ACTIVE VERSUS PASSIVE INHIBITION OF ACTIVATED INFORMATION IN LONG-TERM AND WORKING MEMORY

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ABSTRACT

The focus of this research was to investigate the possible existence of an indirect inhibitory mechanism working on activated yet unattended information in long-term memory (LTM). There exists evidence in the cognition and memory literature, specifically the retrieval-induced forgetting and negative priming literature, as well as others, that suggests indirect inhibition may be acting to moderate activation levels in conjunction with semantic activation. Participants (n=120) were given a memory load of different category exemplars and were then instructed to either recall a given dominant category membership or a novel subordinate category membership. The novel category recall instruction required a reorganization of exemplar category associations and the hypothesized inhibition of dominant categories. Following recall, a series of category comparison frames presented new exemplars from the dominant categories of the memory load. Indirect inhibition of the dominant categories would be evidenced by longer response time (RT) on subordinate relative to dominant recall trials. RTs for the category comparisons associated with subordinate recall were not significantly different from the comparisons associated with dominant category recall. These data are incongruent with the hypothesis of an indirect inhibitory mechanism acting on activated yet unattended information in LTM. Instead, they are consistent with Cowan's (1999) model of working memory (WM) that posited active-but-unattended information in WM is subject to time-based decay but not interference.

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ACTIVE AND PASSIVE INHIBITORY PROCESSES IN WORKING MEMORY

A large body of research has focused on memory activation processes within working memory (WM) and long-term memory (LTM). In contrast, the research on inhibitory processes in both WM and LTM is less prevalent. There is a body of literature on cognitive inhibitory processes, but no research specifically addresses the relationship between inhibition and activation when there is strong response competition.

Cowan's (1999) embedded-processes model of working memory is an example of the focus on activation versus inhibition in working memory. WM is defined as the subset of long-term memory that is activated. Furthermore, activated LTM information can be directly in the focus of attention and thus strongly activated, or it can be outside of attentional focus but activated to a level that renders it passively available for processing operations. Several theorists have previously argued that conventional attention-dependent WM capacity limits cannot account for the amount of information required for performance of complex comprehension and problem solving tasks (Anderson, 1983; Broadbent, 1993; Ericsson & Kintsch, 1995; Kintsch, Patel & Ericsson, 1999). Cowan's activated but unattended component of WM is particularly important, because it extends the amount of information that is available in WM beyond what can be attended.

Cowan's (1999) model bases the limits of information in WM at any given time on both decay and interference. The information that is in the focus of attention is subject to decay over time. The research proposed here focuses on the level of activation of task-relevant information that is outside of attentional focus under conditions of response competition. In this context, response competition is the act of generating a correct response when processing certain stimulus information is necessary for that response and the processing of other stimulus information is associated with an incorrect response. This is assumed to initiate an active selection process between necessary and unnecessary information in an effort to resolve the response conflict (Kane & Engle, 2003). The question of interest in the current research concerns the activation level of the selected against information (competing information) after the resolution of response competition. Is successful responding associated with an inhibitory process that lowers activation of previously primed competing information, or does activation of competing information simply decline gradually with time while necessary stimulus information is in the focus of attention?

For this project, the main focus will be Cowan's (1999) WM model for the reason that it is somewhat ambiguous regarding the possibility for an active inhibitory process in the subset of LTM. On one hand, Cowan clearly ascribed the limit of activated but unattended information in WM to decay over time. However, Cowan also stated, "When I refer to activation and attention, I mean relative amounts, presumably including below-baseline amounts of activation for inhibited stimuli" (p. 65). If this is indeed the case that the amount of activation may be relative, then the addition of an active inhibitory process to moderate activation in the subset of LTM along with decay over time would seem necessary. However, it is unclear whether Cowan's reference to inhibitory processes pertains exclusively to information in the focus of attention, or whether it includes active-but-unattended information. This study tests the possible role of indirect inhibitory processes that affect semantic information in the activated memory (short-term store) that is not in the focus of attention.

It is important at this point to clarify the issue addressed by this study. According to Cowan, interference and active inhibition work to mediate the activation levels of information in the focus of attention. This concept is also found in various working memory models (Carpenter & Just, 1992; Engle, et al., 1995), but it is not the focus of this research. The focus for this study is the semantically activated information in the subset of LTM that has been passively activated through semantic priming by the information in the focus of attention. When this semantically activated information in the subset of LTM has been deemed unnecessary due to the task demands in the focus of attention, does the active inhibition of information in the focus of attention also passively inhibit the semantic information that was previously indirectly activated? This study tests the hypothesis that active inhibition of competing information that is in the focus of attention can indirectly inhibit semantically related information that was previously passively activated.

The question being investigated here is motivated by a particular type of WM model, notably Cowan's Embedded-Processes Model (1999), as opposed to other prominent WM models. Other widely accepted models of WM differ in important aspects from the model used here. There are models positing that WM is defined entirely by activation (Carpenter & Just, 1992), as well as other models that view attention and WM as almost synonymous (Baddeley & Logie, 1999; Conway & Engle, 1994). Cowan's embedded-processes model (1999) along with similar models like

Unsworth and Engle’s (2007) Primary and Secondary memory model differ from these other WM models in the role of an active-but-unattended subset of LTM and in the relative separation between passively active information and attention. It is these features of the model that motivate the question of whether attention demands that are presumed to inhibit information in the focus of attention also inhibit related, previously activated information that is currently outside the focus of attention.

Semantic Activation

With the uncertainty of inhibitory processes possibly acting on activated information in WM, there were a few findings from different research paradigms that lead to an interest in resolving this ambiguity. First, Woltz and Was (2006; 2007) found that when subjects were given examples from two different categories (e.g., *daughter uncle ruby diamond*) as a memory load and then instructed to either explicitly remember one category or forget the other, there was evidence of priming for both categories. The level of priming for new exemplars of the explicitly remembered categories was more robust, but both showed evidence of priming. The priming in this study was measured by an increase in response speed for same/different comparisons (*emerald-sapphire, aunt-car*) for primed categories compared to neutral unprimed categories (*century-month*). This would suggest that even if one category was consciously excluded, the semantic activation of the category remained and facilitated performance on new exemplars. These findings could be taken to suggest that inhibition of previously activated semantic categories is unlikely. However, from an adaptive point of view, if such automatic and lasting activation is indeed the case, there should be a way to moderate this activation through inhibitory processes under different task conditions in which activated information is detrimental rather than merely unnecessary. The manipulation of attention demands in working memory through response competition is, I believe, a key component needed to test the existence of inhibition. As a point of clarification, explicitly being told to ignore certain information is not synonymous with response competition in this context. Response competition is a retrieval-based demand where a response must be generated based upon stimuli that contain conflicting response possibilities.

Retrieval-Induced Forgetting

The second set of findings related to the current question comes from research dealing with retrieval-induced forgetting. Hulbert and colleagues (Hulbert, Shivde, & Anderson, 2012) presented subjects with multiple examples of a certain category (*Red=blood, tomato*, etc.) and then asked them to perform stem completion tasks for a subset of examples (*Red=bl*___) and not others (*tomato*, etc.). When asked to recall all examples of the given category, those examples not in the stem completion tasks were less likely to be recalled. The recall phase of this study consisted of subjects being given a category (*Red*) with instructions to write down the associated exemplars they had studied (*blood, tomato*) in time limited trials (30 s). As a control condition, some subjects were not given any stem completion tasks; they were only shown examples and therefore were not asked to retrieve any examples prior to the recall phase.

The forgetting effect was not seen if subjects were only repeatedly shown the examples without the stem completion task. In other words, poor recall of some examples was due to retrieval rather than exposure to other examples. This effect was also seen to cross categories; the association of *red=blood* would cause a lower frequency of recall for other red items given within a different category, as in *fruit=strawberry*. This last finding suggests that when the competing responses from the category of red were asked to be recalled, the process of manipulating certain information in WM (*Red=bl*___) inhibited the recall of other-category examples that shared the relevant feature. When interpreted in terms of Cowan's (1999) WM model, it appears that continued attentional focus on a subset of category exemplars lowered the activation of previously attended exemplars, and even semantically associated exemplars from other categories, that were currently outside of attention.

There may be another possible interpretation of retrieval-induced forgetting from an activation only perspective. The response of *blood* (which was included in the stem completion task) could have a greater activation and subsequent stronger association than the other responses. However, if we take into account the findings that forgetting of examples crossed categories, an activation only explanation may not be adequate. If examples associated with other categories that are red (*Fruit=strawberry*) are less likely to be recalled as well, this suggests that an active inhibitory process suppressing all things associated with red, and not just certain examples, may be involved.

If we view these data from the context of Cowan's (1999) model, this is evidence for there being a process to decrease the activation of information in the subset of activated but unattended LTM. It is not clear from this study whether when a certain category is inhibited, that information is dropped below a baseline level of activation or merely returned to a neutral state. Nevertheless, this evidence allows for the possibility that an inhibitory process works concurrently with activation processes within active-but-unattended elements in LTM.

Negative Priming and Cognitive Resources

Another relevant body of evidence stems from research by Engle and colleagues (Engle, Conway, Tuholski & Shisler, 1995) suggesting that negative priming could be eliminated with the introduction of a cognitive load. The method of their study was to give subjects two letters on a computer screen, one red and one green. Subjects were told to name the red letter and ignore the green letter. After naming the red letter, a word was given that the subjects were instructed to remember but not say aloud. This process was repeated four times and at the end of the fourth trial, the subjects were to recall each word. Within the four trials, some were control trials where neither the red nor the green letter was seen on the previous trial, and some were target trials where the red (to be named) letter was previously the green (to be ignored) letter. This induces the effect of negative priming; the ignored stimulus from one trial is then shifted to become the target for a subsequent trial. Response times for the target stimulus (red letter) that was ignored in a previous trial was significantly longer than for a stimulus that has not been previously ignored.

Negative priming is generally viewed as an attention driven effect (Engle, Conway, Tuholski & Shisler, 1995). Attention and working memory are closely tied together, with sometimes very little if any separation of processes. Negative priming is in essence the active inhibition of a stimulus which subsequently results in longer response times for inhibited stimuli. The important finding with regard to the current issue was that if enough of a cognitive load was introduced, the effects of negative priming were lost. With the addition of each word to be remembered, the effect of negative priming of the red versus green letter was diminished until no effect was measurable after the addition of the fourth word to the memory load. Interestingly, the subjects who could not recall each word in the recall phase still showed the effects of negative priming over the four trials. Subjects either could recall each word while not showing a negative priming effect or a subject could not recall each word and did show a negative priming effect. These data suggest that cognitive resources are being used to actively inhibit responses.

If the findings from this study are applied to Cowan's model, the same resources that are being used for attentive processing in WM may be used also by inhibitory processes as well. While these data are relevant to active processes in the focus of attention, it can be seen as a demonstration of how response competition can result in inhibition when sufficient attentional resources are available.

Meaning Selection

There has been additional negative priming research done in the field of meaning selection of ambiguous words. Nievas and Mari-Beffa (2002) conducted a study in which negative priming effects were shown with selected against subordinate meanings of ambiguous words. Ambiguous words (glasses) were given separately without any context which were followed by a clue to the meaning of the word (water). When the dominant meaning of a word was cued (drinking glasses), there was a negative priming effect on the subordinate meanings (eye glasses). This effect was measured by a decrease in response times when given a lexical probe task immediately after the clue. Subjects were to make a decision as to whether a word was an actual word or a pseudoword. If the word was something related to the subordinate meaning of a homograph (eye glasses) whose dominate meaning had been previously cued (drinking glasses) the response times for making that decision were slower when compared to neutral words. This is a different task than the previously mentioned negative priming research, but it also provides evidence for an active inhibitory process in response competition situations. As stated earlier, negative priming is seen to be an attention driven effect, but this study suggests that it can affect semantic priming, a passive activation process in LTM.

There is by no means a consensus in the reading comprehension literature as to whether or not active inhibition plays a role in meaning selection (Gorfein, 2001). This is still a subject of debate and research; there exists a large body of literature on discourse processing and reading comprehension, of which the Nievas and Mari-Beffa (2002) study may not be representative. This study was conducted with isolated words rather than words presented in a passage. However, despite the limited generalizability to text comprehension, tasks that present isolated words versus passages are better suited to address the current research question because they allow greater specificity in measuring semantic facilitation and inhibition effects.

FORMULATION OF QUESTION AND HYPOTHESIS

The question formulated from integrating the evidence from each of these research areas is centered on the possibility of inhibitory processes operating concurrently with activation processes within the subset of LTM that is active but outside attentional focus. Considering the data from the semantic activation section, it is possible to have long-term priming lasting more than a few seconds. It is also possible that semantic activation can occur with relatively brief exposure and can persist even when instructed to explicitly ignore certain information.

Evidence from the Retrieval-Induced forgetting literature supports the idea that an active process may be involved in inhibition. The inhibition of responses is not example-specific but can be semantic in nature. There is an increase in the strength of category connections and semantic priming correlated with an increase in manipulation of information in WM. Evidence for this comes from the fact that using the information in stem completion tasks increased the effect whereas only reading the information did not. The connection between information in the focus of attention and the semantically activated subset of LTM may consist of both activation and inhibition.

The negative priming literature provided evidence for the use of cognitive resources by inhibitory processes. With the increase of the memory load, the negative priming effects were greatly diminished. This supports the idea that inhibition can be an active process in situations of response competition.

Based upon these ideas, it seems possible that when individuals are presented with response competition regarding active information in the focus of attention, there may be inhibitory processes working to resolve that both in and out of the focus of attention. That is, the inhibition of information in the focus of attention may indirectly lower the activation of associated information in the subset of LTM that has been passively activated through semantic priming. Although Cowan (1999) has suggested that activation levels in WM can be relative as a function of inhibition, it is unclear whether this applies exclusively to information in the focus of attention. He has clearly stated the assumption that decay over time is the only limit to activated information outside of attention. This assumption would be challenged by evidence for inhibitory effects on information that is only semantically related to the contents of attention.

In Cowan's model, the information in the focus of attention is assumed to indirectly activate semantically related information in the activated subset of LTM. When the information in the focus of attention contains a response competition, what is the effect of the previously indirectly activated information in the subset of LTM? Figure 1 illustrates the relationship between the information in the focus of attention and the indirectly activated information in the subset of LTM. Is the semantic information that has been indirectly activated also subject to indirect inhibition?

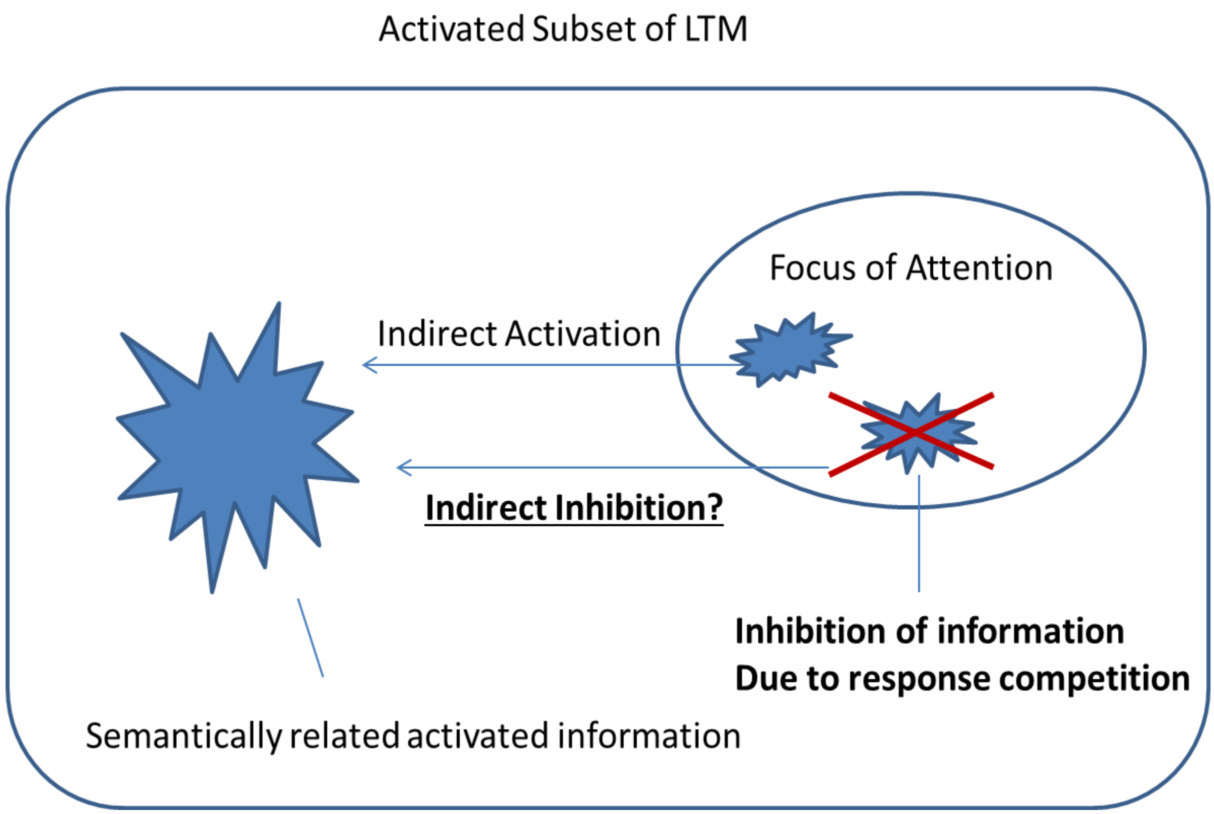

Figure 1. Depiction of hypothesized activation and inhibition in the activated subset of LTM.

EXPERIMENT OVERVIEW

As previously stated, the goal of this experiment is to investigate the possible role of inhibitory processes in determining levels of activation in unattended information in WM. Inhibition of previously activated information is expected to occur when task demands include response competition. Accordingly, the task created for this experiment assesses levels of activation inferred from priming effects under processing demands with and without response competition. Each trial of the experimental task consists of four phases: presentation of a memory load consisting of category exemplars, instructions for selecting a subset of memory load items, recall of the selected items, and finally, category comparison decisions for new exemplars. The category comparisons are intended to measure semantic priming effects for category information presented in the memory load, and response competition is manipulated in the selection and recall phases that precede the category comparisons.

Figure 2 presents an example of the four trial components. The presentation of the memory load always consists of two exemplars from one category (e.g., weather terms) and two from another category (e.g., types of speech). The names of the two categories are also given to ensure there is no confusion as to what categories are represented in the list (the presentation of category names is not shown in Figure 2 and precedes the memory load items). In reference to the WM model by Cowan that is under scrutiny, the

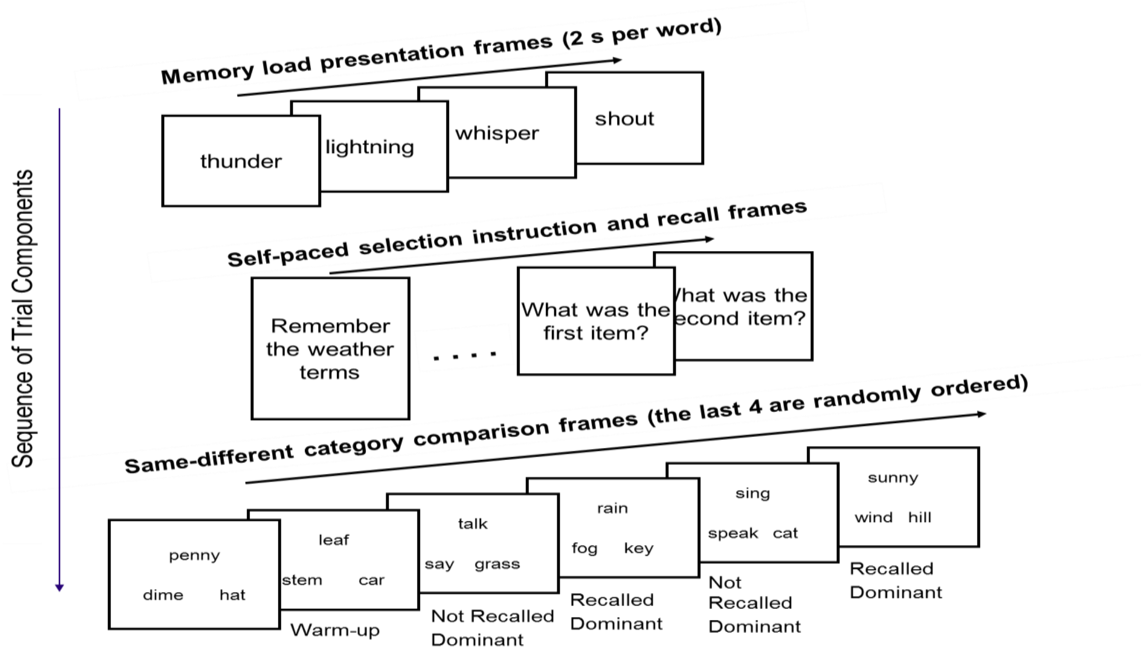

Figure 2. An illustration of the sequence of tasks within each trial.

presentation of the memory load in this fashion presumably activates a range of semantic category information in LTM. That is, the actual exemplars given are the focus of attention, and the associated semantic information would also become activated outside of attention (i.e., related category exemplars and features).

Following the presentation of the memory load, instructions are given as to which category exemplars are to be retained for subsequent recall. For control trials (i.e., no response competition), one of the categories previously given will be identified (e.g., either weather terms or types of speech). On target trials (i.e., response competition), a subordinate category, that was not previously stated, will be identified for subsequent recall. In the current example, the memory load would consist of *thunder, lightning* (weather terms) and *whisper, shout* (types of speech). These exemplars are associated with their respective dominant categories, but one term from each dominant category also belongs to a subordinate category. The subordinate category for this example would be *things that are loud* and the terms from the memory load to be recalled would be *thunder* and *shout*. With the disengagement of thunder and shout from their respective primed dominant categories and the creation of the association to the new subordinate category, we presumably created a response competition for the grouping of items in the memory load. The dominant category associations have become unnecessary, interfering information for the task. According to the hypothesis, this would initiate an active inhibitory process that also would decrease the activation level of the now unnecessary activated semantic categories in the subset of LTM.

If the response competition between recalling the subordinate category exemplars and the primed dominant category exemplars has decreased the activation levels for the dominant semantic categories, this should be revealed in the next phase of the trial, the category comparisons. This trial component involves giving an exemplar from a category, referred to as the stimulus word, (e.g. *penny*) and two other exemplars, one from the same category and one from an unrelated category (e.g., *dime hat*). The subject is to determine which of the two exemplars is from the same category as the stimulus word. On control trials, the stimulus words will come from the dominant categories given in the memory load, but not a repeat of any exemplars previously given. For the target trials in which the subject was asked to recall a subordinate category in the memory load recall phase, the category comparisons would still use exemplars from the dominant categories from the memory load.

Continuing with the previous example of a target trial; if the dominant category exemplars of *thunder lightning whisper shout* are given in the memory load with the category labels of *weather items* and *types of speech,* the subject could then be asked to recall the subordinate category of things that are loud (*thunder shout*). The stimulus words in the category comparisons would then come from the dominant categories of *weather items* and *types of speech*. One such trial would give *rain* as a stimulus word with a choice to be made between *fog-key*. The response time for making the comparison of weather terms (which was a dominant category) should be longer on a target trial in which the subordinate category was recalled when compared to a response time for a category comparison involving a dominant category when subordinate category recall was not required. In this experiment, the measure of importance was the difference between response times for dominant categories that had not been recalled in the memory load and dominant categories that were disassociated with the recall of a subordinate category. An increase in these latter response times would be evidence for an inhibitory process working to decrease semantic activation of interfering information due to response competition.

METHOD

Participants

The sample consisted of 124 undergraduate students from the University of Utah Educational Psychology subject pool. All participants received course credit for participation. A total of 4 participants were eliminated due to high error rates (greater than 20%) or a failure to complete the entire study. The remaining data from 120 participants were used in the analysis. The median age of participants was 21 (range 18 to 69) with 59% female.

Apparatus

The experiment was run on desktop computers with VGA CRT displays. The program was created using E-prime software (Schneider, Eschman, & Zuccolotto, 2002).

Experimental task

The experimental task consisted of four phases: memory load presentation, selection instruction, memory load recall, and category comparison frames. Each of 21 trials contained the four components in the described order. The stimuli used in the 21 trials are contained in the Appendix. A portion of the categories and exemplars were obtained from category norms by Battig and Montague (1969), but some additional categories and exemplars were generated. I chose relatively frequent exemplars for each category, because I wanted there to be little or no ambiguity regarding dominant category membership. However, each exemplar in the memory load needed to belong to a dominant category and a subordinate category. The subordinate category membership needed to be logical and not too obscure, yet not so closely related that participants might generate the subordinate category association without instruction.

As is shown in the Appendix, categories were organized in 21 sets, with each set containing three categories; two dominate categories and a common subordinate category. The category triplets were chosen so that there was minimal conceptual overlap within sets. For each participant, one category from each set was assigned to be the focused dominant category in the memory load, one was assigned to be the ignored dominant category in the memory load, and on response competition trials, one exemplar from each category was set as the member of a subordinate category. Six versions of the experiment were created that represented a complete counterbalancing of triplet category assignment to recall condition (recalled dominant, nonrecalled dominant and subordinate).

Each trial began with the statement *Get ready to memorize words* displayed for 4 s, followed by a blank screen for 1 s. This was followed by a dominant category name (e.g., *Weather items*) and then two exemplars presented on the display one at a time (e.g., *thunder, lightning*). This sequence was repeated twice on each trial (e.g., *Types of speech: whisper, shout* and *Weather items: thunder, lightning*). Each word set was preceded by an asterisk displayed for 750 ms in the location of the words (center of screen) and then a blank screen for 1 s. Each word was displayed for 1,500 ms, followed by a blank screen for 500 ms. The order of the memory load words was constrained so that the exemplars from a category would be contiguous (i.e., categories were not alternated). Which category came first was randomized.

There was a 2 s delay after the final memory load item. This was followed by an instruction frame that directed the participant to remember only two of the four terms in the memory load. The instruction always named the category to be recalled, rather than the category exemplars (e.g., *what were the weather items?* Answer: *thunder, lighting*). In two thirds of the trials, a dominant category was asked to be recalled, and in one third of the trials (the target trials), the subordinate category was asked to be recalled (e.g., *what were the loud items?* Answer: *thunder, shout*). The subordinate category was not named during the presentation of the memory load. The participants could take as long as needed to identify and rehearse the two target exemplars in the memory load. They were instructed to press the space bar when ready to proceed.

Following the selection instruction and a 1 s delay after the participant pressed the space bar, the participants were prompted to recall the two words held in memory. There were two recall frames that asked, *what was the <first, second>word that was a <category name>?* The participants were instructed to type the first two letters of each word they were recalling.

Following the second recall frame, there was a 1 s delay, followed by the instruction, *Get ready to COMPARE words . . . Rest your fingers on the <right arrow>and <left arrow> keys*. This instruction was presented for 3 s, followed by a 2 s blank screen to allow the participants to prepare for the comparison frames. Each comparison frame began with three asterisks presented for 500 ms, in a triangle formation corresponding to the location at which the three stimulus words would appear. The asterisks were followed by a blank screen for 750 ms and then the three stimulus words. The subjects were to determine which of two exemplars on the base of the triangle belonged to the same category as the exemplar in the top position of the triangle. The stimuli remained on the screen until the participant responded by pressing either the Left Arrow or Right Arrow key. A 1 s interval separated the response and the asterisks preceding the subsequent comparison.

There was a total of six category comparison frames in each trial. The first two frames were warm-ups that contained words unrelated to the contents of the memory load or any category used in any of the word sets. The remaining four frames were in random order for each participant. For both target and control trials, they consisted of two frames for each of the two dominant categories in the memory load. There were no comparison frames using the subordinate categories.

Following the category comparison frames, feedback was provided for the entire trial. The participants were informed of their accuracy for the recall frames and their average accuracy and response time for the category comparison frames. Prior to the next trial, the participants were reminded that they should try to obtain perfect accuracy on the recall frames and try to respond as quickly as possible without making errors on the category comparison frames. The feedback and goal reminder frames were self-paced.

Procedure

The participants performed the experimental task in a single 1-h session. They performed the experiment in groups of 1–4, with each participant seated in a computer carrel separated by sound deadening panels. Equal numbers of participants performed the six counterbalanced versions of the experiment (*n*=20 per version).

RESULTS

Scoring and Data Editing

The data from the memory load recall on subordinate recall trials were manually scored for accuracy. Subordinate recall was scored as correct if both category exemplars were recalled, regardless of order. If the subject incorrectly recalled one of the two words or left one response blank, then recall for that trial was recorded as incorrect. If recorded as incorrect, the RT data from the corresponding comparison frames were not used. The purpose behind this scoring was to ensure that only the subordinate trials in which the expected cognitive processes were taking place would be used in the data analysis. If there was evidence that the subject failed to successfully disassociate the dominant categories and form new subordinate associations, then the subsequent RT data would not test the inhibition hypothesis.

It is important to clarify that if one of the words was recalled correctly and the other response was blank, that particular trial was counted as incorrect. The problem posed with this type of response is that there was no way to ensure that the first category was disassociated and the new category was activated since one of the two words from each dominant category would be used in the subordinate category. If the subject correctly recalled one of the dominant words and left the next blank, it could not be confidently assumed that the appropriate cognitive processes were achieved and that trial was counted as incorrect and omitted from analysis.

The accuracy for the memory load recall of the target subordinate trials was .94, 95% CI [.92, .95] which was very close to the dominant recall trials .95, 95% CI [.94, .96]. This is evidence that the subordinate recall demands could be completed with an adequate level of accuracy. As was expected, the average recall RT for subordinate category exemplars (M=10.30 s, SD=3.25) was significantly longer than the recall RT of dominant category exemplars (M=6.44, SD=1.62), $F(1,114) = 248.96$, $p < .001$, $\eta_p^2 = .69$. Recall RT was defined as the time between the cuing of recall and the start input. Typing time (input time) was not included in the analysis. This RT difference is consistent with the assumption that correct subordinate category exemplar recall required additional cognitive effort.

Response Time and Accuracy Data

The main comparison of interest was the difference between RT of all comparison frames for the trials with the subordinate recall and RT from comparison frames representing the unfocused category of dominant recall trials. The data from comparison frames representing the focused category from dominant recall frames are included for reference, but these data were not used in testing the hypothesis of indirect inhibition.

The hypothesis of an indirect inhibitory process moderating the activated information in the subset of LTM would manifest as an increase in RT of the comparison frames for both dominant categories following subordinate recall compared with those representing the unfocused dominant category following dominant category recall. This was one of three possible data outcomes. The second would be for the RT frames following subordinate recall to be faster than those representing the unfocused dominant category following dominant recall. This outcome would not be interpreted as evidence of inhibition. Instead, if activation level is a direct function of the amount of attention devoted to semantic content, then additional attention required to dissociate exemplars from their dominant categories would increase rather than decrease the activation level of those categories. The final possible data outcome would show no significant difference in RT between comparison frames following subordinate recall compared with those representing the unfocused dominant category following dominant category recall. A finding of no difference would be consistent with Cowan's (1999) original assertion that decline in activation level is a function solely of time.

Table 1 presents mean RT and error data for the category comparison trials. As seen in this table, there was not an observed increase in comparison trial RT following subordinate recall, but rather a small decrease in mean RT when compared to the unfocused dominant category comparisons following dominant category recall. This trend approached but did not reach statistical significance even with the large sample, $F(1,114)=3.73$, $p = .056$. Also evident in Table 1, the error rates for each type of trail were similar. However, there was a small but significant reduction in errors in subordinate comparison frames compared to those in unfocused dominant frames, $F(1,114)=6.03$, $p = .016$, $\eta_p^2=.05$. Thus, both RT and error data reflected a slight tendency for participants to perform better rather than worse on category comparisons following subordinate category recall. However, these effects were marginal in magnitude.

The mean RT for dominant focused comparison frames was significantly smaller than that for the dominant unfocused frames, $F(1,114) = 11.87$, $p < .001$, $\eta_p^2=.09$. There was no significant difference in error rates for these latter two trial types, $F(1,114) = 2.88$, $p=.092$. As noted, these data do not test the inhibition hypothesis, but they do support an

Table 1

Means and Standard Deviations for Response Time and Errors of Comparison Frames

Note: Standard deviations are presented in parentheses.

Comparison Trial Type	Response Time (ms)	Errors (percentage)
Dominant Focused	1721 (562)	7.5 (6.3)
Dominant Unfocused	1799 (564)	8.6 (6.7)
Subordinate	1749 (524)	7.1 (7.1)

expected priming pattern for dominant categories: Greater attention on a specific category in the memory load produced greater facilitation in subsequent processing of new category exemplars.

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DISCUSSION

The focus for this study was to investigate the possibility of indirect inhibition working concurrently with indirect activation in the subset of LTM that is outside attentional focus. There were three distinct possible data patterns that could have been observed. Each possible outcome has its own theoretical implications, but only the hypothesized outcome would be evidence for indirect inhibition. The proposed hypothesis was that evidence of indirect inhibition would be found with the relative increase in RT for target trials when compared with control trials. These target trials included a response competition demanding the disassociation of memory load exemplars from a dominant category and the association with a subordinate category. The goal was to indirectly activate the related semantic information of the dominant category followed by indirectly inhibiting that same information through the act of dissociation and formation of a new category membership. Through this design, it was hypothesized these target subordinate recall trials would cause RT on subsequent dominant category comparison frames to increase due to the indirect inhibition of information. This was the first possible data outcome.

The second possible outcome would be for the category comparison frame RT of the subordinate recall trials to be faster than those comparison frames associated with the dominant recall trials. Evidence which points to this being a viable outcome is the data from the Woltz and Was (2006; 2007) studies mentioned previously. Their finding that response time savings occurred for categories that participants were explicitly instructed to ignore suggests that it could be possible to actually see a decrease in RT for disengaged categories. The relative facilitation of these categories may be increased due to increased focus of attention to the memory load contents that is required to complete the subordinate recall operation. This increase in focus and processing time can manifest as an escalation of semantic activation with consequent decreases in RT. This outcome, although not hypothesized, would be the strongest evidence against inhibitory processes in Cowan's active LTM component of WM.

The final possible outcome would be for there to be no difference, either faster or slower, in subordinate recall trial comparison frame RT compared with the associated dominant recall trial frames. A data pattern like this would be consistent with the view that activation of the dominant categories occurs during initial encoding, and subsequent dissociation neither increases nor diminishes activation levels. A decrease in activation presumably would occur exclusively as a function of time as posited by Cowan (1999).

Analysis of the data concluded that the hypothesized increase in RT was not achieved. In fact, there was decrease in RT which approached statistical significance, but the magnitude of the effect was very small. This effect could be viewed as support for the interpretation that increased processing in the focus of attention, even if it is processing to disengage from content, indirectly increases activation of related semantic content. However, I believe the current evidence is weak support for that view. When considering the large average increase in time spent in memory load processing during the subordinate recall trials, the observed but nonsignificant RT reduction of 50 ms from trials that took an average of almost 1800 ms represents a relatively small magnitude of facilitation at best. Alternatively, I view the marginal priming trend as more consistent with a decay-only model of WM.

The presence of priming even for semantic content that has been selected against under response competition fits well with Cowan's model of working memory. As mentioned previously, Cowan's model posits decay over time to be the only restraint on activated information in the subset of LTM that is active but outside of attentional focus. According to Cowan's model, there is no limit to the amount of information that can be activated at one time and there is no explicit reference to inhibitory processes in the focus of attention indirectly inhibiting information in the subset of LTM.

Another model of memory that would predict this outcome is a model of Primary Memory and Secondary Memory. Unsworth and Engle (2007) describe a memory model which is similar to that of Cowan's embedded processes model. The primary memory is the mental workspace, or what is currently the focus of attention. Secondary memory is akin to what Cowan calls activated long-term memory. This two-compartment model of memory describes and explains many factors of working memory, but it also does not mention an inhibitory process in secondary memory. The finding of semantically primed categories remaining in an activated state in the subset of LTM despite response competition corresponds to models that describe inhibitory processes only within the focus of attention or primary memory.

Cowan does leave open the possibility of an inhibitory process creating relative amounts of activation within the subset of LTM, but these data do not appear to support that idea. This inhibition would need to be an indirect process, much like the indirect activation mechanism, due to the unattended nature of the information. The indirect inhibition in the subset of LTM would have caused a relative decrease in the strength of activation of the related semantic information for the disassociated categories. There was no relative decrease in strength of activation measured through RT for these disassociated categories. From this finding, it appears that there is no indirect inhibitory mechanism working in the active but unattended subset of LTM, rather only indirect semantic activation and decay over time.

This research aimed to investigate the difference of response times between response competition trials versus nonresponse competition trials. A limitation of the current design is that there was no baseline RT measure to reflect unprimed performance and no manipulation of time interval between memory load recall and category comparisons. Due to a limited number of stimulus sets appropriate for the current task manipulations, a decision was made to test the current hypothesis with an expectation that follow up experiments would be necessary for a complete understanding of the phenomena. As detailed earlier, if the data had shown that the RT for category comparisons in response competition trials were longer, this would have been consistent with indirect inhibition of information in the subset of LTM. Further research would have been needed to distinguish if this outcome was due to indirect inhibition or to a limited capacity of information in the subset of LTM. The limited capacity explanation would predict that RT would be equivalent to a baseline (unprimed) level. The inhibition explanation would predict that RT would be greater than a baseline level. Given the findings of neither a sizeable increase nor decrease in RT, this now becomes an unnecessary extension of the current research.

Based upon the previous research using this paradigm, there was ample evidence for the assumption that the dominant categories were indeed semantically primed. Across six experiments of this format without subordinate category recall trials, there was an increase in correct response rate in category comparisons of approximately 10% for primed versus unprimed categories (Woltz & Was, 2006, 2007). Given the consistent effect sizes in those experiments and the large sample size of the current experiment, it seems unlikely that priming effects did not exist for the dominant categories. Furthermore, there is current evidence consistent with this assumption. The significant decrease in RT for focused dominant comparisons compared to unfocused dominant comparisons was also found by Woltz and Was (2006, 2007) and was interpreted to reflect the relationship between attentional focus in the memory load phase and subsequent facilitation on new category exemplars. Nevertheless given the current findings, the existence of priming effects under all trial conditions should be established in a future experiment.

Another viable avenue for future research would involve inclusion of subordinate categories in memory load recall for control trials, with target trials unexpectedly demanding recall of dominant categories - essentially reversing the paradigm used here. Inhibition might have been difficult to demonstrate in the current study using dominant categories whose activation is already strong due to preexisting memory strength. The previously discussed Nievas and Mari-Beffa (2002) study supports this being a useful vein to pursue. Their data showed inhibition of subordinate homograph meaning when primed with dominant homograph meanings. A future study could potentially investigate the same issue with the types of items used here. The subject would be shown subordinate categories during the memory load, then on some trials be asked for dominant category recall. It could very well be that subordinate categories can be inhibited in favor of dominant categories but dominant categories are not inhibited in favor of subordinate categories.

Future research also could investigate the existence of direct versus indirect inhibition of category exemplars. For example, the current paradigm could be modified to include a dominant category exemplar from the memory load in one of the comparison frames. In the current experiment, comparison frames consisted of two novel exemplars from the dominant categories. The addition of an exemplar from the memory load provides a test of whether category exemplars could be directly inhibited. This task manipulation would still require a new category evaluation if the frame included one old and one new exemplar, and the inhibition hypothesis would be the same: RT for comparison frames after subordinate recall should be larger. A design like this would have the benefit of comparing and testing the existence of indirect inhibition affecting new category exemplars, but also direct inhibition on exemplars that were rejected previously as category exemplars to be recalled. If no inhibition is detected, it would provide even stronger support for Cowan's idea that only decay over time diminishes activation.

CONCLUSION

The purpose of this study was to explore the possibility that indirect inhibition acts along with decay over time in moderating activation of information in the active subset of LTM. There is ample evidence through the research in semantic priming that information is easily activated and under some task demands can remain in an active state for relatively long periods of time. Evidence from the negative priming and Retrieval-Induced forgetting literature gave support for the possibility of indirect inhibition of information outside the focus of attention.

There were minimal performance differences across different trial types that would lend evidence to indirect inhibition in this study. Although additional evidence is needed, these data are most consistent with decay over time as the primary factor affecting information in the subset of LTM. The main limitation to this study was a lack of an unprimed neutral baseline condition. There are avenues posited here for future experiments which need to be conducted before more confident conclusions can be drawn as to the existence of indirect inhibition.

APPENDIX A

CHART OF MEMORY LOAD STIMULI

Dominant Category			Dominant Category			Subordinate Category		
GAMES	checkers	chess	NATIONS	Mexico	England	ITEMS WITH A QUEEN	chess	England
RECREATION OBJECTS	pool table	bowling alley	CLOTHING	pants	shoes	ITEMS WITH A POCKET	pool table	pants
FLOWERS	rose	tulip	FURNITURE	sofa	lamp	ITEMS WITH A BULB	tulip	lamp
PRECIOUS GEMS	diamond	ruby	PANCAKE INGREDIENTS	syrup	batter	ELEMENTS OF BASEBALL	diamond	batter
TREES	elm	pine	CRAFTS	scrap booking	knitting	ITEMS WITH NEEDLES	pine	knitting
MUSICAL INSTRUMENTS	banjo	trumpet	TOYS	doll	yo-yo	ITEMS WITH A STRING	banjo	yo-yo
BODIES OF WATER	river	lake	FORMS OF ENERGY	electricity	gasoline	ITEMS WITH A CURRENT	river	electricity
WRITING TOOLS	pen	pencil	SEA CREATURES	crab	squid	ITEMS WITH INK	pen	squid
AIRPLANE PARTS	propeller	wings	OUTDOOR VEGETATION	grass	bush	ITEMS WITH BLADES	propeller	grass
DOMICILES	hut	cottage	COLORS	purple	blue	CHEESES	cottage	blue
VEGTABLES	corn	peas	PARTY DECORATIONS	streamers	balloon	THINGS THAT POP	corn	balloon
WEATHER PHENOMENA	blizzard	hurricane	SEWING SUPPLIES	thread	needle	ITEMS WITH EYES	hurricane	needle
SENSORY ORGANS	eyes	ears	ITALIAN CITIES	Rome	Venice	THINGS WITH CANALS	ears	Venice
PASTRIES	maple bars	donuts	GRASSY PLAYING AREAS	soccer field	golf course	ITEMS WITH HOLES	donuts	golf course
BODY PARTS	foot	leg	OUTDOOR HOME AREAS	patio	yard	UNITS OF MEASUREMENT	foot	yard
FOOTWEAR	shoe	sock	DRINKS	soda	punch	AGGRESSIVE ACTS	sock	punch
BIG CATS	tiger	lion	CHRISTMAS THINGS	presents	candy cane	THINGS WITH STRIPES	tiger	candy cane
BED THINGS	blanket	pillow	FARM ANIMALS	chicken	pig	ITEMS WITH FEATHERS	chicken	pillow
THINGS YOU RIDE	bicycle	skateboard	BREAKFAST ITEMS	coffee mug	cereal bowl	THINGS WITH HANDLES	bicycle	coffee mug
TYPES OF COMMUNCATION	tweet	email	PARTS OF A TREE	wood	bark	ANIMAL NOISES	tweet	bark
GRAINS	sorghum	rice	SPORTS	lacrosse	baseball	THINGS YOU THROW	rice	baseball

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