If You Can't Help, at Least Don't Hurt!

Examining Long Term Memory's Support of Working Memory

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by

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Abstract

There is an exchange of information between working memory (WM) and long-term memory (LTM). The flexible gate hypothesis describes how beneficial information from long-term memory is admitted into working memory while information that might cause interference is blocked. The present study offers a critical test of this hypothesis be examining serial recall accuracy, response time, and cognitive capacities. A variant of the Hebb paradigm was used, in which participants' recall performance was tested through immediate serial recall of lists. All analyses supported past research of no proactive interference with evidence of proactive facilitation. Therefore, we conclude that there is a flexible gate that is selective and adaptive, allowing only helpful information from LTM to pass through to WM, while simultaneously blocking potentially harmful information.

If You Can't Help, at Least Don't Hurt! Examining Long Term Memory's Support of Working Memory

Working memory is described as the ability to retain and manipulate information in active attention (Reynold et al., 2022). Most mental activities require the management of multiple pieces of information. In some cases, not all the relevant information is presented at once. Therefore, it is important to be able to hold the initial pieces of information until all the important information is presented. Once all the information is presented, the pieces can be intertwined together, and a person can begin to think about the relations among the relevant information (Reisberg, 2013).

Encoding information into working memory is easy because doing so is automatic (Reisberg, 2013). Information a person is currently "working on" is held in working memory. If a person switches tasks to work towards a new goal, the previous information is replaced with the most relevant information, thus, *maintaining* information in working memory is more difficult than encoding given its limited capacity. Because working memory holds onto the information a person is currently thinking about, the information is readily available while active, but susceptible to loss once it becomes inactive (Reisberg, 2013). Some of these limited-capacity shortcomings of working memory (e.g., size and duration) may be compensated for depending on activation of relevant long-term memory representations (Baddeley, 2000).

Working memory is responsible for providing access to representations for goal-directed processing such as language comprehension, reasoning, planning, hypothetical thinking, and creative problem-solving (Oberauer, 2009). Such complex cognition is dependent on a person's ability to combine and manipulate information in working memory. For a working memory system to be successful it must be able to retain new information, maintain previous information, and build new structural representations (Oberauer, 2009). These representations must be dynamic so that they can be continuously updated as new information is presented. Manipulation is another important element within the working memory system. A person must be able to hold all the presented information and determine which pieces of information are important in completing the complex cognition. There is a need for attentional selection, mentally choosing one piece of information and determining where to place it while all the other information stays in its position. Additionally, there is a need for a procedural system, a mechanism for determining what to do with the selected piece of information (Oberauer, 2009).

Overall, working memory is not a system dedicated to a singular purpose, rather, is it used as a general-purpose mechanism serving all cognitive functions (Baddeley, 2000; Oberauer, 2009; Reisberg, 2013). Working memory is an executive process that is flexible and easily reconfigurable. This makes it possible to adjust the parameters of the working memory based on the problem presented (Baddeley, 2000). For example, working memory would operate differently when the goal is to remember the placement of all the pieces on a chessboard, then when the goal is to play a round of speed chess.

With that being said, working memory is responsible for continuously acquiring new information and acting on the information that is appropriate for the situation. For working memory to be effective, it must be able to avoid proactive interference from long-term memory (e.g., mistakenly writing the date as 2023 shortly after the 2024 New Year). Long-term memory is responsible for storing previously stored knowledge about a vast amount of information. In each unique situation, the information within working memory must be updated based off the presented goal and the system must decide, at least implicitly, whether to allow the contents of long-term memory to influence the contents of the working memory and when to prevent them (Baddeley, 2000; Oberauer, 2009).

Working memory is limited in size (e.g., capable of holding only five or six words), so the current contents of working memory will be lost if the system becomes engaged in something else. Therefore, it is important for temporary information to be transferred into more permanent structural representations in long-term memory (Oberauer, 2009; Reisberg, 2013). Long-term memory holds all knowledge including specific knowledge and more generalized themes. This includes autobiographical knowledge about events throughout a person's lifetime. Unlike the working memory system, which is very fragile, the information in long-term memory remains there regardless of whether a person is thinking about it at the current moment or not (Reisberg, 2013). Working memory is a stimulated compartment of long-term memory where new long-term memories can be formed (Greene et al., 2024).

Working Memory May be Supported by Long-Term Memory Processes

Processes linked to working memory are usually influenced by long-term memory (Oberauer, 2009). There are three ways that long-term memory can influence working memory. First, activating relevant pre-existing knowledge from long-term memory can assist in increasing the efficiency of working memory processes. Second, long-term memory can support working memory by narrowing down search sets for the reconstruction of memory traces (Oberauer, 2009). Memories are usually stored in long-term memory based on how well the pieces of information fit together. Since groups of related information are usually stored together, they can be retrieved into working memory with greater ease if the right cue is provided. Finally, long-term memory can help support working memory by keeping information stored in serial order. For example, when required to recall serial lists, information early in the list has relatively high activation, but as the list progresses, activation level diminishes. Relevant information from long-term storage can help maintain a level of activation that supports the entire list (Oberauer, 2009).

As mentioned above, working memory is limited in size, therefore it is essential to transfer important knowledge to long-term memory before it is lost. Memory rehearsal in a free recall procedure is one example of how long-term memory supports working memory. In a memory recall procedure, participants are more likely to remember the first few words of a list known as the primary effect and they are also more likely to remember the last few words of the list known as the recency effect (the so-called “serial position effect”; Reisberg, 2013). Performance on short-term recall tasks are dependent on the serial position of an item in the memory list (Oberauer, 2003). When a list of words is presented during a free recall procedure, participants are tasked with trying to remember as many words as possible. Since working memory is responsible for the material a person is actively working on, the initial words presented would be replaced with the words most recently seen or heard. As the participant continues to listen to the list of words, the previous words will be bumped out of working memory. At the conclusion of presentation of the words, the last few words will not be bumped out of working memory because there is no additional information to disrupt these items. When a person is asked to recall the words, the last few words will be easily and accurately recalled because they remain active in working memory. This is known as the recency effect, which demonstrates that working memory contents are easily and quickly retrieved (Morrison, Conway, & Chein, 2014; Oberauer, 2003; Reisberg, 2013).

Contrastingly, the primacy effect comes from a different source of memory: long-term memory. For a piece of information to be transferred to long-term memory, additional work and repetition are required. One example of how a piece of information makes it to long-term memory is through memory rehearsal. When a word is presented, a participant usually repeats that word in their head until a new word is presented (e.g., “apple”). Once the second word is presented the participant continues to repeat the two words until the third word is presented (e.g., “apple, truck”). This pattern will continue throughout the list, as many words as the participant can remember. The first couple words in the list are privileged because they do not have to share attention with many other words. As the list progresses, the participant must divide their attention between a larger number of words. The words presented later in the list are rehearsed less often than the words at the beginning of the list. Since the words at the beginning of the list are rehearsed more often, they are more likely to be transferred to long-term memory, which is demonstrated by the primary effect. By requiring the participant to complete a task before the recall of the list of words, researchers can demonstrate that long-term memory supports working memory. If a task requires a participant to utilize their working memory, participants are less likely to accurately recall the words previously categorized as being part of the recency effect because the task bumped those words from working memory. However, the participants were still able to recall the beginning items, demonstrated by the primacy effect, because these words had been transferred to long-term memory. Long-term memory is not dependent on the current activity therefore, it was unaffected by the task (Reisberg, 2013).

Working memory capacity can be expanded by using a technique referred to as chunking. Chunking is strategy used to combine pieces of information in one cluster to free up space in working memory (Bartsch & Shepherdson, 2023). The more pieces of information that can be “chunked” together, the extra information that can be actively worked on in working memory (Thalmann et al., 2019; Mathy et al., 2023). For chunking to be successful a person must pull from their previous existing knowledge stored in long-term memory (Akyürek et al., 2017; Bartsch & Shepherdson, 2023). For example, when a person goes to leave their house, they must think about what items they need to grab before they walk out the door. These items might include keys, wallet, ChapStick, umbrella, etc. If a person is required to remember multiple items, there will not be much sufficient space in working memory to remember additional information. However, through chunking and a person's preexisting knowledge that these household items are necessary each time a person leaves the house, a person can chunk these items into one cluster to free up space in working memory. Rather than trying to remember each individual item, a person can remember them as a cluster of "household items."

This same pattern of chunking can be demonstrated when trying to memorize phone numbers. A typical phone number is a list of ten numbers. If a person were asked to recall a new list of ten numbers, they would struggle to recall them in the correct order. However, if the ten numbers were organized into three smaller chunks (e.g., XXX- XXX-XXXX), the numbers are easier to remember and recall accurately. While chunking is beneficial for increasing the amount of information that can be stored in working memory, it does not increase the actual capacity of working memory (i.e., amount of usable storage space available in the system). A person is still only able to remember around 7 "chunks" of information, however the more effective the chunk, the greater the amount of information that can be contained within one slot. To create connections between pieces of information to create each "chunk" a person must pull from their preexisting knowledge in their long-term memory.

Working Memory May be Disrupted by Long-Term Memory Processes

In most cases, it is beneficial for working memory to draw on previous knowledge in long-term memory; however, preexisting knowledge in long-term memory may lead to proactive interference. Proactive interference is defined as an issue in acquiring new information due to previously learned, but no-longer-relevant information (Rhodes et al., 2022; Keppel & Underwood, 1962). For instance, if the preexisting knowledge in long-term memory is similar but nonetheless different from the information relevant to the goal, one might rely on long-term information resulting in the incorrect recall of information (Mizrak & Oberauer, 2022). An example of when preexisting knowledge in long-term memory might result in the incorrect recall of information in the working memory can be seen with phone numbers. Prior to everyone having cell phones, people were required to memorize important phone numbers. If over time, one of these phone numbers changed and now has the chunk 102 instead of 103, one might erroneously rely on the information in LTM resulting in the incorrect recitation of the new phone number. Similarly, in the days following December 31, it is not unusual to erroneously write the date using the just-past year.

This is most commonly seen in paired associate learning where prior knowledge about A-B pairs hinders the subsequent learning of A-C pairs (relative to previously unseen pairs, occasionally indicated as D-E pairs) (Rhodes et al., 2022). Paired associate learning is a model used to comprehend how people encode and retrieve newly formed associations among stimuli. In this type of learning, participants learn multiple different pairs that consist of both a stimulus and a response. The first letter in the pair always refers to a stimulus or cue and the second letter refers to an associated response (Rhodes et al., 2022). For example, the participant might first see the color “yellow” which would be referred to as the stimulus (A) in the A-B pair. Following the presentation of the color “yellow”, the participant would then be shown the word “banana” which would be referred to as the response (B) in the A-B pair. The prior learning of these A-B pairs hinders the subsequent learning of A-C pairs. Participants experience increased difficulty in learning these new A-C pairs because both the A-B pairs and the A-C pairs share the same stimulus, however that stimulus is paired with a different response. For example, in an A-C pair, the participant is still presented with the stimulus “yellow”, however that stimulus is now paired with the response “car”. Participants are also presented with a third set of pairs during paired associate learning referred to as D-E pairs. D-E pairs are important in this type of learning because they serve as a baseline or control for the different types of pairs. In D-E pairs, there is no deliberate similarity to the other two lists because both the stimulus and response are previously unseen items.

The Flexible Gate Hypothesis: Maximizing LTM Support of WM While Minimizing Cost

Previous research has shown that there is an exchange of information between working memory and long-term memory. Working memory performance is greater with increased attentional capacity because individuals can more readily utilize information in long-term memory to support recall (Jeffries et al., 2004). According to the “flexible gate hypothesis,” only long-term information that is beneficial to working memory is permitted to pass through, while long-term information that is possibly harmful is blocked (Mizrak & Oberauer, 2022). Studies show that this gate is adaptive and selective, and only allows information to pass through when it is beneficial (Mizrak & Oberauer, 2022; Oberauer 2009; Oberauer et al., 2017). Even in tasks where long-term knowledge is only partially beneficial, the helpful information assists performance (proactive facilitation) with no interference from less relevant information (no proactive interference) (Mizrak & Oberauer, 2022). For example, in Mizrak and Oberauer’s (2022) study of serial recall letter span task, well-learned lists supported working memory (facilitation), but lists using the same letters in a different order did not disrupt working memory even though the letters were the same. This is surprising because in other memory tasks related information often interferes with memory retrieval. For example, according to interference theory, previously learned information can disrupt the recollection of new information and vice versa (Reisberg, 2013).

Oberauer has tested the flexible gate hypothesis which shows that long-term memory is used only when it necessary, therefore there is no harm in utilizing it. For example, in one experiment, participants were required to learn the colors of 120 unique objects (Oberauer et al., 2017). A paired associate paradigm was used, and participants were required to encode three object-color pairs during each trial in the learning phase. For example, during the learning phase a sofa was learned as being the color pink and a car was learned as being the color green. After the conclusion of the learning phase, participants were given a visual working memory test, where they were required to remember three colored objects. One of the objects was a learned object presented in the same color (e.g., the sofa in the same color pink), another learned object in a different color (e.g., the car in the color blue), and third colored object that was new (e.g., a boat that was green). During this phase of the experiment, participants were asked to recall the color of the object in the current trial. During this experiment, recall of the objects whose color was mismatched from the learning phase was not worse than the recall of the new object (Oberauer et al., 2017). However, participants were more likely to report the long-term memory color instead of the working memory color for these objects (e.g., reporting the car as green instead of blue).

Mizrak and Oberauer (2022) wanted to further investigate the flexible gate hypothesis to gain additional data on whether LTM information that is beneficial for the function of WM is allowed, while LTM that is potentially harmful to the task at hand is blocked. This experiment used a variant of the Hebb paradigm. Oberauer used the Hebb paradigm because this paradigm already showed that participants benefit from their LTM when recalling Hebb lists (Mizrak & Oberauer, 2022). The Hebb paradigm is named after Hebbian theory in which repeatedly and sequentially stimulated neurons wire together – often summarized as "cells that fire together wire together." Similarly, the Hebb paradigm in memory research refers to the observation that repeatedly presented lists of items become represented in long-term memory. Participants perform higher on recall on these repeated lists regardless of whether they are aware of the repetition (Guérard et al., 2011). Further explanation regarding the Hebb paradigm will be explained in a later section of this study.

Mizrak and Oberauer (2022) report five different experiments. Each experiment was made up of 64 trials and all participants were exposed to three different types of lists: Hebb list (e.g., repeated presentation of the same items in the same order), No-overlap filler lists (e.g., new items that do not overlap with the Hebb list), and Overlap filler lists (e.g., items from the Hebb list but presented in different random orders). During each of these experiments, participants were exposed to randomly generated lists, where every third or fourth trial a study list repeated itself (e.g., Hebb list). By presenting participants with repeated lists (e.g., Hebb lists), serial recall performance gradually increases compared to the randomized lists (e.g., No-overlap filler lists, Overlap filler lists) (Mizrak & Oberauer, 2022). The researchers hypothesized that through the course of frequent presentation of the repeated lists, the memory for that sequence of items in the list will become more and more established in LTM.

In Oberauer et al. (2017), some degree of proactive interference was shown when participants were asked to recall the color of an object that mismatched what they originally learned in the learning phase. Mizrak and Oberauer (2022) planned to further investigate how much previously learned information affects recall by using the Hebb effect paradigm. Similar to the recall of a colored object, the researchers utilized a filler list that contained the same items as the Hebb lists but shuffled in a different order during each trial. This Overlap filler list is important for investigating proactive interference because by using the same items as the Hebb list, there is the potential for interference if the items act as retrieval cues leading to activation of the Hebb list as well. The No-overlap filler lists acted as a control condition for proactive facilitation on the Hebb trials and proactive interference on the Overlap fillers trials (Mizrak & Oberauer, 2022). The No-overlap filler lists were made up of items that were different than the Hebb and Overlap filler lists. Since the Overlap filler lists contain the same items as the Hebb lists, it is expected that more proactive interference will be experienced during those trials compared to the No-overlap filler trials. Both the Overlap filler and No-overlap filler lists were seen an equal number of times throughout the study, however in the case of the Overlap filler lists, the Hebb list is learned strongly in LTM, while in the case of the No-overlap filler lists, the lists will not be learned into LTM because the lists are never repeated.

Mizrak and Oberauer (2022) found evidence for proactive facilitation and no evidence for proactive interference. They found no evidence of LTM contribution to memory performance in the trials containing the OF lists. These results generalized the findings of Oberauer et al. (2017), that the flow of information between LTM and WM is controlled by a flexible gate that is selective and adaptive. The flexible gate only admits information from the LTM that is beneficial to the WM task. Since the flexible gate is both selective and adaptative, information that is only partially beneficial can be let through the gate while the additional information that is harmful is blocked.

Hebb Effect

To investigate the flexible gate hypothesis more closely, Mizrak & Oberauer (2022), utilized a pattern known as the Hebb paradigm. In 1961, Donald Hebb found that repetition of the same series of lists led to improvement of immediate serial recall in comparison to random lists (Araya et al., 2022; Burgess & Hitch, 2006; Araya et al., 2023; Page & Norris, 2009; Guérard et al., 2011), while the non-repeated lists remained stable (Araya et al., 2023). Improved recall on repeated lists compared to non-repeated lists is known as the Hebb Effect. The Hebb effect is an example of long-term sequence learning because the repeated list is filed in serial order into long-term storage. For the improvement of serial recall to occur, the sequence must be presented as a whole from the beginning of the list. This type of learning relatively fast and long lived (Page & Norris, 2009).

Previously, researchers believed that Hebb repetition learning occurs from chunking in simple span tasks, but from position-item associations in complex span tasks (Araya et al., 2023). Recently, results suggested that the mechanism underlying the Hebb repetition effect is the same in both simple and complex span tasks. The Hebb effect will only occur if the items appear in the same list position and in relation to the same neighboring items on each repetition (Araya et al., 2022; Araya et al., 2023). In instances where only the second position was maintained in the same position, there was no repetition learning. This finding shows that Hebb repetition learning does not happen from the gradual learning of individual position-item associations but rather lists as a whole (Araya et al., 2023). Learning also does not occur if the order of the list is shifted and wrapped around (e.g. ABCDE is repeated as CDEAB). This finding demonstrates that the Hebb effect does not occur based on learning independent item-item associations. For the Hebb effect to occur, the list must be present as a whole, or a chunk. By grouping the list into a unified chunk, that list can be stored into long term memory in the correct order while ensuring there are no distractors (Araya et al., 2023). The removal of distractors in working memory is relatively quick, therefore most of the distractors are removed before a long-term memory is formed based off the remaining information being held in working memory.

Goals of the Present Study

The aim of this study is to examine the flexible gate hypothesis more closely. First, although past research on the flexible gate hypothesis has shown that there is no interference from long-term memory in terms of accuracy, the proposed study is designed to explore whether long-term memory can actively hurt working memory in terms of response time. Since information is being passed through the gate, there is expected to be a cost in terms of efficiency, which might be detected by measuring response time. Second, in previous research, participants were instructed to repeat back in order a list of letters or numbers that was just shown to them. Repeating items back in order is not a strong test of working memory in terms of processing capacity. A more rigorous test would be to ask participants to complete a backward span task (i.e., recalling the items from the list in reverse order). Requiring participants to recall a repeated list in reverse order will provide opportunity to explore the possibility that long-term memory can disrupt working memory. For example, a well-learned list of letters will likely interfere with recalling in reverse order a different list that uses those same letters (proactive interference). This finding would be a challenge for the flexible gate hypothesis.

Method

Participants

A total of 56 (20 males and 36 females) undergraduates from an independent liberal arts university in the Midwest participated in this study. All participants were required to be at least 18 years of age. Participation in the study lasted approximately 15-30 minutes. All participants who were enrolled in an introductory psychology course received credit towards a research requirement. The number of participants for this study was based off a previous study done completed by Mizrak and Oberauer (2022) using within-subjects experimental designs.

Materials and Procedures

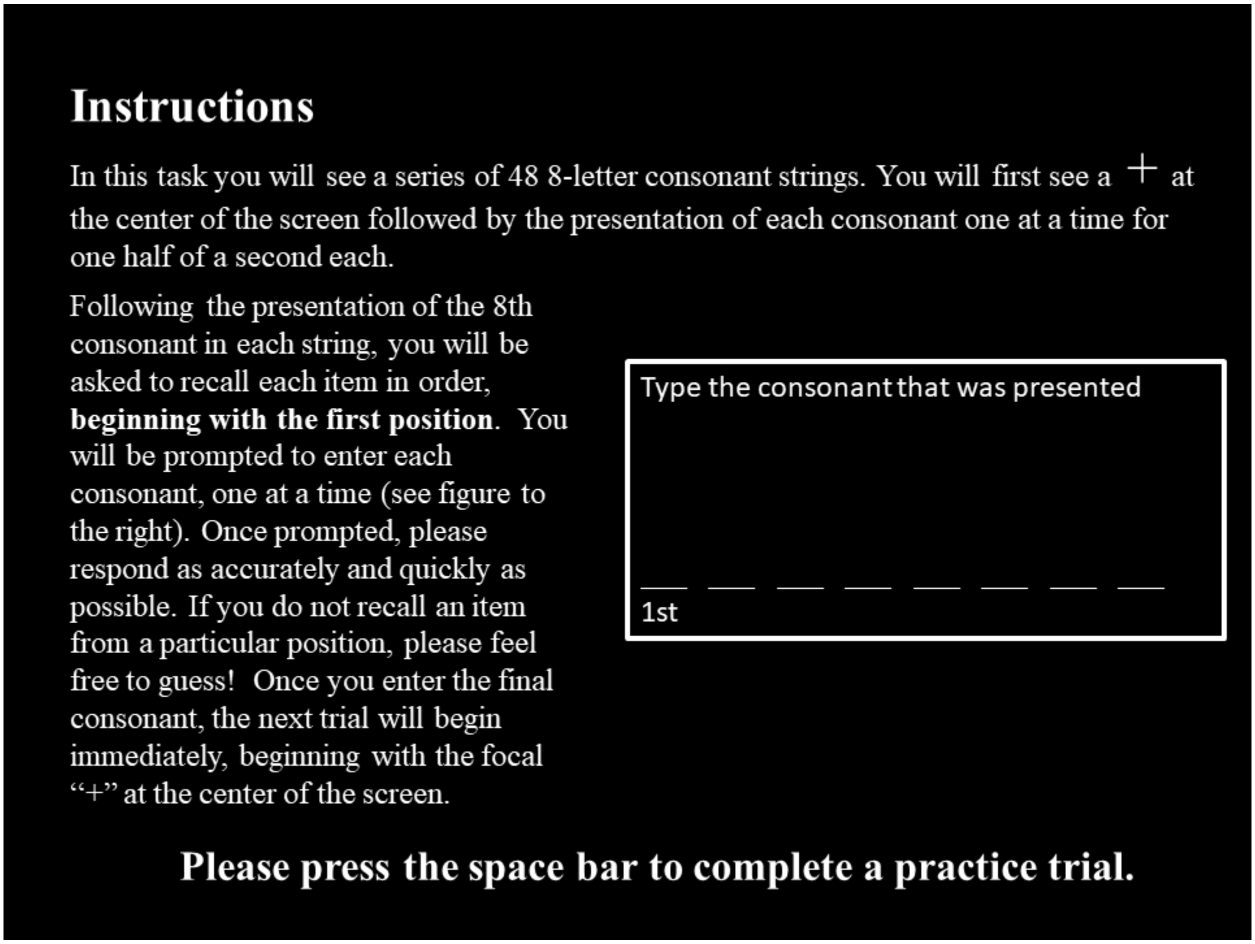
The study consisted of sixteen different consonants from the English Alphabet. All vowels were excluded to prevent real words from accidentally being created during the presentation of the letter strings. Each participant saw the same sixteen consonants regardless of the version of the test that they completed. Four different versions of the test were created to rule out the confounding variable of one list of consonants being easier to remember than the others. If one list of consonants were used as the Hebb list and Overlap filler list in one version of the test, they were used as the No- overlap filler list in the other version of the test. Overlap filler lists consisted of the same consonants as the Hebb list, but they were shuffled in a new random order for each trial. Sample lists are shown in Appendix A.

Participants were tested individually or in groups of two in the university's psychology lab. Once the participants arrived in the lab, they were greeted, and consent was obtained. The consent form was presented on the first page of the computer task (see Appendix B). If consent was obtained, participants proceeded to the first part of the study, if not, they were thanked for their time and permitted to leave. Before the beginning of the task, the researcher ensured that all participants were 18 years or older. If the participant was under the age of 18, they were thanked for their time and excused. During the duration of the assessment, no identifying information was collected or used.

The serial recall memory task was delivered within the DirectRT Precision Timing Software (Version 2012.4.0.166; Jarvis, 2011) for precise delivery of study items and collection of response time data. After entering the participant's sex, the following instructions were displayed:

Figure 1

Instructions for the Study



Note. Depicted above are the instructions presented to the participants before the beginning of the trial. Participants were presented with the instructions above if they were completing the forward span task. Participants were presented with similar instructions if they were completing the backward span task, except the were asked to recall each item in order **beginning with the last position** rather than the first position.

Once you press the space bar, you will have the opportunity to complete a practice trial.

Following Mizrak and Oberauer's (2022) procedure, a cross appeared in the center for 1,000 milliseconds to direct participants attention to the position that each consonant appeared. Each 8-consonant string was presented one item at a time, and each item was on display for 500 5 milliseconds. After all eight consonants were presented, there was a 1,000-millisecond delay and then participants were instructed to complete immediate serial recall. Participants were randomly assigned to one of two groups: forward serial recall or backward serial recall (i.e., they were asked to recall the list in the exact order it was presented or in reverse order). Participants entered their responses using the computer keyboard. They received a prompt for each position, one at a time (see the box inset in Figure 1 for a sample prompt addressing the 1st position)**.**

Recall was always prompted in serial order (1st through 8th or 8th through 1st), depending on which condition they were in. Regardless of which recall task the participant was asked to complete (i.e., forward or backward span), they saw three different types of trials: 1. Hebb list (16 trials) – The Hebb list was a series of eight consonants presented 16 times throughout the test. This list always appeared with the same consonants in the same order (e.g., NVFRQCYZ). 2. Overlap Filler list (OF; 16 trials) – The OF list was compromised of the same eight consonants as the Hebb list, but the consonants were presented in a different random order each time (e.g., FNZRYCVQ). 3. No-Overlap Filler (NOF; 16 trials) – The No- overlap filler list (NOF) was comprised of series of eight consonants that were different from those used in the Hebb and OF lists (e.g., XBDLPKST). A different random order of those consonants was used each time the list is presented. Those 48 trials were presented in a randomized order to prevent scores being influenced by participants detecting a pattern. The DirectRT program stored participants' sex, responses, and the amount of time required for each key press. The accuracy of the responses was hand calculated using a key created for each of the four tests. No other data was collected or stored. Accuracy and reaction time data were analyzed as a function of list type (Hebb, OF, NOF) and recall task (forward or backward serial recall). Following the completion of all 48 trials, participants were debriefed as follows:

> Thank you for participating in this study. The goal was to investigate the “flexible gate hypothesis” which governs the flow of information from long-term memory to working memory. According to past research, the “gate” prevents information from entering working memory if it will cause interference. Only helpful information is permitted through the gate. The past research, though, only looked at recall accuracy. In this study we collected both accuracy and response time data to help determine whether interference is occurring.

Participants were thanked for their participation and contact information was shared in case they had additional questions.

Results

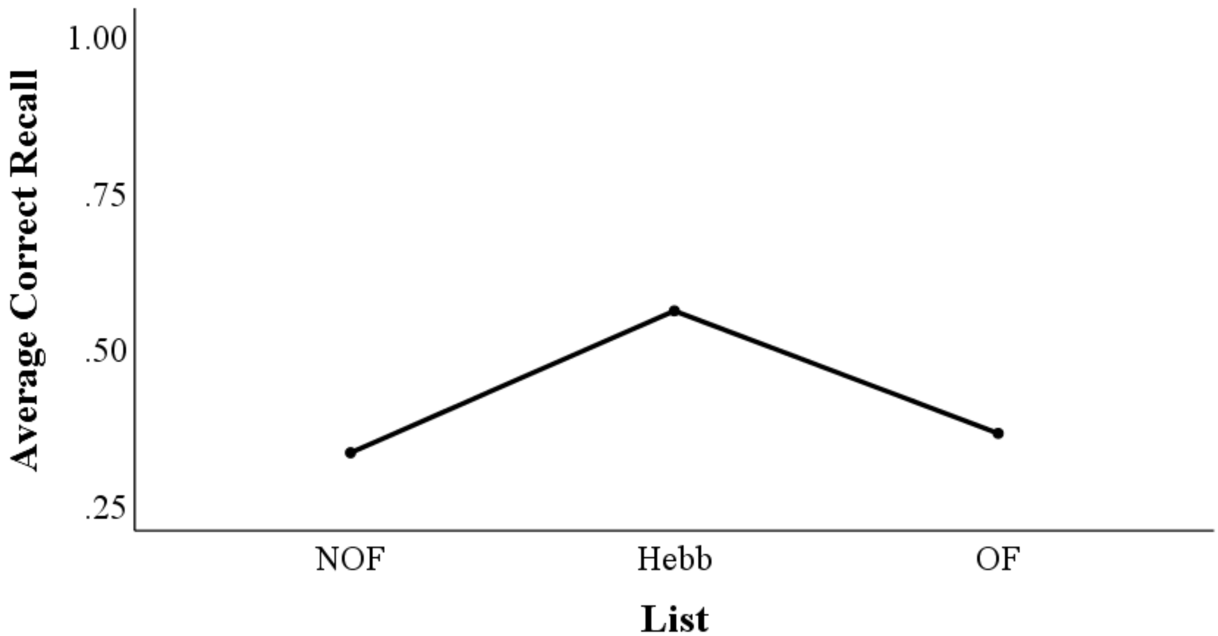
Recall Accuracy Performance

Participants were expected to score the highest on recall accuracy for the Hebb list and lowest on recall accuracy for the OF lists to the extent that overlap interferes with performance. However, if the flexible gate prevents interfering information from being activated in working memory, then participants should perform no worse on OF items than items from a new list (NOF list). If LTM memory (e.g., Hebb list) interferes with WM (e.g., recall of the Overlap filler list) this would be evidence of proactive interference.

Figure 2 shows recall accuracy across list types. Recall accuracy on list types was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant effect of list type $F(1.38, 37.28) = 53.46$, $p < .001$. Bonferroni post-hoc comparisons indicated that recall was statistically significantly higher for the Hebb list than each of the other two, *p*’s < .01. This finding indicated that the Hebb list was encoded into long- term memory (LTM), and they were able to use their LTM representation to guide their performance on the recall task. This result is consistent with Mizrak & Oberauer’s (2022) findings.

Figure 2

Recall Accuracy on List Type



Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average recall accuracy for the three list types. This figure is representative of all the participants that completed the forward recall task.

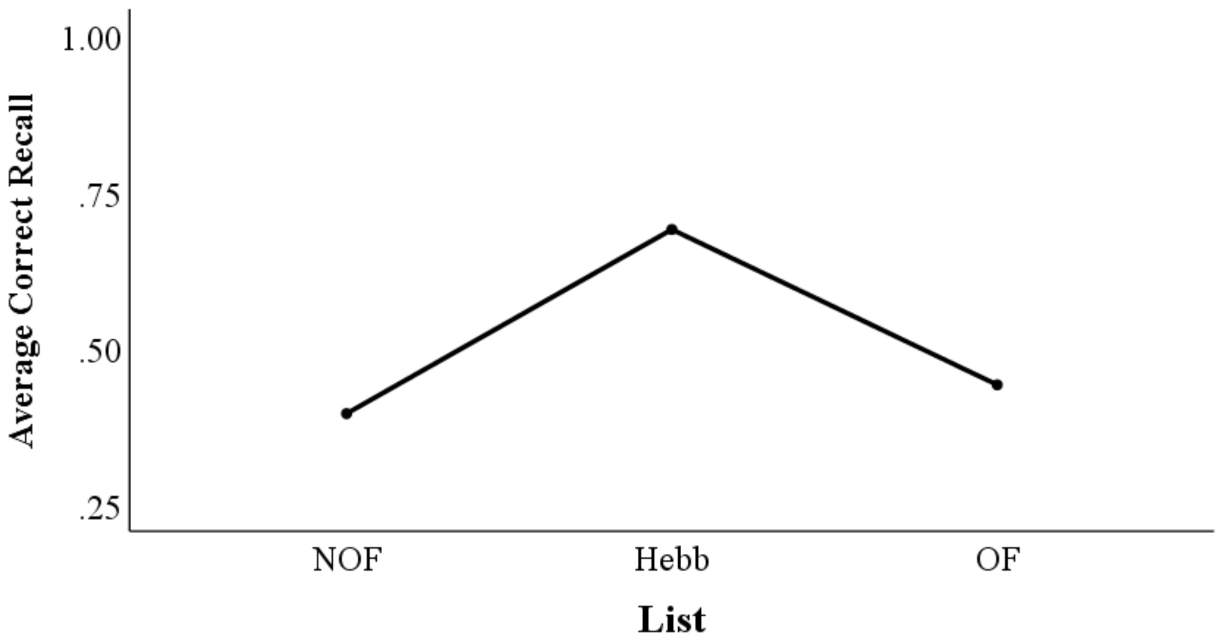
A stronger test of whether the Hebb list might interfere with processing the OF lists, given the overlap in letters, would be to focus on those participants who demonstrate relatively strong learning of the Hebb list. An analysis using only participants who scored 50% or higher on Hebb list recall replicated past research demonstrating no proactive interference between the

Hebb list and OF list. Like the result with the total sample, there is only evidence of proactive facilitation because participants scored the best on the Hebb list and at comparable levels for the NOF and OF lists. This supports the flexible gate hypothesis because even in instances where the Hebb list is encoded into LTM, only LTM information beneficial to the task at hand is allowed into working memory, while information that is possibly harmful for the function of the working memory is blocked.

Figure 3 shows recall accuracy across list types for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). Recall accuracy on list types was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant effect of list type $F(1.43, 21.46) = 51.03$, $p < .001$. Bonferroni post-hoc comparisons indicated that recall was the statistically significantly higher for the Hebb list than each of the other two, p's < .01. This stronger test of the flexible gate hypothesis replicated the previous finding and offers additional support to the flexible gate blocking out interfering information.

Figure 3

Criterion Reached for Hebb Performance Level: Recall Accuracy on List Type



Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average recall accuracy for the three list types. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the forward span task.

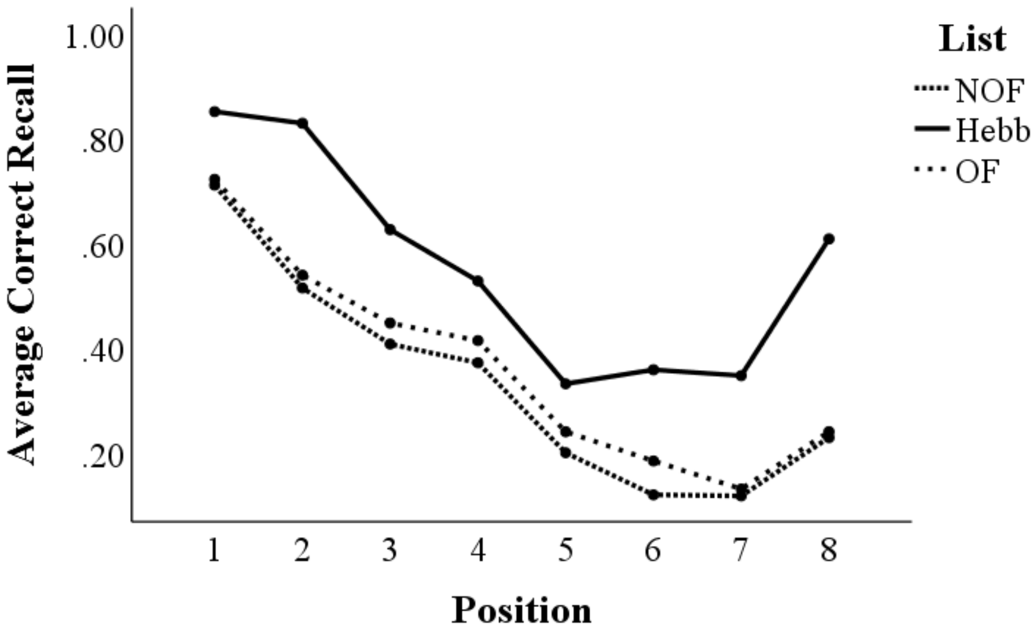
Serial Position Effect

We hypothesized that the OF lists would suffer the most from the serial position effect because in the OF lists, the middle items experience both within-list interference as well as potential interference from the Hebb list. The serial position effect is the tendency that participants will recall the beginning and end items the best and the middle items the worst. The primacy effect is the tendency to recall the beginning items with the best recall accuracy because those items are relatively well rehearsed and make it into LTM. Similarly, a recency effect is seen in a strong serial position curve because those items are relatively active in WM leading to easier retrieval. Items in the middle of the list have the worst recall accuracy because they experience the most interference from both early items and late items. The data show a strong primacy and recency effect for the Hebb list, whereas the NOF and OF list only show a primacy effect. There was no statistically significant difference between recall accuracy across the positions in the NOF and OF lists.

Figure 4 shows recall accuracy across list type by position. Recall accuracy on position as a function of list was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant List Type x position interaction, $F(6.60, 178) = 4.91$, $p < .001$. Follow-up *t* tests using the Bonferroni-Holm correction were calculated on the first, fifth, and eighth positions in each list. The Hebb list shows a strong serial position curve demonstrating both primacy and recency effects (higher recall on the first and last positions relative to the middle). Both NOF and OF lists showed only the primacy effect (higher performance for the initial items than those in the middle and at the end).

Figure 4

Recall Accuracy by List Type Across Position



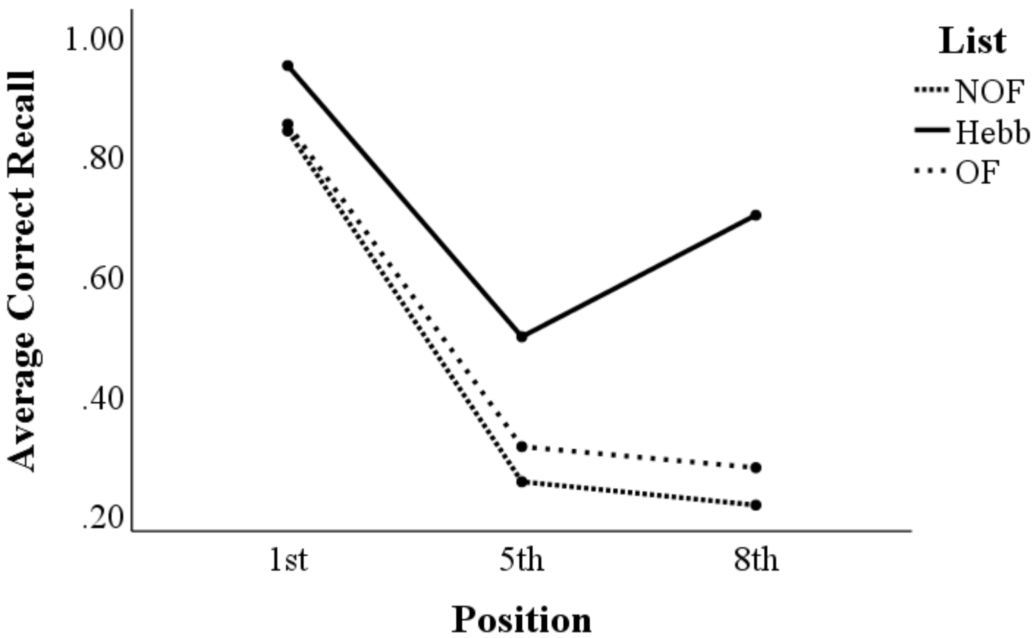
Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are represented by the three different lines in the figure above. Each dot represents the average recall accuracy at each of the eight positions. This figure is representative of all the participants that completed the forward recall task.

This analysis supports past research and the flexible gate hypothesis because if proactive interference occurred, recall performance for the middle items would be significantly worse on the OF list compared to the Hebb and NOF lists. Instead, the analysis shows that all three list types experience within-list interference resulting in poor recall accuracy of the middle items. While Figure 4 does not show evidence of proactive interference, it does provide evidence for proactive facilitation because the Hebb list shows a strong serial position effect. Through repeated exposure to the same list, participants were able to rehearse these items more frequently allowing them to transfer to LTM, resulting in higher recall accuracy.

An analysis was conducted using only participants whose recall accuracy was 50% or higher on the Hebb list because it is a stronger test of the effect of LTM on working memory. By removing the participants who did not learn the pattern of the Hebb list, we can investigate the flexible gate hypothesis more closely. We can eliminate the possibility that the reason there was no proactive interference is because the Hebb list was not learned in LTM memory. The participants who scored 50% or higher on recall accuracy of the Hebb list were most likely to experience proactive interference when recalling the OF list. This was demonstrated by the serial position effect, where the middle items have the lowest recall accuracy because these items experience both within-list interference as well as potential interference from the Hebb list. Figure 5 shows recall accuracy across list types by position for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). Recall accuracy on position as a function of list was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant List Type x Position interaction, $F(4, 60) = 13.90$, $p < .001$. Similar to Figure 4, Bonferroni-Holm-corrected *t* tests indicated a primacy and recency effect in the Hebb list, but only a primacy effect for the NOF and OF lists.

Figure 5

Criterion Reached for Hebb Performance Level: Recall Accuracy by List Type Across Position



Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are represented by the three different lines in the figure above. Each dot represents the average recall accuracy at each of the three positions. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the forward span task.

Although it was hypothesized that recall accuracy would be the lowest for the OF list, there was no difference between the NOF and OF list for the middle position. Both lists showed a strong primacy effect similar to the Hebb list, however they did not show a recency effect. There was no statistically significant difference between recall accuracy across the positions in the NOF and OF lists.

This analysis supports past research and the flexible gate hypothesis because participants scored statistically significantly higher on the Hebb list compared to both the NOF and OF lists. By seeing the Hebb list repeatedly throughout the trials, participants were able to rehearse that list of items more frequently allowing them to transfer that list to LTM. This supports the flexible gate hypothesis because it demonstrates proactive facilitation, the idea that LTM information benefits WM performance because it matches the information that needs to be held in WM. This is shown in all three positions in Figure 5. Participants scored statistically significantly higher on the Hebb list across all three positions compared to both the NOF and OF lists. In addition, there is no evidence of proactive interference between the Hebb list and OF list because participants scored equally poorly on the NOF list as they did the OF list. Out of eight items, participants correctly recalled an average of three items or less on both the NOF and OF lists for the middle positions and final position. Those same participants correctly recalled an average of four items or more on the Hebb list for the middle positions.

Response Time Performance

Previous studies have investigated the flexible gate hypothesis or the idea that only LTM information that is beneficial to the task at hand is utilized, while information that is possibly harmful to the current task is blocked from WM (Mizrak & Oberauer, 2022; Oberauer 2009; Oberauer et al., 2017). These studies have investigated the flexible gate hypothesis through memory tests that involve both WM and LTM. The challenge is to determine if proactive interference occurs between LTM and WM, or if there is only evidence of proactive facilitation. Mizrak and Oberauer (2022) designed a study involving three different list types (e.g., NOF, Hebb, and OF lists). The goal of their study was to determine if proactive interference occurred between the Hebb list and OF list due to OF list containing the same letters as the Hebb list, but presented in a different order. The NOF list was used as a control in this study as a comparison group to the OF list. Mizrak and Oberauer's (2022) study specifically looked at whether proactive interference and proactive facilitation occurred in terms of recall accuracy.

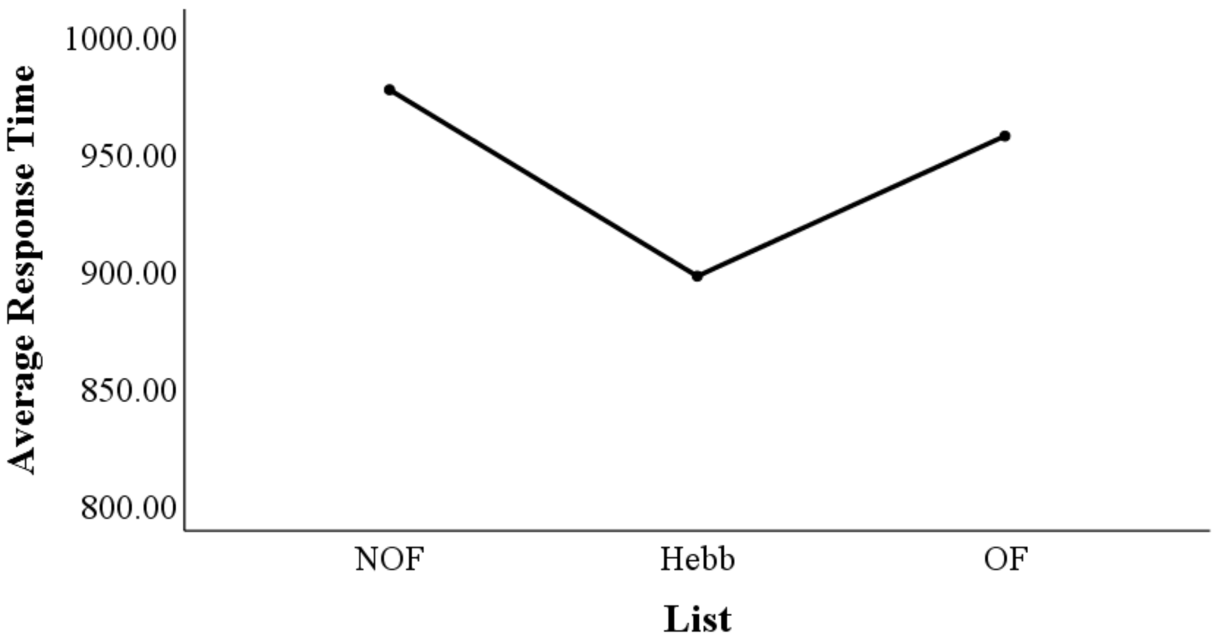
The analyses above look specifically at recall accuracy. These tests found that participants performed equivalently on the NOF and OF lists, if not slightly better on OF (at least performance was not worse which would have suggested interference). Although, participants performed equally on the NOF and OF lists, it is possible to find equal levels of performance with different underlying processes. This can be seen in response time. Participants might take longer to respond on the OF lists due to interference from LTM even though participants performed equivalently on the two lists in recall accuracy.

To investigate this phenomenon, analyses were conducted looking specifically at response time across the three different list types. The first analysis was to investigate the difference in response time across different list types (e.g., NOF, Hebb, OF). We hypothesized that participants would respond the fastest on the Hebb list and slowest on the OF list due to the list containing the same letters as the Hebb list. Through repeated exposure, items on the Hebb list are learned into LTM. Since the OF list contained the same items as those learned in LTM, there would have been evidence of proactive interference in terms of slower response time, if the items from LTM interfered with the WM task of recalling the OF list.

Figure 6 shows response time across list types. Response time on list types was analyzed using a one-way repeated measures ANOVA. The ANOVA did not yield significant effect of list type, $F(1.52, 40.99) = 2.65$, $p > .05$. Although Hebb response time was in the predicted direction (i.e., faster than the other lists), the ANOVA may not have yielded a significant effect of list type due to a large variation in the data. Across all three list types, there was a standard deviation of an average of three seconds. Note that both excellent memory and poor memory can result in very fast responding (i.e., quickly responding because an item is activated in memory or quickly responding when you know you do not know).

Figure 6

Response Time on List Type



Note. Response time of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average response time for the three list types. This figure is representative of all the participants that completed the forward recall task.

These findings were different than hypothesized, because it was expected that response time on the Hebb list would be statistically significantly faster than both the NOF and OF lists. Since the NOF and OF lists were not repeated throughout the study in the same order, like the Hebb list, those lists would not have the opportunity to be learned into LTM. By learning the list into

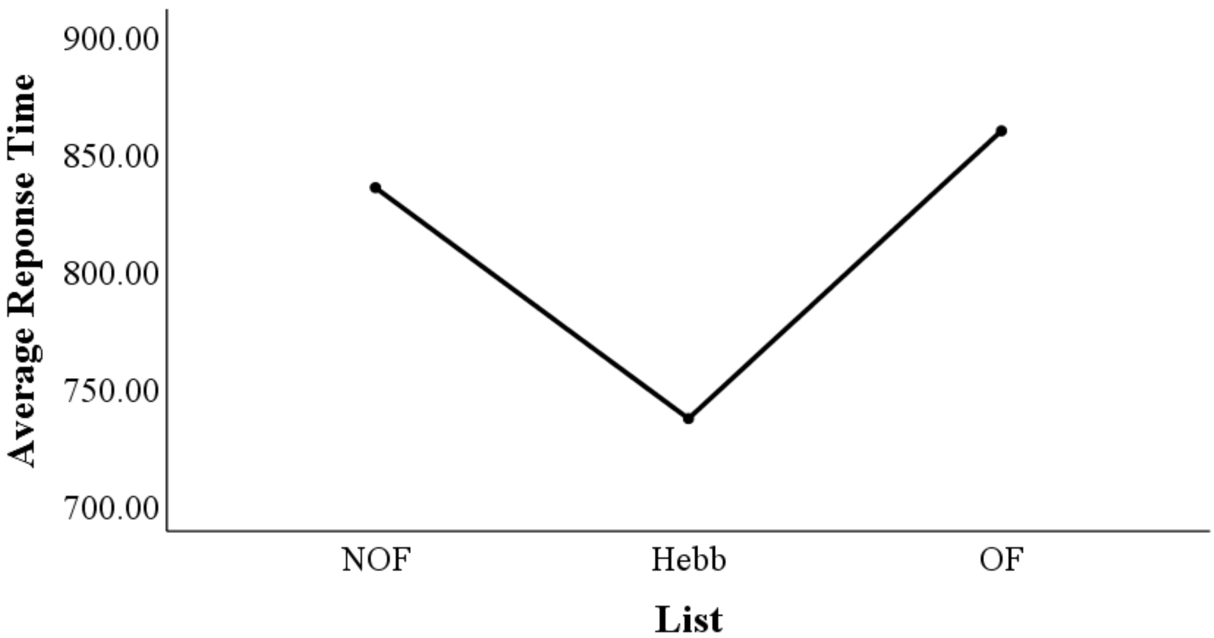
LTM, response time should become faster on the Hebb list because the participant would be able to pull that information from LTM to help support WM.

For the next analysis, only data of participants who scored 50% or higher on recall of the Hebb list were used. An analysis using only this group of participants was used because they demonstrated the Hebb repetition effect. The idea that as a list of items is repeated, it increases the performance in immediate serial recall. This is an important phenomenon when investigating the flexible gate hypothesis because the flexible gate pulls information from LTM to benefit WM tasks. It was hypothesized that participants would respond the fastest on the Hebb list and slowest on the OF lists. Participants were expected to respond the slowest on the OF list due to Hebb effect. Since the items in the OF list were the same as the letters in the Hebb list, it was hypothesized that proactive interference would occur since those letters were already learned into LTM. In addition, it was also hypothesized that participants would respond faster on the Hebb list compared to both of the other two lists (e.g., NOF and OF). This would demonstrate proactive facilitation, or the idea that when LTM information benefits WM performance it is utilized because it matches the information that needs to be held in WM.

Figure 7 shows response time across list types for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). Response time on list types was analyzed using a one-way repeated measures ANOVA. The ANOVA did not yield a significant effect of list type $F(1.23, 18.38) = 3.86$, $p = .058$. One possible reasoning behind this finding is the large variability in the response time data. After limiting the data to include only participants who reached a criterion level of performance on the Hebb list of 50% or higher recall accuracy, the standard deviation for the OF list was almost 2 seconds more than the Hebb list.

Figure 7

Criterion Reached for Hebb Performance Level: Response Time on List Type



Note. Response time of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average response time for the three list types. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the forward span task.

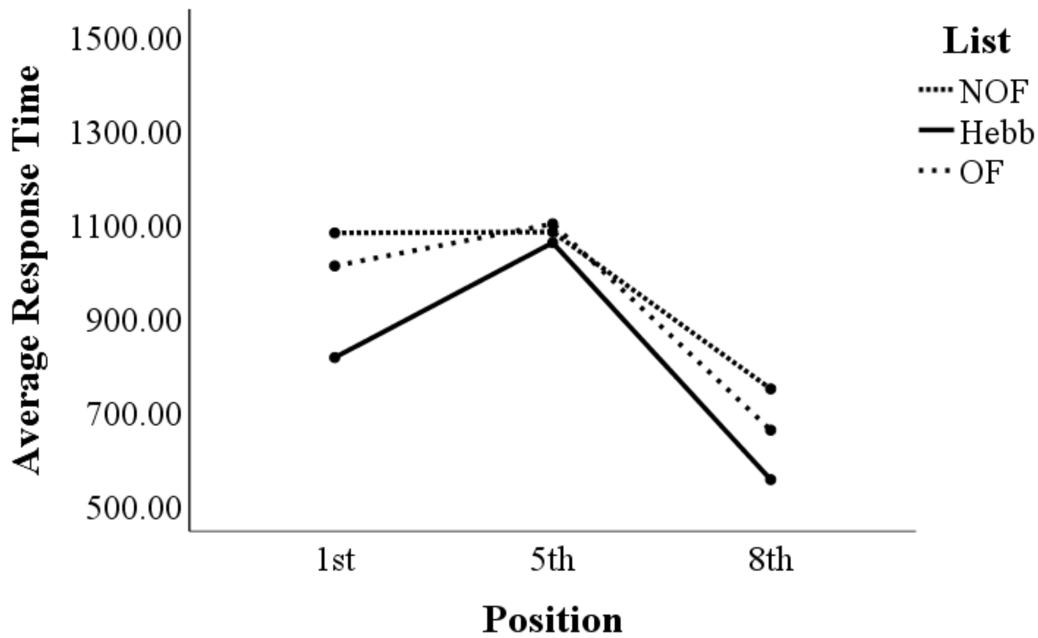
These findings may indicate that the flexible gate hypothesis has no influence on response time. There is no evidence of proactive interference suggesting the Hebb list leads to slower response time in the OF list. Additionally, there is no evidence of proactive facilitation as participants did not respond statistically significantly faster on the Hebb list compared to the NOF and OF lists. Future researchers should be cautious when reporting on this finding due to the large variation in the response time data.

Additional analyses were conducted on response time data using only participants whose recall accuracy was 50% or higher on the Hebb list. Proactive interference occurs when previously learned materials in LTM hinders subsequent processing in WM (Rhodes et al., 2022). To be able to test whether proactive interference occurs during processing, we examined how long it took participants to recall items within each list. While no interference was found with respect to accuracy, it is possible that it took participants longer to recall items in the list that overlapped with the Hebb list than the one that did not.

The participants who scored 50% or higher on recall accuracy of the Hebb list were most likely to experience the slowest response times when recalling the OF list. Furthermore, we hypothesized that response times would be the slowest in the middle position of the OF list because these items experience both within-list interference as well as potential interference from the Hebb list. Figure 8 shows response time across list types by position for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). Response time on position as a function of list type was analyzed using a one-way repeated measures ANOVA. The ANOVA did not yield a significant effect of List Type x Position interaction $F(4, 60) = 0.96$, $p > .05$. A lack of significance across list types by position for response time may be due to the large variation in data. Across the different list types, there was a standard deviation of over four seconds for some of the positions.

Figure 8

Criterion Reached for Hebb Performance Level: Response Time by List Type Across Position



Note. Response time of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are represented by the three different lines in the figure above. Each dot represents the average response time at each of the three positions. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the forward span task.

There was no difference between response times, as all three list types were within 40 milliseconds of each other. Therefore, there was no evidence of greater interference in terms of RT for the middle items.

Both the NOF and OF lists show a recency effect for response time. Participants responded the quickest in the end position compared to both the first position and the middle position. There was no statistically significant difference between response times across all three list types, demonstrating a lack of proactive interference. However, there is evidence of both a primacy and recency effect in response time on the Hebb list. Although response time was faster on the Hebb list on the 1st and 8th positions, it was not statistically significantly faster than the NOF and OF list.

Backward Serial Recall

This study aimed to investigate the flexible gate hypothesis and the effect it plays on recall accuracy and response time in a working memory task. After analyzing the data, there is evidence of the flexible gate hypothesis supporting recall accuracy. In analyses including all participants who completed the forward span task as well as participants who scored 50% or higher recall accuracy on the Hebb list for the forward span task, recall accuracy is higher on the Hebb list compared to the NOF and OF list. These findings indicate that participants are utilizing the information from their LTM to benefit recall from their WM. In addition, the analyses indicated that there was no proactive interference between the Hebb list and the OF list. It was hypothesized that recall accuracy would be the lowest for the OF list since the OF list contains the same items as the Hebb list just presented in a different order. This hypothesis was shown to be incorrect by the serial position effect. Participants scored equally as poorly on the middle items on the Hebb list as they did on the NOF and OF lists. Overall, the average recall accuracy was equivalent for both the NOF and OF lists.

Contrastingly, there was no evidence that the flexible gate hypothesis supports response time. In all the analyses investigating response time, there were no statistically significant findings. These findings indicate that the Hebb repetition effect, the phenomenon that repeated presentation of the same list increases performance in immediate serial recall, has no effect on response time. If it does, our methodology was not sensitive enough to detect it. Evidence of the

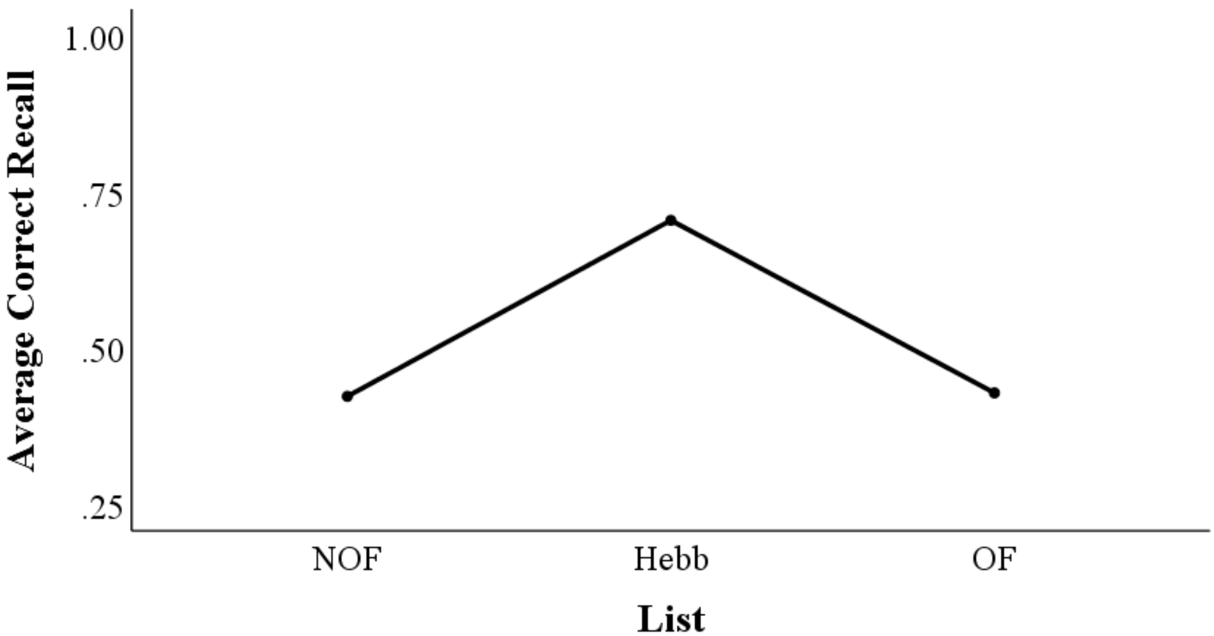
Hebb repetition effect would support the flexible gate hypothesis because proactive facilitation should occur. Participants should respond faster on the Hebb list compared to both the NOF and OF list. A lack of support for the flexible gate hypothesis could be due to variability in the data.

The flexible gate regulates what information from LTM is allowed into WM. Mizrak and Oberauer (2022) found that no proactive interference occurs between the Hebb list and OF list because the flexible gate blocks the information that is harmful to the current task while allowing the beneficial information to pass through. To challenge this phenomenon, we included a memory task that requires more WM resources – backward span. At the conclusion of the presentation of the items, half of the participants were asked to recall the items in reverse order. Requiring participants to recall the items in reverse order challenges the flexible gate hypothesis because participants must pull what they know from LTM to WM while simultaneously flipping the learned list to be able to recall it backwards. It was hypothesized that this could lead to greater interference because recalling the items in reverse order requires more working memory resources.

Figure 9 shows backward span recall accuracy across list types for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). Recall accuracy on list types was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant effect of list type, $F(2, 26) = 79.593$, $p < .001$. Follow-up *t* tests indicated that recall was statistically significantly higher for the Hebb list than each of the other two, *p*'s $< .01$. Performance on the NOF and OF lists were equivalent, $p > .05$.

Figure 9

Backward Span Accuracy as a Function of List Type



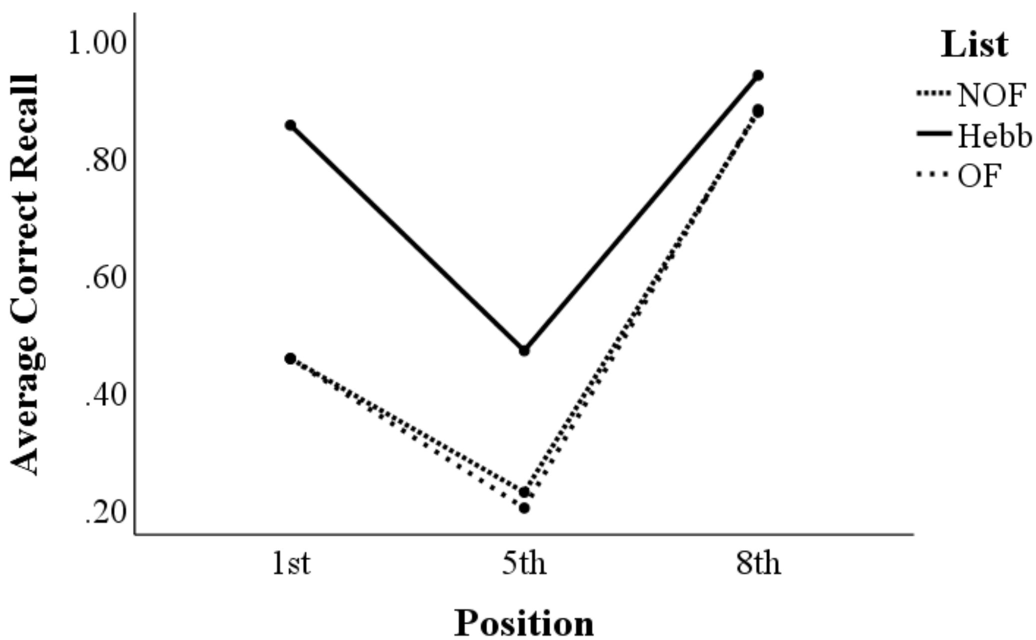
Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average recall accuracy for the three list types. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the backward span task.

These findings were comparable to those in Figure 3 which looked at recall accuracy across list type for participants who completed the forward digit span task. The data showed evidence of proactive facilitation as participants score statistically significantly higher on the Hebb list than the NOF and OF lists. However, the data did not show evidence of proactive interference as participants scored equally on the NOF and OF lists. These findings continue to be supportive of past research and the flexible gate hypothesis.

Figure 10 shows recall accuracy across list types by position for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). The data depicted in this figure are only for participants who completed the backward span task. Recall accuracy on position as a function of list was analyzed using a one-way repeated measures ANOVA. The ANOVA yielded a significant List Type x Position interaction, $F(4, 52) = 7.96$, $p < .001$. Bonferroni post-hoc comparison indicated stronger performance on the Hebb list relative to NOF and OF, which were equally poor on the first position, which was recalled last in the task. Recall for the 8th position, which was recalled first, was equally strong in all three groups.

Figure 10

Criterion Reached for Hebb Performance Level: Recall Accuracy by List Type Across Position



Note. Recall accuracy of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are represented by the three different lines in the figure above. Each dot represents the average recall accuracy at each of the three positions. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the backward span task.

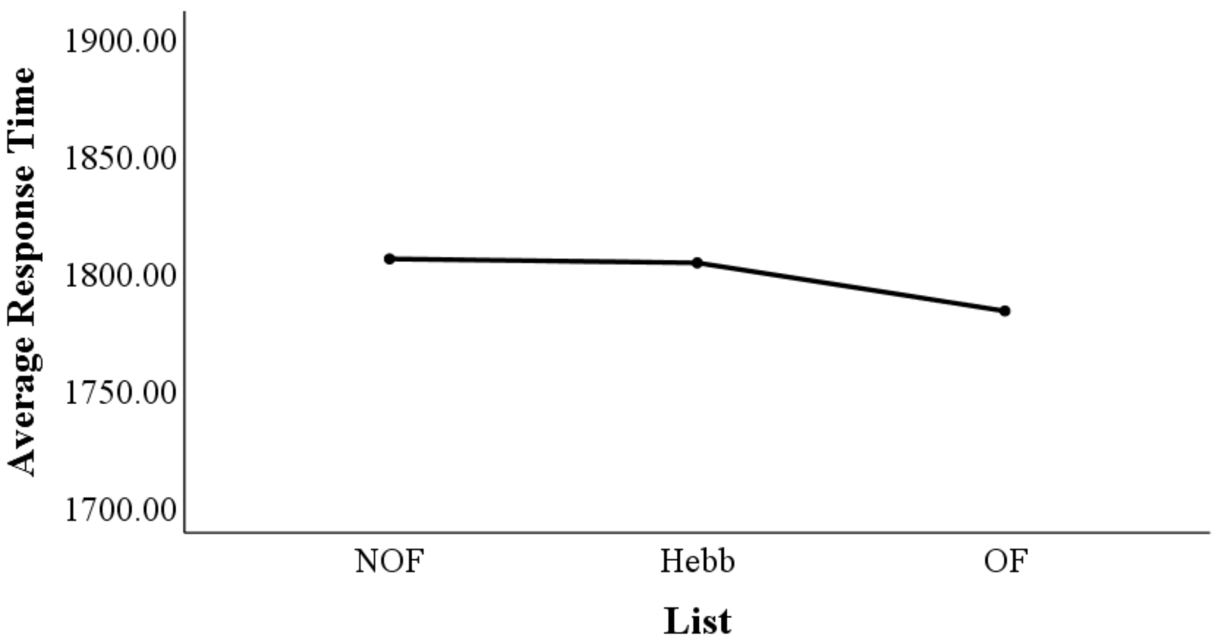
Although it was hypothesized that recall accuracy would be the lowest for the OF list, there was no difference between the NOF and OF list for the middle position. All three lists showed both a strong primacy effect and strong recency effect. There was no statistically significant difference between recall accuracy on the NOF and OF lists. This finding supports the flexible gate hypothesis because there was no proactive interference between the Hebb and OF list. Furthermore, the data provides evidence of proactive facilitation because participants scored statistically significantly higher on the Hebb list compared to the NOF and OF lists. By seeing the Hebb list repeatedly throughout the trials, participants were able to rehearse that list of items more frequently allowing them to transfer that list to LTM. Even though the participants were required to recall the items in reverse order, they still scored statistically significantly higher than the NOF and OF lists.

The final analysis in this study is similar to Figure 9; however, it investigates response time across list type on the backward serial recall instead of recall accuracy. All the analyses in this study have shown a statistically significant effect for recall accuracy across list type, but not response time. We hypothesized that response time would be slower for the OF list compared to the Hebb list. With the increased difficulty of recalling items in reverse order, it was expected that response time would be slower for the OF list even if recall accuracy was not statistically significantly different. Since participants must flip the list of items in their WM to accurately recall them, the cost of utilizing additional WM resources was hypothesized to be seen in response time for the OF list being statistically significantly slower. This is due to increased proactive interference from the Hebb list being learned into LTM.

Figure 11 shows response time across list types by position for participants who reached a criterion level of performance on the Hebb (e.g., 50% or higher recall accuracy). The ANOVA did not yield a significant main effect of list type, $F(2, 26) = 0.03$, $p > .05$. There is no significant effect of list type on response time perhaps due to the demanding nature of the backward serial recall. It took participants an equal amount of time to respond across all three list types. This finding is interesting, however, because not even LTM is helping the response time for the Hebb list to be faster.

Figure 11

Response Time on List Type for Participants Completing the Backward Span Task



Note. Response time of No-overlap filler (NOF), Hebb, and Overlap filler (OF) lists are shown in the figure above. Each dot represents the average response time for the three list types. This figure only includes participants whose recall accuracy for the Hebb list was 50% or higher. This figure is also limited to participants who completed the backward span task.

Discussion

In this study, we aimed to examine the role long-term memory plays in working memory. Our goal was to examine this relationship by looking at the flexible gate hypothesis more closely. Previous research found that information flow between long-term memory and working memory is controlled by a flexible gate that admits information from LTM that is beneficial to WM and blocks information from LTM when it is potentially harmful to WM (Mizrak & Oberuaer, 2022; Oberauer et al., 2017). If the flexible gate is controlled and selective, there should be evidence of proactive facilitation because only useful information should be allowed into WM. On the other hand, if the flexible gate is not controlled and allows harmful information from LTM to WM there should be evidence of proactive interference. In a memory task, there will be evidence of both proactive facilitation and proactive interference if LTM contribution is more mandatory than voluntary. Otherwise, information from LTM would be blocked consistently and neither proactive facilitation nor proactive interference would occur.

Previous research on the flexible gate hypothesis looked specifically at recall accuracy. Mizrak and Oberuaer (2022) found that in a memory span task there was evidence for proactive facilitation and no evidence for proactive interference. If LTM contribution was mandatory, the contents of LTM would be automatically retrieved when the OF list and Hebb list were presented because there would be sufficient resemblance to the current information in the WM. This would result in proactive interference when the OF list was presented, because there would be a mismatch in information in WM, and proactive facilitation when the Hebb list was presented because the information in LTM would match the information in the WM. However, there was only evidence of proactive facilitation because only recall accuracy for the Hebb list was statistically significantly higher upholding the hypothesis that the flexible gate is adaptive and selective.

Although it was found that there is no interference from LTM in terms of accuracy, we hypothesized that LTM could actively hurt WM in terms of response time. Since information from LTM must pass through the flexible gate to be utilized in WM, we expected there to be a cost in terms of efficiency, which could be detected by measuring response time. Evidence against the flexible gate hypothesis would be seen in the quickest response time for the Hebb list and the slowest response time for the OF list. Demonstrating both proactive interference and proactive facilitation.

Findings from our study found that there was no significant effect of list type on response time. However, the ANOVA was close to yielding a significant effect of list type, $p = .058$. One possible reasoning behind this finding was the large variability for the response time data. These findings both support and challenge the flexible gate hypothesis as there was no evidence of proactive interference, but also no evidence of proactive facilitation. Although, no evidence of proactive facilitation may be due to large standard deviation across list types.

Additionally, in previous research, participants were presented with a list of eight items and asked to recall them back in order. Completing a forward span task is not a strong test of working memory in terms of processing capacity. We hypothesized that a more rigorous test would be to require participants to complete a backward span task (e.g., recalling the items from the list in reverse order). By requiring participants to recall a presented list in reverse order, there will be increased opportunity to explore the possibility that long-term memory can disrupt working memory. Participants will utilize more working memory resources as they are required to hold a list of items in their WM while simultaneously flipping the list to be able to accurately recall it in reverse order. We hypothesized that requiring participants to complete a backward span task would challenge the flexible gate hypothesis because a well-learned list of letters will likely interfere with recalling in reverse order a different list that uses those same letters (proactive interference).

After analyzing the results from our study, we found that the backward span task supports the findings of the Mizrak and Oberuauer (2022) in terms of recall accuracy. Even when participants were required to recall items in reverse order, the flexible gate proves to be adaptive and selective and provides evidence of proactive facilitation and no evidence of proactive interference. Participants scored statistically significantly higher on the Hebb list compared to the other two lists, exhibiting proactive facilitation. Moreover, participants scored equally as poorly on the middle position across all three lists, demonstrating a lack of evidence for proactive interference. If there was evidence of proactive interference, participants would have scored statistically significantly poorer on the OF list compared to the other two lists (e.g., NOF and Hebb). Rather, there were strong primacy and recency effects shown in all three list types (e.g., NOF, Hebb and OF). One caveat, though, is that performance on both OF and NOF were poor perhaps reflecting a floor effect. That is, there was no room for OF performance to drop below NOF performance!

While the results from the backward span task supported the flexible gate hypothesis in terms of recall accuracy, they did not support the flexible gate hypothesis in terms of response time. There was no statistically significant effect of list type on response time. One possible explanation for why there was no significant effect of list type on response time is due to the challenging nature of the backward serial recall. This challenges the flexible gate hypothesis because response time was no faster on the Hebb list compared to NOF and OF lists. Even though the Hebb list was being learned into LTM, there was no evidence of proactive facilitation, indicating that participants were not relying on their LTM to increase their response time.

Limitations

One limitation of this study was the presentation of the items in the OF lists. In our study, the items in the OF lists were presented in a randomized order in each trial. Although those lists contained the same items as the Hebb list, there was no way to guarantee that the OF list would contain chunks of items that would match the Hebb list. If there were trials where chunks of items in the OF list matched the Hebb list, we may have been more likely to see interference. One way this limitation can be addressed in the future is by manually creating OF lists that have chunks of items that match the Hebb list. If the OF lists contain chunks of items that match the Hebb list, we might be able to test if greater interference occurs because the participants will be more likely to pull from their LTM because the information in their LTM will partially match the information in WM.

Another limitation of our study was the relatively poor performance on the NOF and OF lists with respect to the performance Mizrak and Oberuaer (2022) reported. Participants scored on average 20% lower across all three list types compared to results reported by Mizrak and Oberauer (2022) (e.g., < 60% correct recall on the Hebb list in our study compared to almost 80% correct recall on the Hebb list in Oberauer's study). It was unclear why our subjects performed at such a low recall level, however it could have some influence on our findings. One way this limitation can be addressed in the future is by testing participants individually. Additional background noise from testing two individuals at a time could have had an influence on the lower recall averages.

Conclusion

Utilizing long-term memory that matches information in working memory improves overall performance. In instances where only part of the information stored in LTM is beneficial, unnecessary information is blocked while valuable information is used to increase performance. Our results generalize the findings by Mizrak and Oberuaer (2022) and support the flexible gate hypothesis. The flow of information from LTM to WM is controlled by a gate that is selective and adaptive, allowing only information that this beneficial to the task at hand to be admitted into WM. Regardless of whether a participant is completing forward or backward span task, there is evidence of proactive facilitation and a lack of evidence of proactive interference in terms of recall accuracy. Participants did not display evidence of proactive facilitation or interference in their response times, however those findings may be due to the large variation in the data.

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Appendix A

Letter Sequences for First Counterbalancing Set

	List		
Trial*	No-Overlap Filler	Hebb	Overlap Filler
1	BQMPZHKF	SWCXGNVL	XGSNVLCW
2	QPFZKBHM	SWCXGNVL	NGSWVXCL
3	PHQBZKMF	SWCXGNVL	NWGLCSVX
4	QHMKPFZB	SWCXGNVL	WXCLVSNG
5	BFPHQZMK	SWCXGNVL	LNSVXCWG
6	FMQHKBZP	SWCXGNVL	VWXNLCGS
7	ZBFQHMKP	SWCXGNVL	NVCLGWXS
8	PFKBQMHZ	SWCXGNVL	LNWSCGXV
9	KHMPBFZQ	SWCXGNVL	XSCVNGWL
10	QBPFZKMH	SWCXGNVL	SLNCXVWG
11	ZBHQFPKM	SWCXGNVL	XGVSNWCL
12	BZMQPFHK	SWCXGNVL	LXCWGSNV
13	HKQZFPBM	SWCXGNVL	XWGVSLNC
14	BZKPHMFQ	SWCXGNVL	CNLVWGXS
15	FBQKZHPM	SWCXGNVL	CGSWXVLN
16	KHFPBZQM	SWCXGNVL	XLCSVNWG

* The 48 trials were presented in a different random order for each participant

Appendix B

Consent Form

Project Title: If You Can't Help, at Least Don't Hurt! Examining Long Term Memory's Support of Working Memory

Investigators: Abbey Dillon (dillona2@ohiodominican.edu; 330-806-8781); Project advisor, Dr. John Marazita (marazitj@ohiodominican.edu; 614-251-4687)

Source of Support: This study is being performed in partial fulfillment of the requirements for a BA in Psychology, with credit from the Honors Program at Ohio Dominican University. This study is supported by ODU Psychology Department resources and has been approved by the Ohio Dominican University Institutional Review Board (Dr. Valerie Matthews, Chair, matthev@ohiodominican.edu, 614-251-4685).

Purpose: Past research suggests that the connection between long-term and working memory operates like a "flexible gate" with helpful information passing from long-term memory to support working memory while potentially interfering information is blocked from passing through. The aim of this study is to examine the flexible gate hypothesis more closely using working memory span tasks, some of which are repeated multiple times to assess how their retention supports (or does not support) working memory. You will be presented strings of eight consonants and then will be asked to recall them exactly as presented (forward span) or in reverse order (backward span). Consonant strings will be presented through a computer program, which will also record your responses and reaction times to recall the strings. This task will take approximately 20 minutes to complete. These are the only requests that will be made of you.

Eligibility criteria for this study is you must be 18 years of age or older.

Risks and Benefits: There are no risks greater than those expected from day-to-day activity. Completing the measures is no more demanding than what is expected in a typical classroom setting.

Compensation: Students in PSY-100 courses will be awarded partial credit towards the completion of their class research requirement. No other compensation will be given.

Confidentiality: Data will be collected anonymously during this study, and participants are only asked to report their sex for the purpose of describing the participant pool. Your name will never appear on any research instruments and all data will be collected without identifiers. All the collected data will be stored in a computer file, which will only be accessible by the researcher and the advisor. Your responses will only appear in statistical data summaries.

Right to Withdraw: You are under no obligation to participate in this study. You are free to withdraw your consent to participate at any time.

Summary of Benefits: While there are no direct benefits to you from this study, the data will help clarify theory and research on the relationship between long-term and working memory, particularly with respect to the validity of the flexible gate hypothesis which proposes that only helpful information from long-term memory passes through the gate while unhelpful information is blocked. Such research is important for theory development in cognitive psychology, and valid theories are critical for developing effective research-based applications in the areas of education, psychology, business, and forensics, for example.

Voluntary Consent: I have read the above statements and understand what is being requested of me. I also understand that my participation is voluntary and that I am free to withdraw consent at any time, for any reason. On these terms, I certify that I am willing to participate in this research project.

I understand that should I have further questions about my participation in this study, I may contact Abbey Dillon (330-806-8781; dillona2@ohiodominican.edu) or Dr. Marazita (614-251-4687; marazitj@ohiodominican.edu).

[On Microsoft Form, participants will be able select an option to continue to the research instruments, thus giving their consent, or an option to discontinue]