and recall direction (forward, backward) using a Bayesian repeated measures ANOVA. We found anecdotal evidence against the interaction term ($BF_{01} = 2.253$, $\eta^2_p = 0.039$), moderate evidence against the presence of a recall direction effect ($BF_{01} = 3.199$, $\eta^2_p = 0.023$) and anecdotal evidence against an occurrence effect ($BF_{01} = 2.660$, $\eta^2_p = 0.054$).

We ran again additional exploratory analyses, testing the deviation of the difference scores from 0 using Bayesian one-sample t-tests, separately for each condition. In the forward recall direction, we found anecdotal evidence for an inhibitory effect (BF_{10} = 1.641, d = 0.357) for the first occurrence, and moderate evidence against an inhibitory effect (BF_{01} = 4.641, d = 0.111) for the second occurrence. A similar pattern emerged in backward recall: We found anecdotal evidence against an inhibitory effect for the first occurrence (BF_{01} = 2.349, d = 0.222), which was recalled second in backward recall, and anecdotal evidence against an inhibitory effect for the second occurrence (BF_{01} = 2.549, d = 0.212), which was recalled first (see also **Figure 9**). Serial position curves are reported in **Figure 10.**

Figure 9

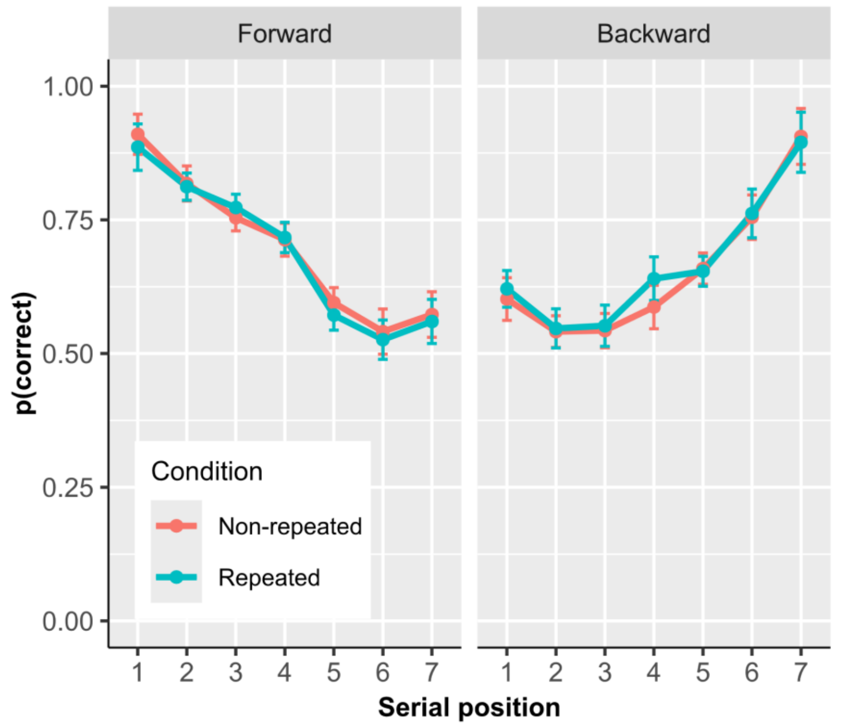
Experiment 3 – Difference score as a function of recall direction and occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Left panel: Forward recall. Right panel: Backward recall. Error bars indicate the 95% confidence intervals.

Figure 10

Experiment 3 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis) and recall direction (forward, backward). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Experiment 3 tested the presence of an inhibitory Ranschburg effect using an immediate serial recall procedure as in previous studies exploring this effect. Once again, we observed a null effect. The only manipulation that differed from previous studies is the inclusion of a back-ward recall procedure, which could have affected the way participants encoded the letter se-quences. Experiment 4 tests if this difference alone can explain the null inhibitory Ranschburg effect observed in the present study.

Experiment 4

Experiment 4 is an attempt to replicate the inhibitory Ranschburg effect under experimental conditions that are as close as possible to the experimental setups in which an effect was originally observed. The experiment was nearly identical to Experiment 3, except that we dropped the backward recall condition.

Methods

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

Material. All stimuli were identical to those of Experiment 2, except that there were 50 experimental trials, resulting in 25 trials for each of the two conditions (repeated/non repeated) with 5 trials per repetition pattern in the repeated condition.

Design. The design was similar to previous experiments, except that with the suppression of the backward recall direction, participants always recalled items in forward order.

Procedure. The procedure was identical to Experiment 3, except that participants always recalled items in forward order, which also means that we removed the recall cue. Participants performed four training trials before the beginning of the main experiment.

Scoring procedure. The scoring procedure was the same as in Experiment 2.

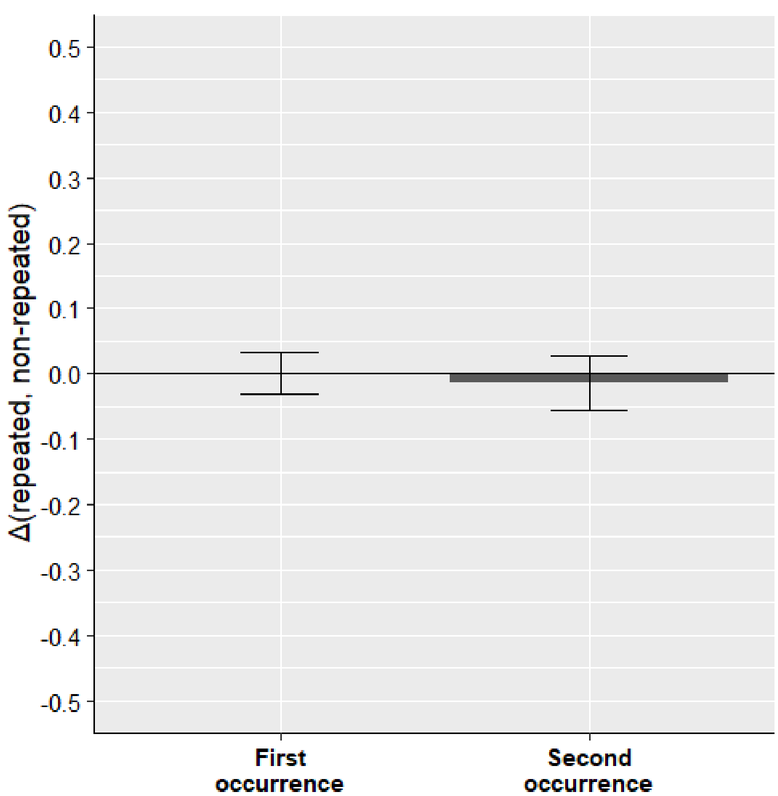
Statistical analysis. Statistical analyses were identical to Experiment 1.

Results

We assessed the presence of an inhibitory effect as a function of occurrence (first, second) using Bayesian paired-samples t-tests on the difference score between the first and the second occurrence. We found moderate evidence against an occurrence effect (BF_{01} = 4.773, d = 0.116). We again examined more directly the deviation from 0 in the difference scores via Bayesian one-sample t-tests. We observed moderate evidence against an inhibitory effect for the first (BF_{01} = 5.862, d = 8.56e-17) and second (BF_{01} = 4.814, d = 0.102) occurrences. These results are illustrated in **Figure 11.** Serial position curves are reported in **Figure 12.**

Figure 11

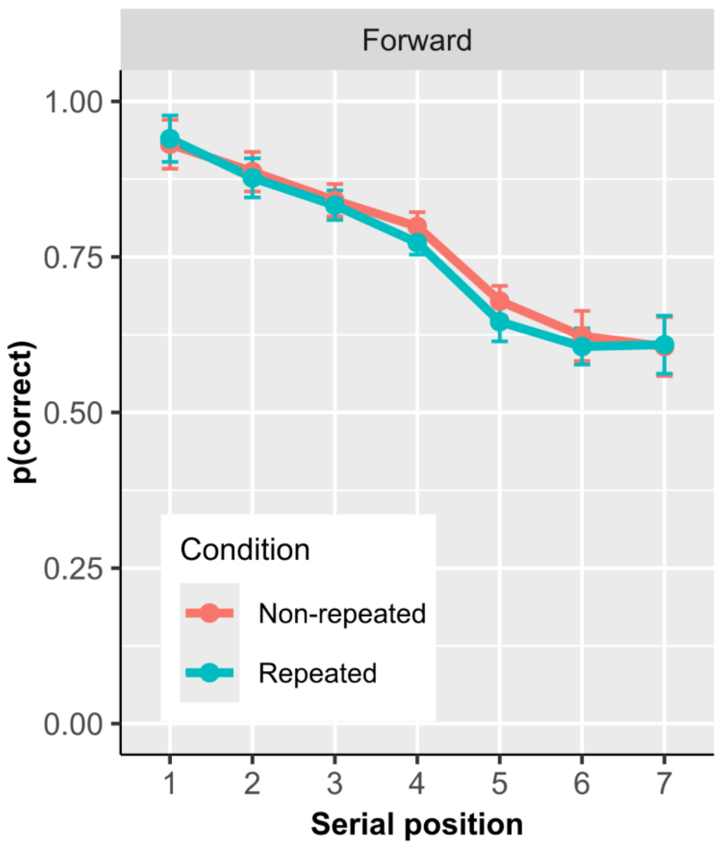
Experiment 4 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure 12

Experiment 4 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Experiment 4 allows us to rule out task difference as a plausible explanation for the absence of a Ranschburg effect. While using exactly the same setup as in a number of previous studies, we still found reliable evidence for the *absence* of an inhibitory Ranschburg effect. In order to identify potential factors that may explain these discordant results relative to previous studies, we conducted a review of the different experimental parameters used in previous studies (see **Table 1**). Among all the different parameters we examined, there was one parameter that showed a stronger contrast between our and previous studies: presentation rate. The presentation rate used in previous studies was generally faster (500 ms per item vs 1000 ms per item in Experiments 1 to 4), which may have favored the appearance of the inhibitory effect, participants relying on less controlled encoding processes such as grouping. In the next experiment, we tested this hypothesis by presenting stimuli at a faster presentation rate.

Table 1

Summary of methodological differences between the current study and previous studies

	N subjects	N items	Type of stimuli	Type of repetition	Presentation rate
Present study	Exp 1-6: 40 Exp 7: 41	Exp 1: 6 Exp 2-7: 7	Spatial locations and letters	Spaced and adjacent repetition	Exp 1-4: 1000 ms per item Exp 5: 500 ms per item Exp 6-7: 750 ms per item
Logan (2021)	24	6	Letters	Spaced and adjacent repetition	1000 ms per list
Henson (1998)	Exp1: 24 Exp2a: 12 Exp2b: 12 Exp3: 12	6	Letters	Spaced and adjacent repetition	500 ms per item
Greene (1991)	Exp1: 42 Exp2a: 22 Exp2b: 19 Exp3: 20	8	Digits	Spaced and adjacent repetition	500 ms per item
Jahnke (1972a)	Exp1: 10 Exp2: 40	Exp1: 7 Exp2: 8	Digits and letters	Spaced and adjacent repetition	500 ms per item
Jahnke (1972b)	Exp1: 40 Exp2: 80	7	Words	Spaced repetition	1000 ms per word
Jahnke (1969a)	40	8	Letters	Spaced repetition	500 ms per item
Jahnke (1969b)	Exp1: 20 Exp2: 15	7	Digits	Spaced repetition	500 ms per item
Crowder (1968)	75	8	Letters	Spaced and adjacent repetition	500 ms per item

	Presentation modality	Distance between repetition	N pool stimuli	Response modality	Irrelevant stimuli after encoding
Present study	Sequential	Exp 1-5: 2, 3 Exp 6-7: 1-3	Exp1: 6x6 grid locations Exp2-7: 18 consonants	Written with keyboard	\
Logan (2021)	Simultaneous	1-4	26 alphabet letters	Written with keyboard	\

Henson (1998)	Sequential	Exp 1-2: 1-4 Exp 3: 1-3	6 consonants (JHRQM)	Orally	Irrelevant digits
Greene (1991)	Sequential	1,3	9 digits (1-9)	Written with keyboard	\
Jahnke (1972a)	Sequential	Exp 1: 3 Exp 2: 1-5	Exp1: 10 digits (0-9) Exp2: 10 consonants (GHJKLNQRTX)	Key press	Irrelevant letters and digits
Jahnke (1972b)	Sequential	3	Open pool condition: +- 300 words	Orally	\
Jahnke (1969a)	Sequential	2-5	8 consonants (FHJKLNRQ)	Orally	\
Jahnke (1969b)	Sequential	3	9 digits (1-9)	Orally	Irrelevant letters
Crowder (1968)	Sequential	1-7	12 consonants (CGHJKLM-QRSTX)	Orally	\

Experiment 5

The goal of Experiment 5 was to examine whether the discrepancies between previous studies and the present could be explained by the difference in presentation rates. Indeed, Cowan and Hardman (2021) have shown that if repeated items fall within a grouping structure, it helps recall, but if they fall outside that structure, it hurts recall. Grouping strategies are more likely to occur with slower presentation rate as they are considered to rely on the intervention of controlled processes. To rule out this confounding factor, we used the same experimental setup as in Experiment 4 but used a faster presentation rate.

Methods

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

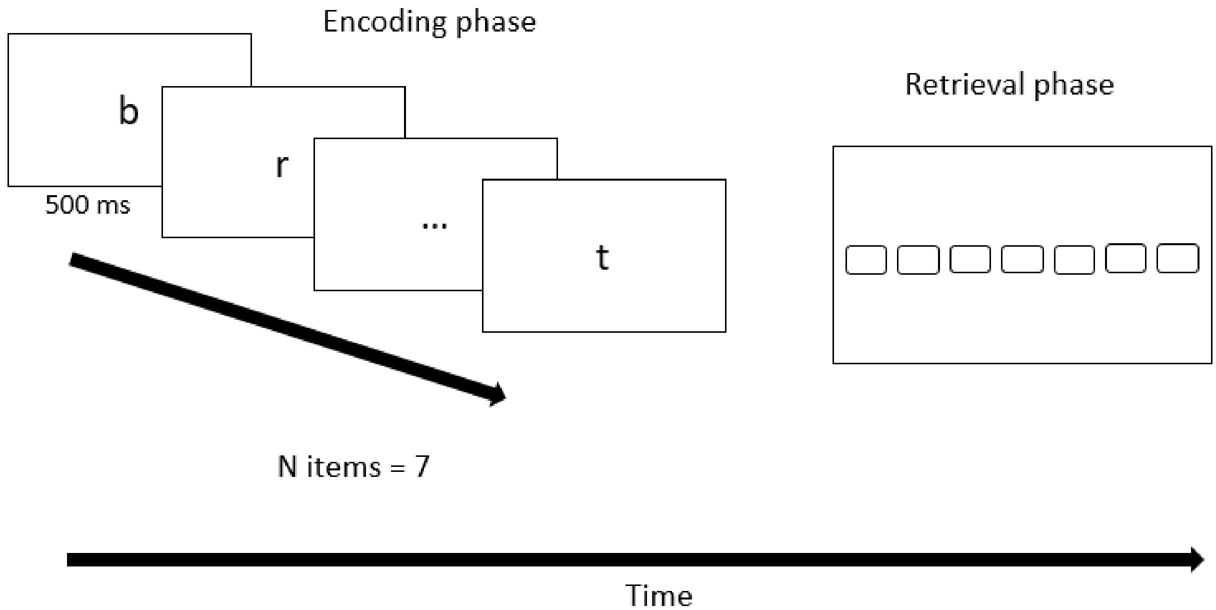
Material. All stimuli were identical to those of Experiment 4.

Design. The design was similar to the Experiment 4.

Procedure. The procedure was identical to Experiment 4, except that items were now presented at a rate of 500 ms per item (400 ms on 100 ms off) instead of 1000 ms. In addition, we removed the requirement to press the “Return” key after typing each letter, as we realized that this aspect of the experimental procedure was rather uncomfortable. Hence, typing a letter in the prompt box automatically moved to the next prompt box without the possibility to modify a response that was already given. There were seven prompt box displayed horizontally as shown in **Figure 13**.

Figure 13

Experiment 5 – Task setup



Note. Participants studied seven letters. At retrieval, participants typed the letters successively a prompt box.

Scoring procedure. The scoring procedure was the same as in Experiment 2.

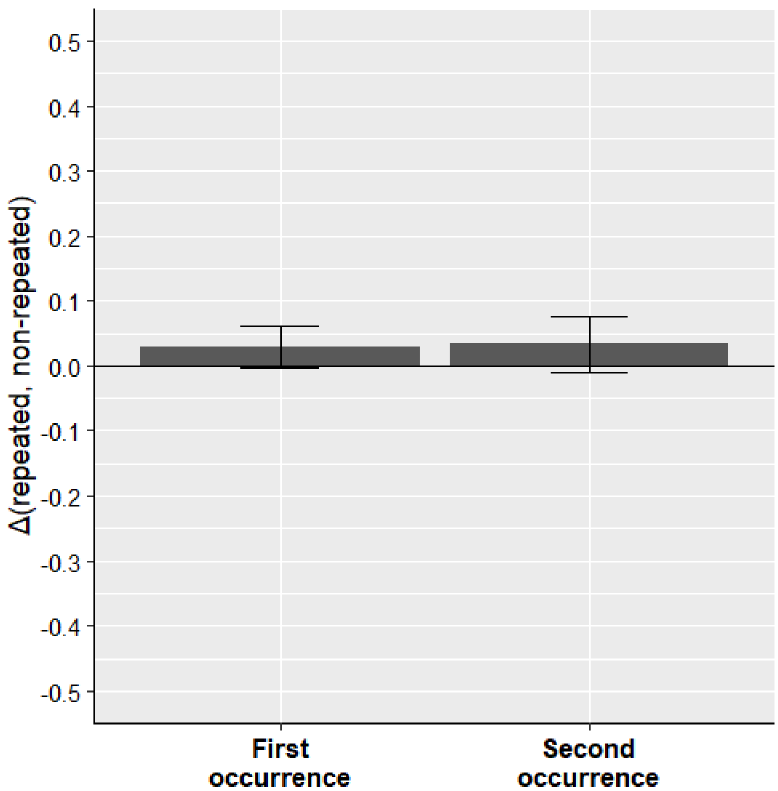
Statistical analysis. Statistical analyses were identical to Experiment 1.

Results

We assessed the presence of an inhibitory effect as a function of occurrence (first, second) using Bayesian paired-samples t-tests on the difference score between the first and the second occurrence. We found moderate evidence against an occurrence effect (BF_{01} = 5.695, d = 0.260). We again examined more directly the deviation from 0 in the difference scores via Bayesian one-sample t-tests. We observed anecdotal evidence against an inhibitory effect for the first (BF_{01} = 1.179, d = 0.297) and second (BF_{01} = 1.864, d = 0.251) occurrences. If anything, the numerical differences led to better recall performance in the condition including repeated items. These results are illustrated in **Figure 14.** Serial position curves are reported in **Figure 15.**

Figure 14

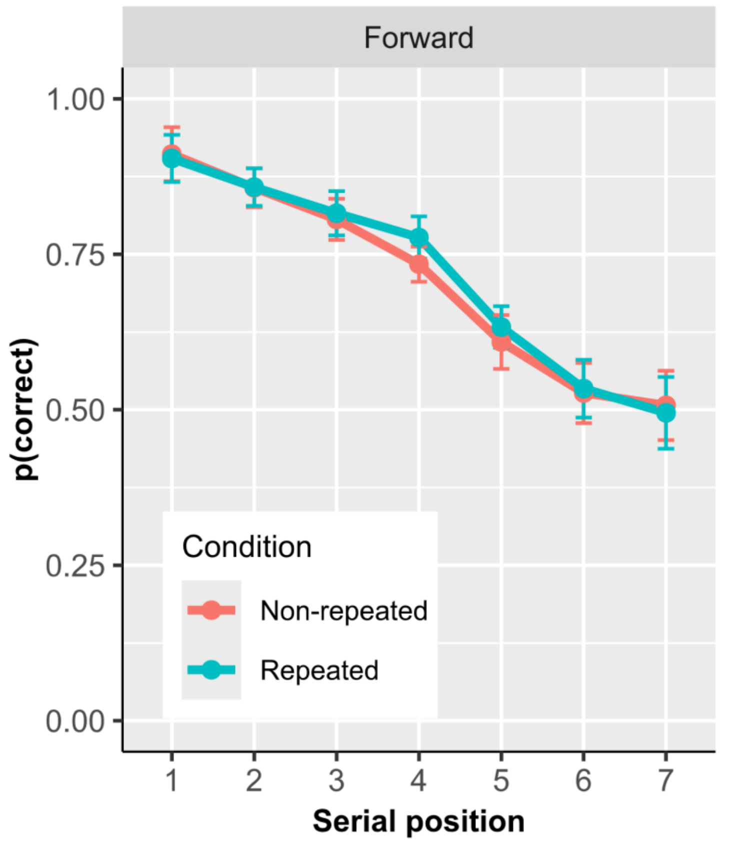
Experiment 5 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure 15

Experiment 5 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Experiment 5 allowed us to exclude presentation rate as a modulating factor in the observation of the Ranschburg inhibitory effect. Another parameter that differed between our and some previous studies (see **Table 1**) is the inclusion of adjacent repetition patterns. Initially, we did not include adjacent repetition pattern because we were focusing on the inhibitory Ranschburg effect, while studies typically report a facilitatory effect for adjacent repetitions.

Experiment 6

In Experiment 6, we examined whether the non-inclusion of adjacent repetitions in our experimental setup could have explained the absence of an inhibitory Ranschburg effect in our study. Although some previous studies also did not include adjacent repetitions and still found an inhibitory effect (Jahnke, 1969a, 1969b, 1972b, 1972a), we nevertheless decided to run a further experiment including both adjacent and non-adjacent repetitions.

Methods

Participants. Forty adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

Material. All stimuli were identical to those of Experiment 2. The repetition patterns were as follows: Distance 1: (2_3, 3_4, 4_5, 5_6), Distance 2: (2_4, 3_5, 4_6), Distance 3: (2_5, 3_6), where each number refers to the serial position of the repeated items. There were 144 experimental trials, resulting in 72 trials in each condition (repeated/non repeated). The repeated condition included 24 trials per distance.

Design. The design was similar to the Experiment 4.

Procedure. The procedure was identical to Experiment 5, except that items were presented at a rate of 750 ms per item (500 ms on, 250 ms off).

Scoring procedure. The scoring procedure was the same as in Experiment 2.

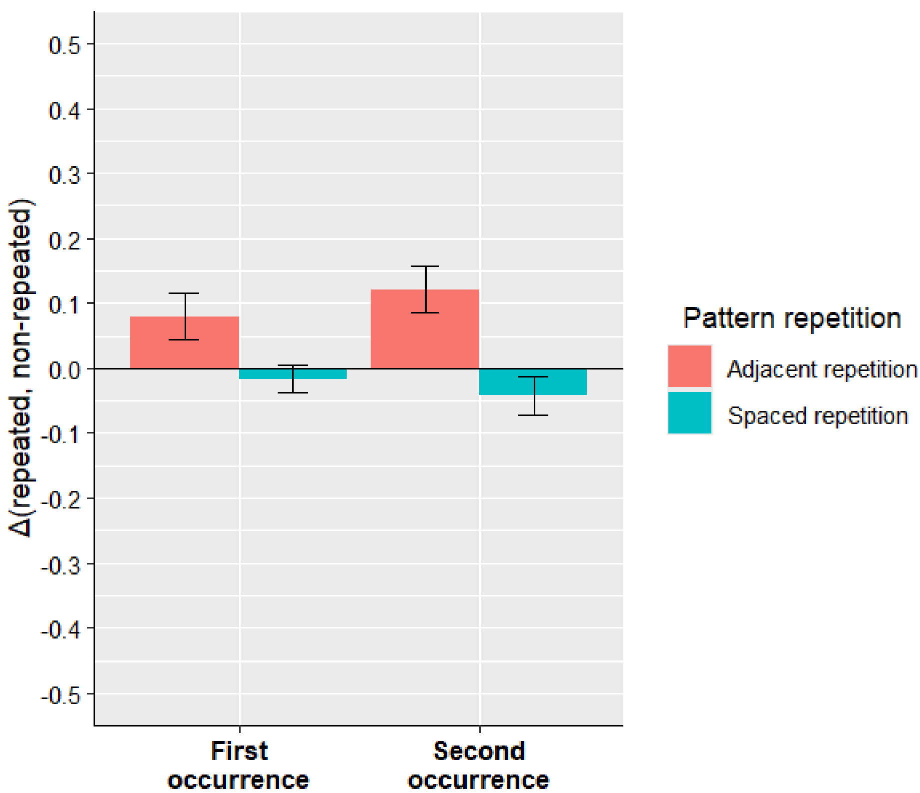
Statistical analysis. Statistical analyses were identical to Experiment 1.

Results

We ran Bayesian one-sample t-tests to test the deviation of the difference scores from 0, separately for each repetition type (adjacent/spaced). When repetitions were adjacent to each other, we found decisive evidence supporting a facilitation effect, both for the first occurrence (BF_{10} = 473.672, d = 0.722) and the second occurrence (BF_{10} = 783910.7, d = 1.118). When the repetitions were spaced, we found anecdotal evidence against an inhibitory effect for the first occurrence (BF_{01} = 2.259, d = 0.183), and moderate evidence supporting an inhibitory effect for the second occurrence (BF_{10} = 5.773, d = 0.323). These results are illustrated in **Figure 16**. Serial position curves are reported in **Figure 17.**

Figure 16

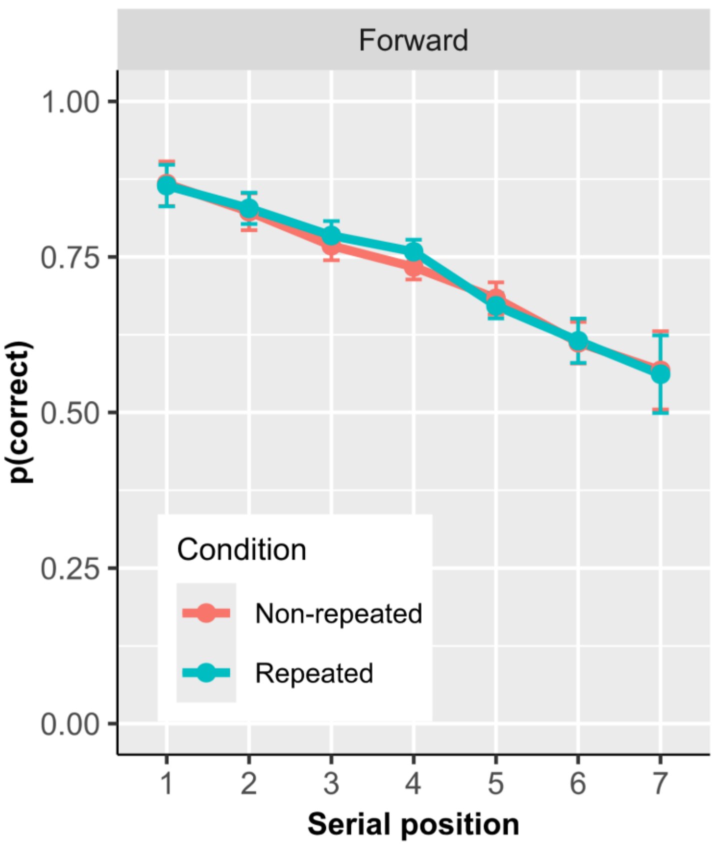
Experiment 6 –Difference score as a function of type of repetition and occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure 17

Experiment 6 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Experiment 6 tested the presence of a Ranschburg effect when adjacent repetition were also included, in line with the procedure used by other studies (Crowder, 1968; Greene, 1991; Henson, 1998b; Jahnke, 1972a; Logan, 2021). When analyzing the facilitation and inhibitory effects separately, we found decisive evidence for a facilitation effect and moderate evidence for an inhibitory effect. At the same time, this is the very first of our six experiments for which an inhibitory effect was found. In the next experiment, we examined the robustness of this observation and further aimed at determining the nature of the inhibitory effect by also including a backward recall procedure, as in our initial experiments.

Experiment 7

The goal of Experiment 7 was twofold. First, we tested the robustness of the inhibitory effect observed in Experiment 6 by replicating it. Second, we tested the nature of the inhibitory effect using a forward/backward recall procedure. The response suppression account of the inhibitory Ranschburg effect predicts that the inhibitory effect should be observed for the first occurrence of the repeated item when the list is repeated backwards.

Methods

Participants. Forty-one adults aged between 18 and 35 were recruited via the online platform Prolific. The same recruitment criteria were used as for Experiment 1. The experiment had been approved by the Ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education of the University of Liège.

Material. All stimuli were identical to those of Experiment 6. There were a total of 144 experimental trials: 36 trials for each of the four conditions (repeated/non repeated, forward/backward recall). There were 12 trials per distance in the repeated condition.

Design. The design was similar to Experiment 6, except that we now included a backward recall condition in addition to the forward recall direction.

Procedure. The procedure was identical to Experiment 6, except that the direction of retrieval was indicated by an arrow pointing to the left or right, prompting participants to recall the sequence in forward or backward order, respectively.

Scoring procedure. The scoring procedure was the same as in Experiment 2.

Statistical analysis. Statistical analyses were identical to Experiment 1.

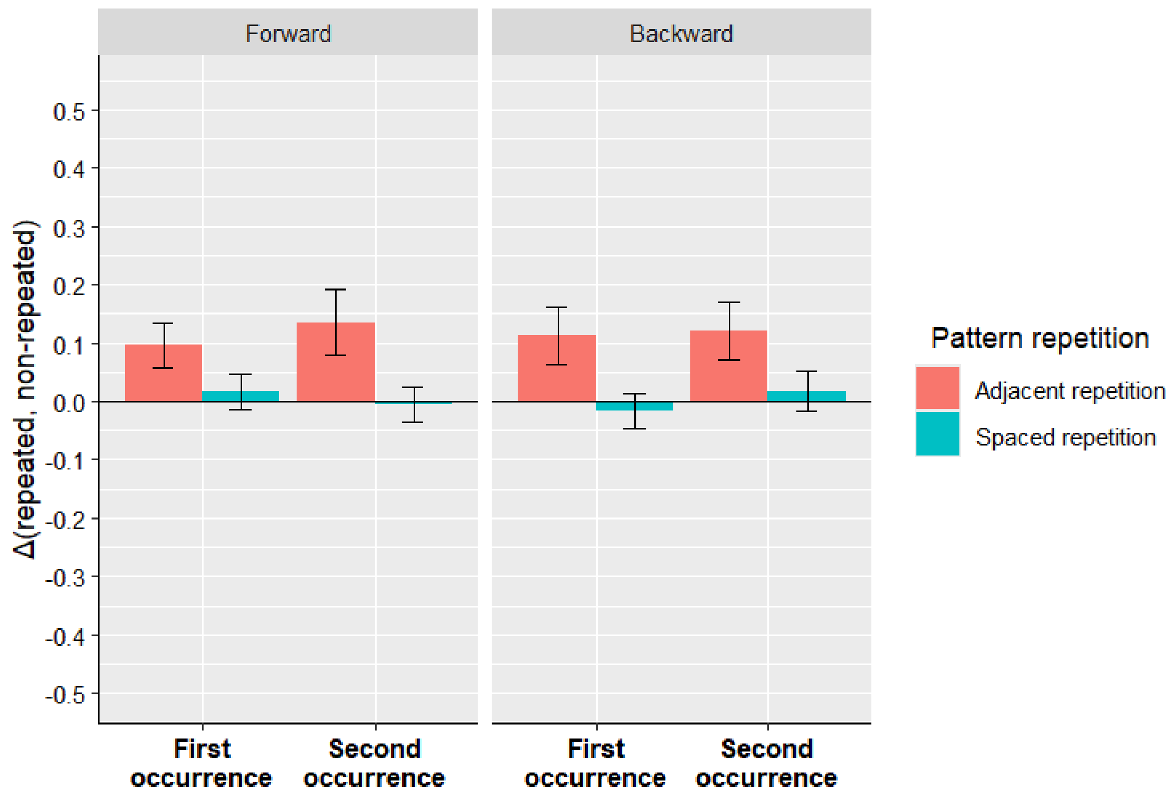
Results

We ran Bayesian one-sample t-tests to test the deviation of the difference scores from 0, separately for each repetition type (adjacent/spaced) and recall condition (forward/backward). In the forward condition, when the repeated items were adjacent to each other, decisive evidence supporting a facilitation effect was observed, both for the first (BF_{10} = 1,964.106, d = 0.788) and second (BF_{10} = 1,084.533, d = 0.756) occurrence. Similar results were observed in the backward condition, with decisive evidence supporting a facilitation effect for the first (BF_{10} = 489.526, d = 0.713) and second (BF_{10} = 1,134.613, d = 0.758) occurrence. In the forward condition of the spaced repetition condition, we found moderate evidence against an inhibitory effect for the first occurrence (BF_{01} = 4.892, d = 0.114), and moderate evidence against an inhibitory effect for the second occurrence (BF_{01} = 7.883, d = 0.032). Similar results were observed in the backward recall condition, with moderate evidence against an inhibitory effect for the first (BF_{01} = 4.378, d =

0.126) and second (BF_{01} = 5.032, d = 0.111) occurrence. These results are reported in **Figure 18**. Serial position curves are reported in **Figure 19.**

Figure 18

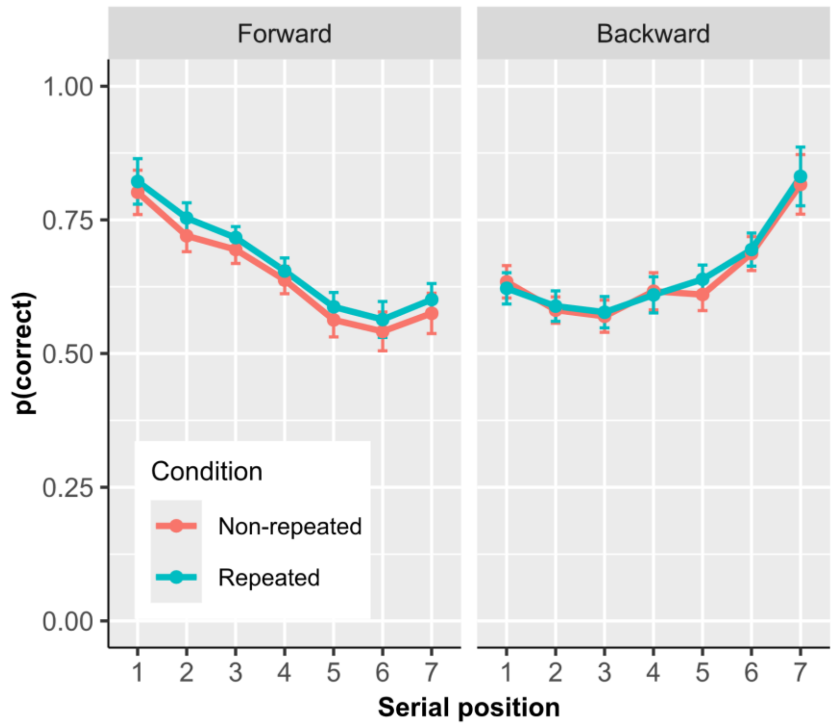
Experiment 7 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure 19

Experiment 7 – Recall performance as function of recall direction and repetition condition for each serial position.



Note. Proportion of correct responses as a function of serial position (x axis). Error bars indicate the 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

Experiment 7 tested the presence of an inhibitory Ranschburg effect when including both adjacent and spaced repetitions as well as when manipulating the direction of recall. We observed a facilitatory effect for adjacent repetitions but, unlike in Experiment 6, we did not observe an inhibitory Ranschburg effect. This result increases again the evidence for a null inhibitory Ranschburg effect across the different experiments ran in this study.

Computational modeling

The present study shows a consistent null inhibitory repetition effect in immediate serial recall/reconstruction. One may argue that our sample size was insufficient to lead to any observable difference between our experimental conditions. This argument is, however, unlikely to hold given that our sample sizes were consistently larger or comparable than those included in previous studies that observed a Ranschburg effect. Yet, we may ask the question of the theoretical size of the inhibitory Ranschburg effect if it is caused by response suppression. Indeed, response suppression is implemented in many computational models of WM for preventing an excess of repetition errors (Lewandowsky, 1999) and it has been argued that this mechanism provides a good explanation for the inhibitory repetition effect (Henson, 1998). In this final part of this study, we use a computational model for estimating the effect size of the inhibitory Ranschburg effect if response suppression was responsible for it.

In this section, we first describe a generic model of WM in which we implemented response suppression. After fitting this model to a control condition which did not include any repeated item, we generated new predictions based on experimental manipulations including repeated items. From these predictions, it is possible to obtain an estimation of the magnitude of the inhibitory repetition effect that should have been observed in our dataset. Specifically, the magnitude of this effect should depend on the value of the response suppression parameter, which itself depends on the rate of repetition errors produced by participants. A high response suppression value results in a large inhibitory repetition effect, but also fewer repetition errors. Conversely, a low response suppression value produces a minor inhibitory repetition effect, which comes at the cost of a higher number of repetition errors.

Mathematical description

Encoding. As a standard way to encode items into WM, we assume that the core process of encoding involves binding items to contexts (Burgess & Hitch, 2006; Henson, 1998b; Oberauer et al., 2012), where the context is the position of the item in the list. In immediate serial recall, the order of items is new and arbitrary and must be maintained in some way. This operation can be performed by associating items to positions. For instance, given a sequence of items "ABC", we assume that people associate "Item A" to "Position 1", "Item B" to "Position 2", and so on. Mathematically, the association strength $a_{i,j}$ between item i and position j follows this formula:

(1) $a_{ij} = \eta_i P^{|i-j|}$

In this equation, P is a free parameter controlling the similarity between contexts. Similar contexts, such as "Position 1" and "Position 2" are more similar than more distant contexts, such as "Position 1" and "Position 6", and this similarity results in positional uncertainty. Due to this positional uncertainty, not only will the target item be associated to its positional context, but so will all other items with at least partially similar contexts. This assumption is necessary in order to reproduce important serial recall phenomena such as order errors and transposition gradients (Hurlstone & Hitch, 2015). The η_i term is the encoding strength, and depends on a primacy gradient of activation in which items are encoded with decreasing strength across input position i:

(2) $\eta_i = \alpha(1.0 - \gamma)^{i-1}$

Where α is the peak of the activation gradient, fixed to 1.0 in our simulations, and γ is a free parameter controlling the steepness of the primacy gradient. The higher the γ value, the faster the activation value decreases across input position.

Retrieval. To retrieve an item, people have to use the cue which is currently available to them, which, in the standard model we implement, is the positional context the item was associated to. For instance, when attempting to retrieve the first item, it is assumed that people start from the cue “Position 1” and try to retrieve “Item A”. However, due to the positional uncertainty described in Eq. 1, this retrieval process leads not only to the activation of the target item, but also the other list items. The list items are re-activated to the extent that they are associated to the context which serves as a retrieval cue Hence, activation A_{ij} of list item i given a retrieval cue j is:

(3) $A_{ji} = a_{ji}$

Models of serial recall typically include an output interference mechanism in which WM representations are degraded after each retrieval attempt. This mechanism is necessary to account for the fact that recall performance decreases across output position (Cowan et al., 2002), a phenomenon also observed in Experiments 1 through 3 of the present study. However, in the current simulations we omitted this assumption because we fitted the model to the data from Experiment 4, which did not involve backward serial recall. This choice has one major benefit. Because in forward serial recall input position is fully confounded with output position, the primacy gradient mechanism is sufficient to describe the decreased recall performance observed across serial positions. Hence, only one parameter value has to be estimated, in this case the γ parameter which controls the steepness of the primacy gradient of activation. Constraining the number of parameters this way eases the process of recovering an accurate value for the response suppression parameter described in Eq. 5 below, which is critical given the importance of this mechanism for the current project.

Extra-list intrusions and omission errors. In immediate serial recall, people often produce omission errors, and, less frequently, extra-list intrusions. An extra-list intrusion corresponds to recalling an item which was not part of the list to be remembered. An omission error corresponds to a failure to recall an item at all (i.e., people leave the response box empty). In models of serial recall, retrieval is a noisy process: The retrieved item is never the original one, but a blurred version of it. This degraded representation must be compared to a set of retrieval candidates in order to produce an appropriate output (Schweickert, 1993). Extra-list intrusions occur when another item than a list-item is selected for output. In the standard architecture we present here, this is implemented by giving an activation value ω to an "extra-list intrusion" item, which gives it a certain probability to be recalled when using the Luce's choice rule described in Eq. 6 below. This probability can be viewed as the average similarity between the target items and the non-list items: The higher the ω parameter, the higher the similarity between target and non-list items, resulting in more extra-list intrusions. Omission errors are modeled by including an omission threshold to item activation values. If items fail to surpass the omission threshold, an omission error is reported. We implement this process by giving an activation value to the omission threshold, which is also included in the competition for retrieval in Eq. 6. The value of this omission threshold is determined by the free parameter θ. The higher the θ value, the higher the omission error rate.

Response suppression. Response suppression is modeled by adapting Eq. 3:

(4) $A_{ij} = a_{ij} - r_i$

The r_i term is used to downgrade the activation of item i in cases where this item was recalled during a previous recall attempt. At the beginning of a trial, all values in the vector r are set to zero. When item i is successfully recalled (either in correct or incorrect order), the value of r at index i is updated:

(5) $r_i = \tau$

Hence, the higher the τ value, the stronger the response suppression.

After computing the activation for all retrieval candidates given a retrieval cue, activations are converted into probabilities using the exponential version of Luce's choice rule:

(6) $p_i = \frac{exp\left(\frac{A_{ik}}{\sigma}\right)}{\sum_{j=1}^{N+2} exp\left(\frac{A_{jk}}{\sigma}\right)}$

In this equation, the sum runs over the number of items N, plus the extra-list intrusion and omission threshold terms. The σ parameter is the noise added at retrieval and is estimated freely. The higher the σ value, the more likely the model will select items randomly. This choice rule corresponds to a selection process in which noise is added to activation values before selecting the most activated recall candidate.

Model fitting

We fitted the above-mentioned model to the data collected in Experiment 4 using maximum likelihood estimators. Fixed and free parameters are reported in **Table 2**.

Table 2. List of fixed and free parameters of the model.

Symbol	Role	Value
P	Positional overlap	[0.0 – 1.0]
α	Peak of the primacy gradient	1.0
γ	Steepness of the primacy gradient	[0.0 – 1.0]

ω	Activation of the non-target items	[0.0 – 1.0]
θ	Value of the omission threshold	[0.0 – 1.0]
σ	Noise parameter used during the selection rule	[0.001 – 1.0]
τ	Response suppression	[0.0 – 100.0]

Note. Fixed parameters are indicated by a single value. Free parameters are indicated by a range.

Fitting procedure. Model fitting was done at the subject level using the raw data (i.e., non-aggregated individual trials). For each recall attempt, we computed the probability to recall each retrieval candidate using Eq. 6. Based on this recall probability, we computed the log-likelihood for the observed response o:

(7) $logL = log(p_o)$

Note that in this fitting procedure, when applying response suppression, we used the *observed response* produced by the participant. We used the deviance as a loss function:

(8) $D = -2.0 \sum logL$

In Eq 8., the sum operator runs over all trials and retrieval attempts.

Parameter estimation was done using a differential evolution algorithm (Storn & Price, 1997). The number of individuals in the population was set to 10n, where n is the number of free parameters considered. The crossover probability and differential weight were fixed to 0.9 and 0.8, respectively. The differential evolution algorithm is guaranteed to eventually converge to a global minimum. There is, however, no definitive way to know when convergence is reached. One way is to define a stopping criterion based on the standard deviation of parameter values from individuals in the population (Zielinski et al., 2006). Convergence was considered reached if the standard deviation fell below 10^{-8}. When this criterion could not be reached, the algorithm stopped after 10,000 iterations.

Model comparison. To compare models with each other, we first computed a Bayesian Information Criterion (BIC) for each model:

(9) $BIC = \sum_{i=1}^{N} Klog(n_o) + D_i$

In Eq. 9, the sum runs over all participants. We therefore computed one BIC for each participant and summed all BICs to obtain an overall assessment for a particular model. The K term is the number of free parameters, and n_o is the number of observations per participant. After computing one BIC for each model, models can be compared by subtracting their BICs. This difference represents the likelihood of the data under a certain model, relative to another model.

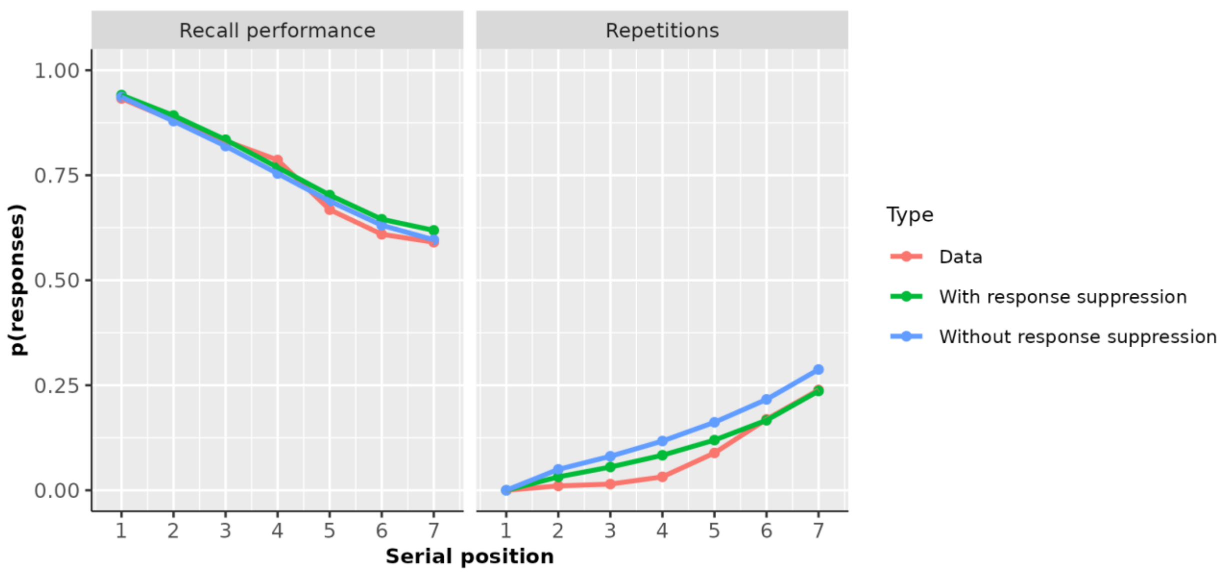
Simulation results

We fitted two variants of the model described above to the dataset from Experiment 4: One model in which the response suppression parameter was estimated freely, and one model in which the response suppression parameter was deactivated by fixing it to zero. This means that the model including response suppression had one additional free parameter (6) than the model without response suppression (5). We fitted these two models to the non repeated condition. We then generated predictions based on the five repetition patterns in the repeated condition of Experiment 4, while keeping all parameter values constant.

Recall performance and repetition errors. The models predictions along with the empirical data for the non-repeated condition are plotted in **Figure 20**. As can be seen in the left panel, both models predict the pattern of recall performance observed across serial positions reasonably well. Both models differ however in the way they account for the rate of repetition errors, as can be seen in the right panel. Specifically, the model including the response suppression parameter better accounts for the rate of repetition errors. Without response suppression, the model produces an excess of repetition errors. A quantitative comparison between both models indicates that the best model was the model including the response suppression mechanism. Subtracting BIC values between models showed that the data were 402 times more likely under the model including the response suppression mechanism than the model not including it.

Figure 20

Models' predictions – no repetition condition

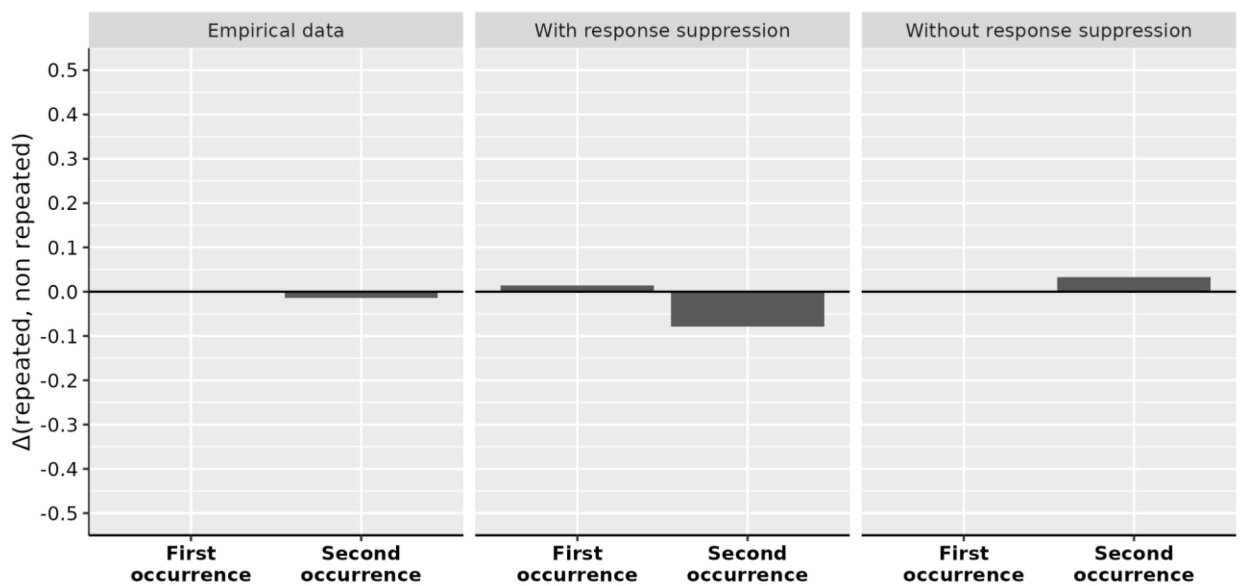


Note. Left panel: Recall performance as a function of serial positions. Right panel: Repetition errors as a function of serial positions.

Ranschburg effect. **Figure 20** shows the empirical data (left panels) and model predictions (middle and right panels) for the inhibitory repetition effect. The middle panel shows predictions from the model including the response suppression mechanism. The right panel shows predictions without the response suppression mechanism. Both models predict no differential effect for the first occurrence of the repeated item (relative to an equivalent item position in the no-repeated condition), in line with empirical data. For the second occurrence, a decrease of performance is predicted for the repeated condition specifically by the model including the response suppression mechanism, contrary to what is observed in the empirical data. Therefore, the model including a response suppression mechanism does predict an inhibitory repetition effect, in line with the theoretical predictions, although this effect could not be observed in our empirical data.

Figure 21

Model predictions – Inhibitory effect



Note. Left panel: Empirical data. Middle panel: Model with response suppression as free parameter. Right panel: Model without response suppression.

Effect size estimation. **Figure 21**, lower middle panel, shows an inhibitory effect in the model including response suppression. Comparing the non repeated condition against the repeated condition shows a mean difference of 0.078. Using this theoretical mean difference, we can estimate the effect size we should have had obtained if response suppression was the locus of the Ranschburg effect. The standard deviation of the difference between the non-repeated and the repeated condition in Experiment 4 equals 0.126. As Cohen's d is the mean divided by the standard deviation, we can estimate that we should have had observed an effect size of 0.078 / 0.126 = 0.62. In a frequentist hypothesis testing framework, with our sample size of 40, this would correspond to a power of 0.966 considering an alpha value of 0.05. In a Bayesian framework, results of an additional simulation for the same sampler and effect sizes (see **Appendix A**) indicate that the probability of obtaining a Bayes factor superior to 3 and 5 is 0.908 and 0.862, respectively. We are therefore confident that the experiments reported in the present study were sufficiently powered in order to observe an inhibitory effect in the population that would have been caused by a response suppression mechanism.

General Discussion

The initial aim of this study was to assess the generality of the inhibitory Ranschburg effect by testing it in the visuospatial domain using a forward/backward recall procedure. Given the absence of an effect in the visuospatial domain, we examined the robustness of the inhibitory Ranschburg effect in the verbal domain. We slowly drifted from an experimental design aiming at expanding the generality of the inhibitory Ranschburg effect (Experiment 1) to an exact replication (Experiment 4). Experiment 2 used an order reconstruction task similar to the visuospatial task in Experiment 1. Experiment 3 used an immediate serial recall task instead of a multiple-choice paradigm. Experiment 4 dropped the backward recall direction. Experiment 5 was a replication of the Experiment 4 but with a faster presentation rate. Experiment 6 included adjacent repetition pattern. Experiment 7 replicated Experiment 6 but adding a recall direction manipulation. In each experiment, we systematically observed evidence *against* an inhibitory Ranschburg effect except in Experiment 6. Finally, we simulated the inhibitory Ranschburg effect using two variants of the same model: One with a response suppression mechanism, and one without. Results from these simulations indicate that if the inhibitory Ranschburg effect was caused by a form of response suppression, we should have been able to observe it.

Contrasting Findings Between This Study and the Literature

While the present study found no reliable evidence for an inhibitory Ranschburg effect, previous studies reported such an effect. How can these contrasted findings be explained? One possible explanation is that previous studies showed an inflated effect size (Gelman & Carlin, 2014) due to the relatively small sample size, and were false positive findings (Henson, 1998a; Jahnke, 1969b; Wickelgren, 1965). This argument is, however, not valid for all of previous studies. The study by Greene (1991) had a similar sample size as our study. The study by Logan (2021), while having a smaller sample size, was nevertheless well powered as it included a large number of trials per experimental condition.

A second important point is that the Ranschburg effect contains two sub-effects: the inhibitory effect and the facilitation effect. Most studies (Crowder, 1968; Greene, 1991; Henson, 1998a; Wickelgren, 1965) tested both effect together. One possibility we considered is that testing only the inhibitory effect in our study could have altered the experimental dynamics, thereby contributing to the absence of the expected effect. This explanation is, however, not valid for all studies. For example, some studies (Jahnke, 1969a, 1969b, 1972b, 1972a) focused solely on the inhibitory effect, and did observe it. This hypothesis was also tested directly in Experiments 6 and 7. While Experiment 6 led to an inhibitory effect for spaced repetitions, this was not the case for Experiment 7 that additionally included a backward recall procedure. We can therefore reject the hypothesis that the inhibitory effect only appears when the facilitation effect is tested via the inclusion of adjacent repetitions

Another factor that could influence the occurrence of an inhibitory Ranschburg effect is the use of a grouping strategy. In the study of Cowan & Hardman(2021), participants memorized list of nine digits that allowed multiple repetition patterns. Their results showed that if the repetition fell into a predominant grouping structure (e.g., ABC-DEDF), it helped recall. If it fell outside (e.g., ABC-DCEF), it hurt recall. One possibility to explain these results is that the Ranshburg effect is due to a form of interference occurring when repeated items share the same within-group position. Aggregating all repetition patterns might therefore lead to a null effect, mixing lists that help and hinder recall performance. To test this hypothesis more directly, we conducted additional analyses by aggregating data from Experiments 2, 3, 4 and 5 on each repetition pattern separately. This additional analysis, reported in Appendix B, shows an inhibitory effect specifically when the second and fifth items repeated. This result is consistent with a form of between-group interference occurring if participants had grouped items following a 3-4 patterns (i.e., ABC-DEFG). At the same time, other repetition patterns either led to no inhibitory effect (p2_4, p3_5 and p3_6) or a facilitation effect (p4_6). The fact that we did not find an inhibitory effect in the repetition pattern p3_6 goes against the between-group interference hypothesis, as this repetition pattern also involves repeated items sharing the same within-group position. A problem with this grouping hypothesis is the fact that we have no way of knowing whether participants used the grouping strategy or not, and how they grouped the different patterns. Another issue boils down to the underlying assumption according to which repeated items sharing the same within-group position should lead to decreased recall performance. Items sharing the same within-group position are typically confused with each other more than the same items in an ungrouped list (Henson, 1998a), a type of error called “interpositions”. As repeated items have the same item identity, an increase of interposition errors for these items should not change the final score, precisely because they have the same item identity and should therefore receive the same score than if those interposition errors did not occur as often. Therefore, the grouping account does not provide a robust explanation for the lack of inhibitory effect observed in the present study.

Another factor we explored was the speed at which the items were presented. In the first experiments, we used a presentation rate twice as long as the one used in most published studies. This may have favored the implementation of controlled grouping strategies, which may have acted against the observation of an inhibitory Ranschburg effect, given the beneficial effect of grouping for WM performance. We tested this possibility in Experiment 5 using a faster presentation rate, but still observed no inhibitory Ranschburg effect.

When examining the literature, we also observed a certain amount of heterogeneity regarding the scoring methods that were used. Most studies (Jahnke, 1969a, 1969b; Wickelgren, 1965) used either an item score (an item is considered correct if recalled, regardless of position) or a strict score (an item is considered correct only if recalled in the correct position), like in our study. An exception is Henson’s (1998a) study, which employed a modified strict score. This scoring method does not penalize transpositions between two critical positions. For instance, given the list *ABCDEF*, where repetition is expected at positions 2 and 4, the recalled sequence *ADCBEF* would still be considered correct. The purpose of this score is to balance out the fact that there is no way of knowing whether two repeated items are transposed or not when recalled, precisely because they are identical. The second point is that this score will not penalize repetitions in a control list. For example, given the list *ABCDEF* where repetition is expected at positions 2 and 4, items 2 and 4 would be scored as correct across both the recalled sequences *ABCBEF* and *ADCDEF*. Thus, each control item appearing in a critical position is considered correct. We reported an additional analysis with this modified score in **Appendix C**. The use of the modified score did not substantially affect the overall pattern of results across all experiments, with a few exceptions. We did find an inhibitory effect in Experiments 2, 6 and 7, but the evidence remained moderate. It is therefore possible that an inhibitory effect exists in our data, but it appears to be specific to the scoring procedure used and limited to a subset of experiments. In addition, this variable alone cannot fully account for the presence or absence of an inhibitory effect in previous studies, as most studies which found this effect used a standard scoring procedure.

A final possibility is that the experiments that did not lead to an inhibitory Ranschburg effect were not published, reflecting a publication bias (Dickersin, 1990). In sum, there is no easy answer to the contrasting results between the present study and previously published studies. Nevertheless, this study clearly shows that the inhibitory Ranschburg effect is less robust than initially considered, given that, if it appears, it does so only in very specific experimental setups.

Theoretical Implications

The Ranschburg effect has been proposed as a low priority benchmark (Oberauer, 2018) due to its lack of replication in other domains. The effect was nevertheless considered as a benchmark because it has, so far, been well replicated in the verbal WM domain and was thought to provide evidence for response suppression. This study shows that the effect does not seem to be robust in either the verbal or visuospatial WM domains. If the effect is limited to specific experimental setups, then these setups need to be defined. Our results question the priority to focus on the Ranschburg effect as a benchmarks for the development of WM theories.

As noted earlier, the inhibitory Ranschburg effect has been taken as evidence supporting response suppression, a mechanism implemented in many WM models (Henson, 1998b; Hurlstone & Hitch, 2015; Lewandowsky, 1999; Oberauer et al., 2012; Oberauer & Lewandowsky, 2011) to account for the low rate of repetition errors observed in human data. It is important to mention that the absence of repetition inhibitory effect cannot be taken as strong evidence against response suppression, as the presence of an inhibitory effect ultimately depends on how models of WM assume representations are stored and removed once recalled. Indeed, certain classes of models do not necessarily predict an inhibitory effect following response suppression. In the Feature Model (Nairne, 1990) and Revised Feature Model (Saint-Aubin et al., 2021), items are stored in primary memory as copies of original items. One way to implement response suppression in these models is to remove the copy once the item has been correctly retrieved. In such a scenario, removing one copy does not affect a second copy of the same item, because items in primary memory are stored independently. This way of storing and removing items from WM produces an absence of inhibitory effect. Hence, the Ranschburg effect is not necessarily symptomatic of the presence or absence of response suppression. What our results show is that if response suppression exists, the Ranschburg effect is unlikely to be symptomatic of it.

Direct evidence against response suppression comes from another set of experiments. One recent study by Kowialiewski and Oberauer (2024) performed a cued recall procedure requiring participants to retrieve multiple times the same item at the same serial position. For instance, after encoding the sequence “ABCDE”, participants could be asked to retrieve the third item, followed by the first, then the fifth item, and then the third item again. In this condition, all models of WM predict that when the same item is tested a second time at the *same serial position*, memory performance should decrease. Contrary to these predictions, the empirical data did not show such memory impairment when the same item was tested a second time.

One alternative explanation to the results of the present study and the results observed by Kowialiewski and Oberauer (2024) is a strategic response suppression mechanism[3]. Specifically, it is possible that response suppression could be turned off whenever the experimental context requires the second recall of an item. In this view, response suppression exists, but can be used more flexibly than what is currently described in our computational models. This idea leads to one important prediction. If people stop suppressing in a context where certain items must be recalled twice, there should be a massive increase of repetition errors. First, such massive increase was not observed in the present study. Our modeling work shows that the rate of repetition errors observed in the data is not consistent with a model in which people had given up on suppressing items. Second, a massive increase of repetition errors was also not observed in the study conducted by Kowialiewski and Oberauer (2024), where participants were instructed to recall each item twice. In their paradigm, an optimal strategy would have been to not use response suppression, as suppressing the items would necessarily lead to important impairments for the second retrieval attempts. These sets of evidence combined lead us to reject a flexible response suppression mechanism as a plausible explanation. Note that we only question a response suppression mechanism through which items are no longer available to memory once recalled. To account for the lack of massive repetition errors in serial recall experiments, models of WM ultimately need a mechanism through which items are discarded from the set of retrieval candidates while still remaining available in memory. Such a mechanism remains to be identified.

Related Phenomena

Although the present study showed a systematic absence of impairment following item repetition, recent studies have examined variants of item repetition effects that do lead to a performance decrement. Roodenrys et al. (2022) observed a phonemic interference effect in immediate serial recall tasks involving within-list phoneme repetitions. In an experimental condition, participants encoded a sequence in which a target item shared phonemes with the preceding items. For instance, considering the target word “cash”, participants encoded the sequence “noise cool bag push *cash* save”. As compared to a control condition in which the target word did not share any phoneme with the preceding words, recall performance for the target word in the experimental condition decreased dramatically. Importantly, this effect cannot be attributed to the classical phonological similarity effect, because it mostly increased the rate of omission errors, the phonological similarity effect affecting mostly order errors (Gupta et al., 2005; Lian et al., 2004; Lian & Karlsen, 2004). This effect was robust as it has been replicated across 6 experiments, and has been reported in subsequent studies (James & and Roodenrys, 2023; Roodenrys et al., 2025). These results are surprising considering the null repetition inhibitory effect reported in the present study, the repetition of an item being an extreme case of phonemic overlap where the similarity between items is one. We have no clear explanation as to why these discrepancies occur, but we believe that resolving them is likely to lead to important theoretical outcomes.

Conclusion

In conclusion, the inhibitory Ranschburg effect did not appear in any of the seven experiments, with the exception of the experiment 6 in this study, neither with spatial nor with verbal stimuli. These results lead us to reconsider the importance of the effect when modeling WM, as it is not a constant effect and may only appear under specific conditions, which remain to be determined.

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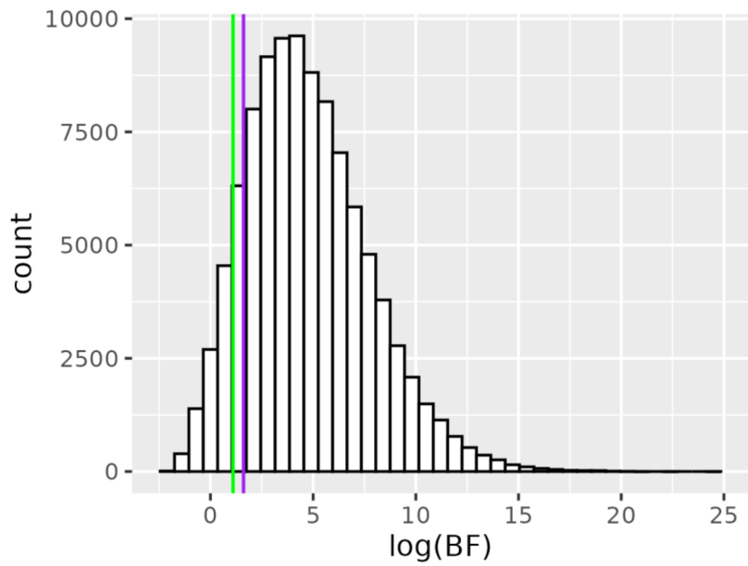
Appendix A

We simulated a fake dataset in which there is a real effect in the population by drawing 40 random values from a normal distribution with a mean of 0.65 and a standard deviation of 1.0. Fixing the standard deviation in the population to 1.0 sets the mean difference to the effect size.

We then computed the Bayes factor from this randomly generated sample, and repeated the operation 100,000 times, thus generating a theoretical distribution of Bayes factors which should have been produced in a scenario where the real effect size in the population equals 0.65. Results of this simulation indicate that the probability to obtain a Bayes factor superior to 3 and 5 was 0.908 and 0.862, respectively. The distribution of Bayes factors (log-transformed to improve readability) is reported in the figure below. The green and purple vertical lines indicate points where the Bayes factor values equal 3 and 5, respectively.



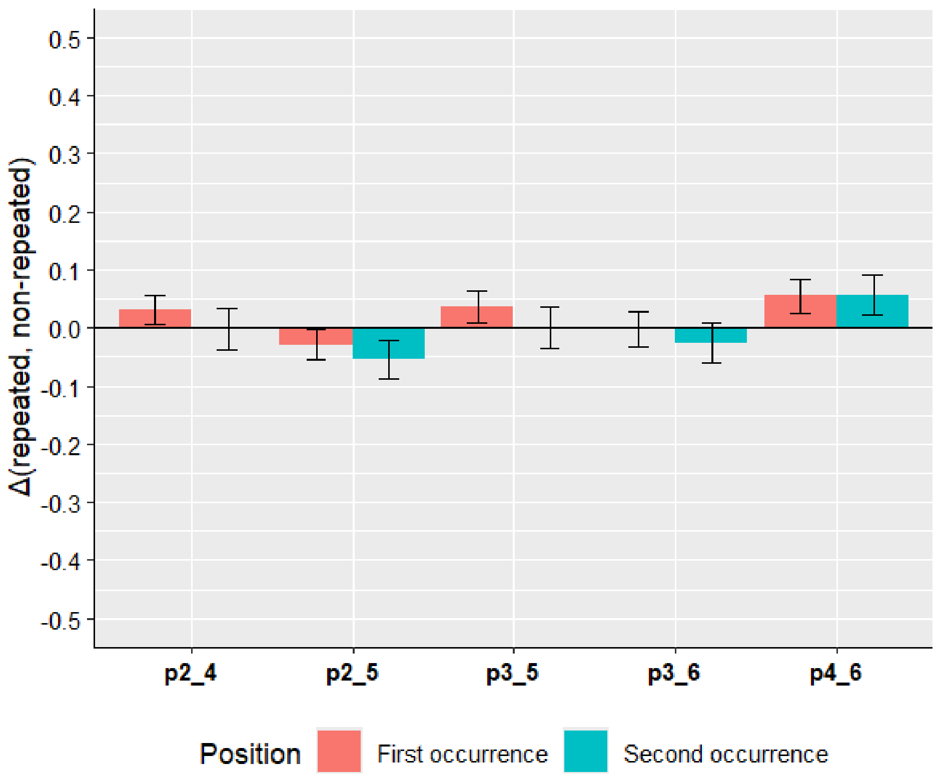
Appendix B

We reanalyzed our data by examining specific repetition patterns. In order to do this, we pooled the data from Experiments 2, 3, 4 and 5 (spaced repetition patterns only), and by focusing only on forward recall conditions. There were 5 trials per repetition pattern for each experiment.

We examined the deviation from 0 in the difference scores for repeated vs non-repeated conditions for each repetition pattern separately, via Bayesian one-sample t-tests. The results are shown in **Figure B1** and associated Bayes factors are summarized in **Table B1.**

Figure B1

Repetition pattern specific performance for data pooled over Experiments 2, 3, 4 and 5 -



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. pX_Y represents a specific repetition pattern, X and Y referring to the specific serial positions involving a repeated item. Error bars indicate the 95% confidence intervals.

Table B1

Bayes factor computed on one sample t-test on the deviation from 0 in the difference scores.

Repetition patterns	First occurrence	Second occurrence
p2-4	BF_{10} = 1.331, d = 0.187	BF_{01} = 11.281, d = 0.008
p2-5	BF_{01} = 1.243, d = 0.168	BF_{10} = 17.060, d = 0.263
p3-5	BF_{10} = 2.335, d = 0.206	BF_{01} = 11.342, d = 0.002
p3-6	BF_{01} = 11.226, d = 0.011	BF_{01} = 3.821, d = 0.118
p4-6	BF_{10} = 49.688, d = 0.289	BF_{10} = 10.258, d = 0.249

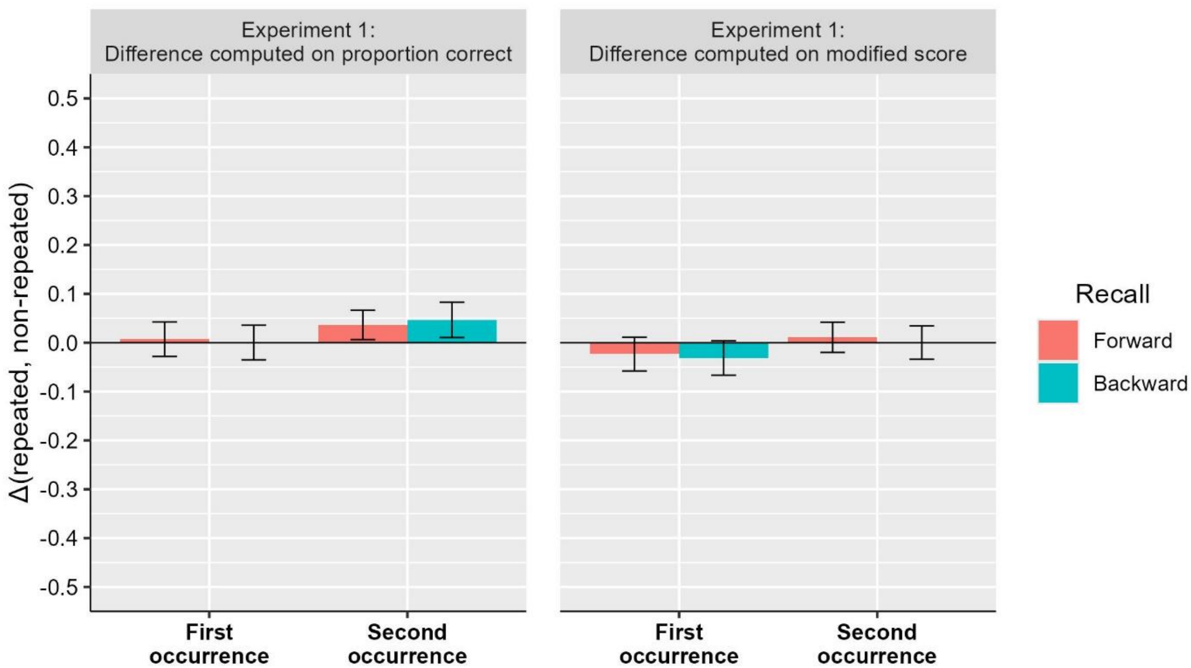
Appendix C

We reanalyzed the presence of a Ranschburg effect for each experiment using the modified scoring method from Henson et al. (1998). The modified score consisted in not counting transposition errors between target items in the non-repeated condition given that these errors cannot be detected for repeated targets in the repeated condition (since they are identical) . The consequence of this modification was to increase the score of the non-repeated condition, thus increasing the chances of observing an inhibitory effect. We conducted one-sample t-tests over first and second occurrences for both recall directions. First, we reanalyzed Experiment 1 using the proportion of item correctly selected instead of the Euclidean distance to allow for a direct comparison with the modified score which is calculated on the proportion of correct items. Results are presented in **Figure C1**, with the proportion correct scores and the modified scores shown in the left and right panels, respectively. The results of Experiments 2 and 3 are presented in **Figure C2**, those of Experiments 4 and 5 in **Figure C3**, the results of Experiment 6 in **Figure C4**, and those of Experiment 7 in **Figure C5**. The results of the reanalysis of Experiments 1–5 are summarized in **Table C1**, whereas the results of Experiments 5 and 7 are reported in **Table**

C2. As shown, the use of the modified score does not substantially change the outcome of results, with the exception of Experiment 2 in the forward recall direction and Experiment 7 in the backward recall direction. Conclusions remained unchanged for all other experiments.

Figure C1

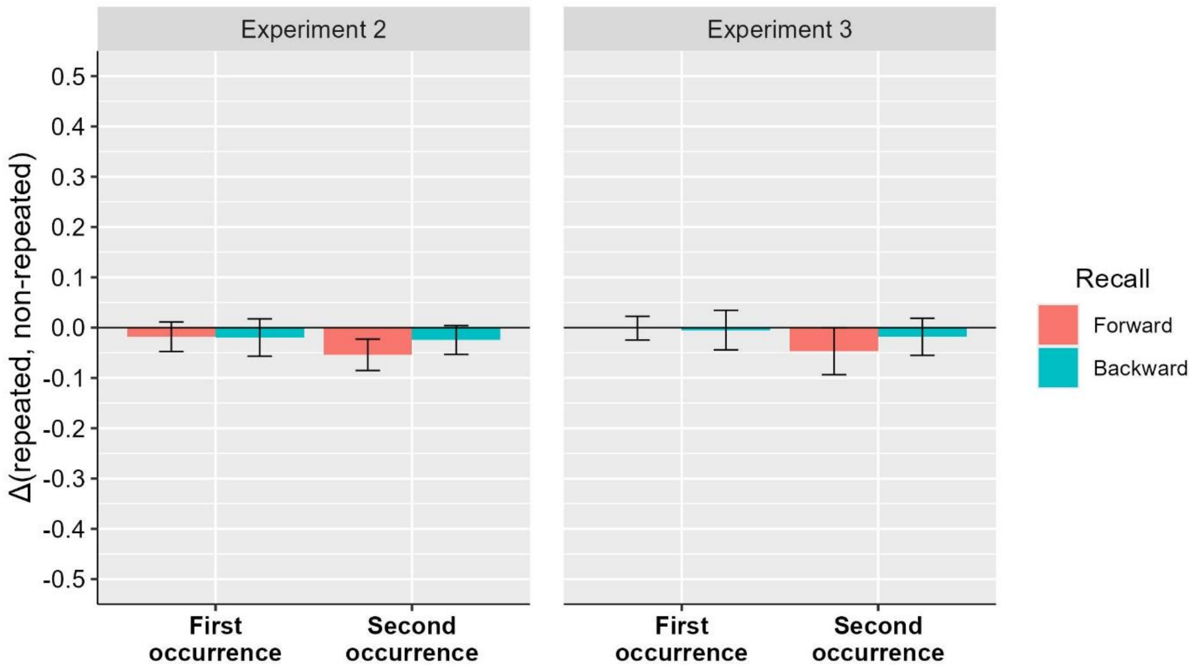
Experiment 1 – Difference score as a function of recall direction and occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals. Left panel: difference computed on proportion correct. Right panel: difference computed on the modified score.

Figure C2

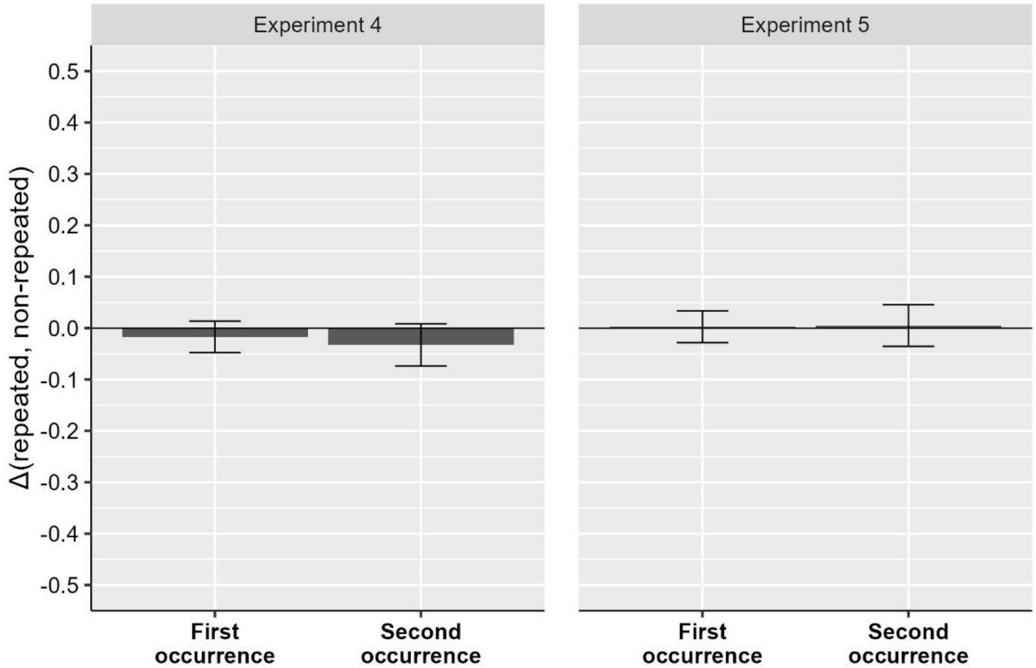
Experiment 2 and 3 – Difference score as a function of recall direction and occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure C3

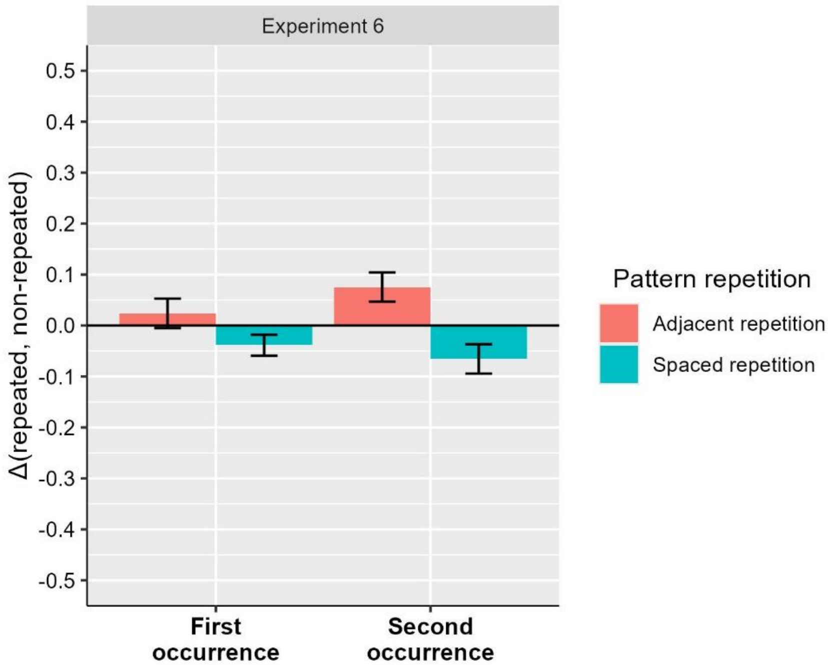
Experiment 4 and 5 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure C4

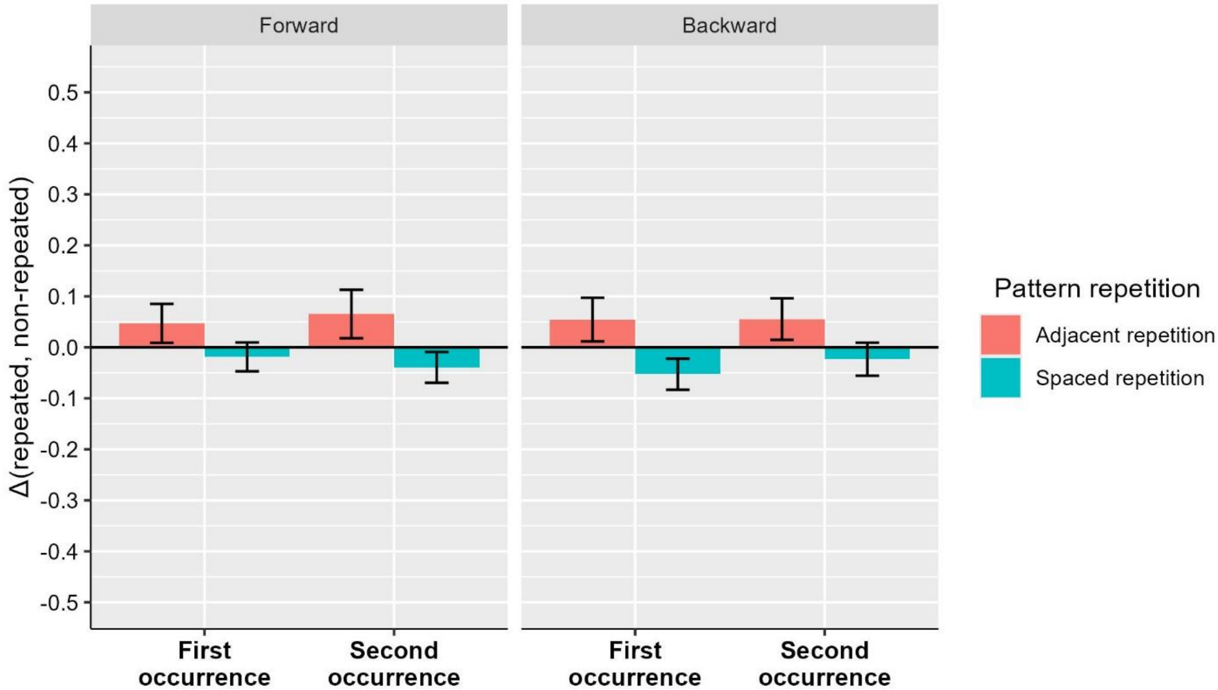
Experiment 6 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Figure C5

Experiment 7 – Difference score as a function of occurrence condition.



Note. The y axis indicates the difference between the repeated (Ranschburg) and non-repeated conditions, a negative score indicating an inhibitory effect. Error bars indicate the 95% confidence intervals.

Table C1

Results from one sample t-test comparison between repeated and non-repeated condition for experiment and experimental condition

Experiments	1st occurrence Forward	2nd occurrence Forward	1st occurrence Backward	2nd occurrence Backward
Experiment 1: Difference computed on proportion correct	BF_{01} = 5.42 d = 0.064	BF_{10} = 2.335 d = 0.385	BF_{01} = 5.861 d = 0.002	BF_{10} = 3.338 d = 0.413

Experiment 1: Difference computed on modified score	$BF_{01} = 2.489$ d = 0.215	$BF_{01} = 4.584$ d = 0.114	$BF_{01} = 1.356$ d = 0.284	$BF_{01} = 5.861$ d = 0.003
Experiment 2	$BF_{01} = 2.879$ d = 0.196	$BF_{10} = 26.814$ d = 0.554	$BF_{01} = 3.411$ d = 0.170	$BF_{01} = 1.494$ d = 0.274
Experiment 3	$BF_{01} = 5.842$ d = 0.013	$BF_{10} = 1.065$ d = 0.319	$BF_{01} = 5.696$ d = 0.039	$BF_{01} = 3.687$ d = 0.157
Experiment 4	$BF_{01} = 3.275$ d = 0.177	$BF_{01} = 1.785$ d = 0.255		
Experiment 5	$BF_{01} = 5.783$ d = 0.0268	$BF_{01} = 5.692$ d = 0.039		

Table C2

Results from one sample t-test comparison between repeated and non-repeated condition for experiment and experimental condition.

	1st occurrence Forward	2nd occurrence Forward	1st occurrence Backward	2nd occurrence Backward
Experiment 6	$BF_{10} = 61.566$ d = 0.417	$BF_{10} = 846.626$ d = 0.506		
Experiment 7	$BF_{01} = 3.572$ d = 0.145	$BF_{10} = 2.783$ d = 0.286	$BF_{10} = 25.633$ d = 0.379	$BF_{01} = 3.084$ d = 0.158

Note. We have only reported the results concerning spaced repetition, as this was our principal interest.