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Testing an associative account of semantic satiation

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Abstract

How is the meaning of a word retrieved without interference from recently viewed words? The ROUSE theory of priming assumes a discounting process to reduce source confusion between subsequently presented words. As applied to semantic satiation, this theory predicted a loss of association between the lexical item and meaning. Four experiments tested this explanation in a speeded category-matching task. All experiments used lists of 20 trials that presented a cue word for 1 second followed by a target word. Randomly mixed across the list, 10 trials used cues drawn from the same category whereas the other 10 trials used cues from 10 other categories. In Experiments 1a and 1b, the cues were repeated category labels (FRUIT-APPLE) and responses gradually slowed for the repeated category. In Experiment 2, the cues were nonrepeated exemplars (PEAR-APPLE) and responses remained faster for the repeated category. In Experiment 3, the cues were repeated exemplars in a word matching task (APPLE-APPLE) and responses again remained faster for the repeated category.

Keywords

Semantic satiation; Reading; discounting; Habituation; Repetition priming; Semantic priming; Lexical representation; Semantic processing; Categories; Semantic retrieval

1. Introduction

Not only do proficient readers quickly and automatically access the meaning of visually presented words (Stroop, 1935), but retrieved meaning lasts for a period of time, particularly when it is relevant to the current context (Swinney, 1979). However, reading is inherently a serial process and eye fixations only allow identification for one or a few words at a time (Just & Carpenter, 1987). The combination of serial reading and meaning persistence poses a conundrum: In light of meaning persistence from previously viewed words, how is the meaning of the currently viewed word accurately retrieved, particularly if the current word mismatches the previous context? Recent experimental and theoretical results with short-term priming may provide a solution to this conundrum. The Responding Optimally with Unknown Sources of Evidence (ROUSE) theory proposes that previously viewed words provide a competing explanation of currently active meaning and this serves to discount the meaning from

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previously viewed words, thus reducing source confusion (Huber, Shiffrin, Lyle, & Ruys, 2001). In the experiments reported below, we test a core aspect of this theory as it relates to the association[1] between lexical representation and meaning.

Short-term repetition priming experiments with threshold identification of target words (i.e., briefly flashed and then masked target words) revealed that prime words presented for short durations produce positive priming whereas prime words presented for longer duration produce negative priming (Huber, 2008; Huber, Shiffrin, Lyle, & Ruys, 2001). The ROUSE theory explained these results by assuming that positive priming arises from temporal source confusion (i.e., evidence from the prime lingers and might be inappropriately applied to the target) whereas negative priming arises from discounting of prime evidence that offsets source confusion. This theory was originally implemented in a Bayesian model applied to features of words and the change from positive to negative priming was handled by too little versus too much discounting (Huber, Shiffrin, Lyle, & Ruys, 2001; Huber, Shiffrin, Lyle, & Quach, 2002; Huber, Shiffrin, Quach, & Lyle, 2002; Weidemann, Huber, & Shiffrin, 2005; Weidemann, Huber, & Shiffrin, 2008).

Three different models have been applied to these short-term priming threshold identification data. However, all three models include source confusion and discounting, and so these models have much in common. Therefore, we only briefly describe their differences. As an alternative to the Bayesian ROUSE model, Ratcliff and McKoon (2001) proposed a simple multinomial model in which source confusion and discounting were implemented in an all or none fashion (see Huber, Shiffrin, Quach, & Lyle, 2002, for a comparison between these two multinomial model). Although the Bayesian and multinomial models follow in the tradition of decision models, the neural correlates of these priming effects were identified in perceptual processing to the briefly flashed target word, prior to the response decision (Huber, Tian, Curran, O'Reilly, & Woroch, 2008). For this reason and others, the ROUSE theory was also implemented in a dynamic neural network that produces the transition from positive to negative priming automatically by "viewing" words for longer durations (Huber & O'Reilly, 2003; Huber, Tian, Curran, O'Reilly, & Woroch, 2008). In this neural implementation, discounting of primes occurs through synaptic depression (Tsodyks & Markram, 1997), which is the temporary loss of connectivity (loss of association) between sending and receiving neurons due to recent activity. In other words, there is habituation for a repeatedly used association.

So how do these short-term priming results and theories relate to the conundrum in which the reading system needs to integrate meaning while reducing confusion between subsequently read words? The answer proposed by ROUSE lies in the claim that discounting occurs through the loss of association between the perceptual evidence for a word and higher level representations. For example, consider the case of encountering perceptually similar words while reading (e.g., 'lied' followed by 'died', such as in "Because the pharmaceutical company lied about the side effects, many patients died"). Loss of association allows the reader to process 'died' as a unique occurrence while still building up meaning across the sentence. This is because the shared perceptual elements ('-ied') are discounted by reducing their link to the meaning of the first word (e.g., to withhold the truth) while preserving their ability to link to the second word (e.g., end of life). This discounting offsets the effect of source confusion such that the second occurrence of '-ied' can be accurately assigned to a new word in the sentence while still retaining the meaning of the first word. If there was no discounting, the reading of '-ied' in 'died' might be mistakenly attributed to the previously viewed word 'lied' and thus

[1]Throughout this paper we use the term association not as it is used with associative production norms in which a cue word is given and an associate is spoken (e.g., Nelson, McEvoy, & Schreiber, 1998), but instead we use association in referring to hypothesized connection strengths between different representations. For instance, consider the types of association identified with the Latent Semantic Analysis model of Landauer and Dumais (1997), which places words in a high dimensional semantic space based on statistical co-occurrence.

not appreciated as a new word. If there was direct discounting of perception, then it would be difficult to process the letters of 'died'. If there was direct discounting of meaning, then the meaning of the first word would be lost before the end of the sentence. However, with discounting of association, the second word is appreciated as a unique occurrence (i.e., reduced source confusion) and yet the meaning of the first word is retained (i.e., semantic integration).

The Bayesian ROUSE model produces a loss of association through the mathematics of discounted causes in light of prior evidence. In other words, it is the relationship between the perceptual evidence and potential causes that is affected. In simulations, this is achieved by assigning a lower level of evidence to a primed perceptual feature (e.g., knowing that the letter T was recently seen, but realizing that the prime contained a T) when calculating how much evidence exists in favor of a particular choice word (e.g., was the word TABLE or FABLE just briefly flashed). In repetition priming experiments, many predictions of the ROUSE model were confirmed, but the use of repetition priming cannot address the assumption that discounting is associative: With repetition priming, there is no behavioral difference between discounting of the representation itself (i.e., direct discounting of the lexical representation or direct discounting of meaning) versus discounting of the association between levels of representation (i.e., discounting of the connection between the lexical representation and its associated meaning). This distinction is highlighted in Figure 1 and the current experiments seek to determine whether excessive exposure to a word causes loss of its lexical representation, loss of its meaning, or loss of the association between the word and its meaning.

To test the claim that discounting occurs through loss of association, we examined the phenomenon of 'semantic satiation' (Jakobovits & Lambert, 1962; Smith & Klein, 1990) in which a repeated words appears to lose its meaning. Indeed, an explanation based on association loss was first proposed by Edward Titchener, nearly a century ago. In regard to semantic satiation, he wrote (1916, pp. 26, 118 – 119):

> Repeat aloud some word – the first word that occurs to you; house for instance – over and over again; presently the sound of the word becomes meaningless and blank; you are puzzled and a morsel frightened as you hear it…When the word 'house' becomes meaningless with repetition (p.26), it is because the bare sound grows more and more vivid and dominant; like the nestling cuckoo, it drives out its normal associates; and these associates, the carriers of its meaning, sink lower and lower into the obscurity of the background. So the meaning almost literally, drops off, falls away.

Semantic satiation affords a unique opportunity to test for discounting through loss of association because we can separate lexical level from semantic level effects in a meaning-based task that involves repetitions of words. The claim that loss of association underlies this phenomenon predicts that semantic satiation is not due to repeated access of a lexical representation, nor is it due to repeated access of the same meaning, but rather that it arises when the same lexical representation is used to repeatedly retrieve the associated meaning. We refer to this theoretical possibility as *associative satiation*. Next, we review the literature on semantic satiation, and compare this associative satiation theory with other theoretical perspectives.

Providing one of the earliest measures of semantic satiation, Severance and Washburn (1907) found that participants reported lapses of meaning after a prolonged visual fixation of written words. Rather than merely fixating on words, Bassett et al. (1919) instructed participants to repeat the same word aloud until it lost its meaning. These early studies relied upon self-report and introspection as dependent measures and so they may be subject to report bias. Later experiments used more objective measures to quantify semantic satiation through ratings of lexical validity (Lambert & Jakobovits, 1960), exemplar commonality (Smith & Raygor, 1956), or the number of produced associates (Kanungo & Lambert, 1963).

None of these early studies measured speeded reaction times, and so they still might include report bias or other control processes. Therefore, Smith and Klein (1990) used a speeded category membership task in which participants judged whether two words were from the same category, with this judgment occurring after a category label was repeated for 3 or 30 times. Although they still found positive priming following both 3 and 30 repetitions, the effect size following 30 times was greatly diminished. However, there is concern in directly comparing performance following 3 versus 30 repetitions because these two conditions are not equivalent in terms of general fatigue and other factors. Therefore, Black (2001) used a more complicated design that repeated a word, which was then followed by word pairs that were either related or unrelated to the repeated word. Thus, unrelated trials served as a baseline control. Critically, the first word of the final word pair was always a homograph (e.g., “ORGAN”), with one of the two meanings related to the repeated word in the related condition. The task was to quickly indicate whether the homograph matched the other word of the word pair (e.g., “ORGAN-HEART”). They found that reaction time increased as a function of the number of repetitions for a related repeated word (e.g., “KIDNEY”) as compared to an unrelated repeated word (e.g., “CEILING”).

This brief review reveals that the measurement of semantic satiation is complicated, and that there are a variety of potentially confounding factors (for a review, see Esposito & Pelton, 1971). One concern is use of two separate tasks (one to induce satiation and one to measure satiation), which may produce report bias and task switching effects. In previous studies, participants were usually asked to repeat one word several times. However, this method does not equate attention across different numbers of repetitions (e.g., Smith & Klein, 1990). For instance, participants may be more alert in general after 3 repetitions than they are after 30 repetitions. This method also involves task switching and other factors that may contribute to the measure of semantic satiation (e.g., Black, 2001). Finally, the use of two tasks makes it difficult to map out the time course of semantic satiation and most two task experiments compared just two levels of semantic satiation (e.g., Balota & Black, 1997; Black, 2001). Instead, we seek to use a single task that both induces and measures semantic satiation, thereby allowing us to measure satiation online as it accrues.

In the literature, excepting Tichener’s claims, two theories have been proposed to account for semantic satiation. Jakobovits and Lambert (1962) proposed that a repeated word reduces the ability of the semantic representation to respond to subsequent presentations. Smith and Klein (1990) also concluded that semantic satiation is induced by fatigue or adaptation in the neural processing that underlies meaning. We refer to this mental fatigue of semantics as the theory of *meaning satiation* (Figure 1b). Esposito and Pelton (1971) proposed an alternative theory that implicates a change in the lexical[2] representation as the explanation behind semantic satiation. This theory states that the lexical representation becomes ineffective after extensive repetitions, resulting in the inability to access meaning because the lexical representation is no longer available as a cue for the associated meaning. This change in the processing of the orthographic or phonological representation is referred as the theory of *lexical satiation* (Figure 1a). In contrast to satiation at the lexical level or satiation at the level of meaning, our theory of *associative satiation* (Figure 1c) states that repeated use of the association between the lexical representation and meaning results in less efficient information transfer between the lexical entry and its associated meaning even though both the lexical and semantic representations remain intact.

[2]We use the term ‘lexical’ in its most generic sense and we make no claims whether changes in lexical processing are due to a change in the visual word form (orthography), a change in the corresponding sub vocal auditory representation (phonetics), or changes in both. Instead, we use lexical generically to refer to the object properties that indicate a particular word in the absence of meaning. The reported experiments use visually presented words, but these results cannot determine whether it is the association between orthography and meaning or the association between phonetics and meaning that underlies the observed semantic satiation.

Previous experimental designs cannot differentiate between these theoretical accounts of semantic satiation. Because previous semantic satiation experiments used repetitions of the same word, they involved repetitions of both the lexical representation and the associated meaning. Therefore, to difference between the theory of *associative satiation*, the theory of *meaning satiation* and the theory of *lexical satiation,* we used a speeded category matching task so that we could test situations where the categorical meaning repeated even though particular lexical entries did not.

2. Overview of experiments

All of the reported experiments used a speeded word matching task that included separate blocks of 20 trials in which a chosen category repeated 10 times. Each trial presented a cue word for 1 second followed by a target word (the cue remained onscreen) until a speeded matching response was given. Presenting the cue word for 1 second prior to the onset of the target is sufficiently long that participants might modify their response strategy depending on whether the cue word is from the repeated category. However, shorter cue durations would be problematic in that any repetition effects would be confounded with changes in the degree of perceptual 'repetition blindness' (e.g., Kanwisher, 1987). Previous results with short-term repetition priming in a perceptual identification task found that it take approximately 1,000 ms of prime viewing for immediate repetition blindness to reach an asymptotic level (Huber, 2008; Huber, Shiffrin, Lyle, & Ruys, 2001; Huber, Shiffrin, Lyle, & Quach, 2002; Huber, Shiffrin, Quach, & Lyle, 2002; Weidemann, Huber, & Shiffrin, 2005; Weidemann, Huber, & Shiffrin, 2008). Therefore, by using a 1 second cue duration, short-term perceptual repetition blindness is equated across different numbers of prior repetitions. Thus, any differences with the number of prior repetitions is assumed to be due to more slowly acting non-perceptual processes, such as occurs with semantic satiation. In the general discussion we consider the issue of strategies in greater detail.

The experimental procedures of all three experiments are shown in Figure 2 (see method section for details). In Experiment 1, the same category label (e.g., 'FRUIT') repeated 10 times as the cue, randomly intermixed across the 20 trials, and the task was category matching (e.g., 'FRUIT – APPLE'), thus requiring meaning access for the same repeated word. In Experiment 2, no word repeated, although the same category repeated 10 times by presenting different exemplars as the cue (e.g., 'PEAR') and the task was again category matching (e.g., 'PEAR – APPLE'), thus requiring repeated access of the same categorical meaning. In Experiment 3, the same word repeated 10 times, but the matching task was identity (cue and target consisting of the same word, e.g., 'APPLE – APPLE') rather than categorical, thus no longer requiring responses based on meaning access. All experiments used a mixed list speeded matching paradigm in which the satiation trials (10 repeated condition) and baseline trials (10 nonrepeated condition) were balanced and presented in a random sequence within a block. These 10 trials were further broken down into 5 matching and 5 mismatching trials.

These three experiments were designed to collectively differentiate among the three aforementioned theories of semantic satiation, with each experiment potentially falsifying some of the theories but not others. The theory of *meaning satiation* states that whenever the same meaning is accessed, that meaning will fatigue. Therefore, for both Experiment 1 (meaning and lexical repetitions) and Experiment 2 (meaning repetitions), the theory of *meaning satiation* predicted semantic satiation, but not for Experiment 3 (lexical repetitions only). The theory of *lexical satiation* states that whenever the same lexical representation is accessed, that representation is fatigued. Therefore, for both Experiment 1 and Experiment 3, the theory of *lexical satiation* predicted slowed responses in the repeated condition, but not for Experiment 2. Finally, the theory of *associative satiation* requires responses based on a repeated meaning combined with repetitions of the associated lexical item to produce observable satiation. Therefore, the theory of *associative satiation* predicted semantic satiation only for Experiment 1 but not for Experiments 2 and 3.

3. Experiment 1a: Category matching, repeated cue (11 categories)

In the first experiment, participants were required to respond based on the meaning of a cue word followed by a target word in a category matching task (e.g., FRUIT followed by APPLE is a match). As in all three experiments, each block of trials used cues from a dominant category that repeated on 10 trials and 10 other categories that only appeared on one trial each, with these trials presented in random order. In Experiment 1, the same category label was used as the cue word for all repeated condition trials. This set up a situation where all of the theories predicted satiation: *Meaning satiation* predicted difficulty in the repeated category trials due to repeated access of the same categorical meaning, *lexical satiation* predicted difficulty in the repeated category trials due to repeated presentation of the same category label, and *associative satiation* predicted difficulty in the repeated category due to lack of access for the meaning of the repeated category based on the repeated category label. Therefore, this experiment was a critical first step, serving to validate this new category matching procedure. Also, because this is the only design of the three experiments that might produce semantic satiation according to the theory of *associative satiation*, we report two replications of this experiment, with the second using a slightly different procedure that ruled out concern that the satiation effect resulted from a particular strategy.

3.1. Method

3.1.1. Participants—A total of 43 students in University of California, San Diego voluntarily participated in this experiment in return for extra credit in an introductory psychology course.

3.1.2. Materials—Eleven single-word category labels were selected (see Appendix Table A1). Twenty single-word exemplars were selected from each category (McEvoy & Nelson, 1982; Van Overschelde, Rawson, & Dunlosky, 2004). All stimuli were presented in white font on the center of a computer screen with gray background. Reaction time was collected using 2 buttons of a 5-button serial response box.

3.1.3. Design and procedure—A 2 (repetition status) X 2 (matching status) factorial design was used, producing 5 replications of these 4 conditions across the list of 20 trials. The order of these 20 trials was determined by a random permutation of the list.

On each trial, a category label was presented above the midline for 1000 ms. Next, an exemplar was presented below the midline while the category label remained on the screen until participants responded. Participants were asked to give a category matching judgment between category label and exemplar. Following their response, the screen was blank for 100ms and feedback (a green check or a red cross) was presented before the next trial began.

One of the 11 category labels was randomly chosen without replacement to repeat on 10 trials as the cue word (repeated condition) and the other 10 trials used a cue word drawn without replacement from the remaining 10 category labels (nonrepeated condition). The correct answer for half of the trials was ‘match’, while it was ‘mismatch’ for the other half of trials. The mismatch trials were created by using exemplars from a different category. In each block, 5 exemplars from the repeated category were paired with 5 other category labels to form nonrepeated mismatched trials and 5 exemplars from 5 different categories were paired with the repeated category label to form 5 repeated mismatch trials. Table 1 shows the design of the 4 conditions with the cue word shown on the left and the target word on the right of the hyphen. In the table, a particular category is indicated by the letter, and different exemplars of a category as indicated by placing a number after the letter. Capital letters in the table indicates that the category label was used. All exemplars were randomly selected without replacement and so the exemplar target words never repeated within a block of 20 trials.

Eleven blocks in which different category labels served as the dominant repeated category formed one set that used all categories equally often. All 220 exemplars were only used once in one set. There were 4 sets with 44 blocks and 20 trials in each block. The presentation sequence of blocks in each set and the pairing of category labels and exemplars of each trial in each set were randomized. There were two practice blocks that used different stimuli prior to the start of the experiment. Participants were encouraged to respond as quickly and as accurately as possible. The reaction time and accuracy of each trial were recorded for data analysis.

3.2. Results and Discussion

Because all 3 experiments used the same paradigm (i.e. a series of 20 trials in a block), a common analysis procedure was applied to all experiments. Participants whose overall accuracy was under 90%[3] were excluded from further analysis. Only correct reaction times were analyzed, and reaction times less than 300 ms or greater than 1500 ms were removed. Because condition order within a block was a random permutation rather than fully crossed, there were two potential methods for analyzing position. One method would be to use trial position within the block, ranging from 1–20, which has the advantage of fully equating the conditions in terms of general fatigue across the list. When we analyzed the results this way, the results were qualitatively the same as reported below. However, one disadvantage of using trial position is that the number of repetitions of the dominant category prior to the current trial is not fully controlled. The other way to analyze position is by the number of previous occurrences for a condition. Note that the first occurrence of the repeated condition is in truth no different than the first occurrence of the nonrepeated condition and so the first occurrence was not analyzed. Collapsing over match status, there were 10 repeated and 10 nonrepeated trials, resulting in 1–9 previous occurrences. To increase statistical reliability, we broke these 9 previous occurrences into thirds (1–3, 4–6, and 7–9) to map out the time course of the repetition effect. Combining across the 44 blocks for a given individual, a median reaction time was found for this 2 (match status) X 2 (repetition status) X 3 (position) breakdown of the data. On average, this meant that 73.3 trials per individual per condition went into the calculation of each median RT (the exact number depended on the random ordering and on the elimination of error trials and RT trimming).

The main result of interest in all experiments was a two way interaction between repetition status and position, which could indicate a slow down in responding for the repeated condition as a function of the number of repetitions of the dominant category. However, an important first step was to check whether the match status of the target word interacted with this two way interaction. Therefore, the analyses of each experiment began with a repeated measures three-way ANOVA on position (3), repetition status (2), and match status (2). If there was no three way interaction according to this test, then reliability was increased by averaging the median RTs across match status to produce a repeated measures two-way ANOVA with just position (3) and repetition status (2). In the General Discussion, we consider why there were no interactions when including target match status, which is somewhat surprising in light of the tested theories, but is to be expected if participants used an adaptive response threshold to minimize errors. To determine whether there was a tradeoff between speed and accuracy, the same repeated measures two-way ANOVA was also applied to the accuracy data. All effects

[3]The same criterion was used for all experiments as determined from performance in Experiment 2, which was the most difficult experiment. When including all participants, or using a cutoff of 50% or 75% accuracy instead, the significance (or lack of significance) in the interaction between list position and repetition status was unchanged in all experiments from that found with this 90% cutoff.

achieving the significance of 0.05 were further investigated with pairwise comparisons. Greenhouse-Geisser corrections were reported for all effects having ≥2 *df* in the numerator.

Ten participants were excluded based on the 90% accuracy criterion, leaving 33 participants for further analyses. A repeated measures three-way ANOVA on correct median RT was applied to the factors of position (3), repetition status (2), and match status (2). Because match status did not interact with the other factors, $F(2,64) = 1.51$, $p = .23$, the results were averaged over match status.

Table 2 shows the median correct RT data for all conditions. A repeated measures two-way ANOVA revealed a significant main effect of position due to a slowing across the number of repetitions, $F(2,64) = 3.86$, $p < .05$. Figure 3 shows the key summary results in terms of the differences between the repeated and nonrepeated conditions averaged across match status as a function of position. This difference analysis factors out any general slowing or speeding across position that would affect both conditions. In other words, an interaction between repetition status and position is revealed as a change in this difference score measure as a function of position. In keeping with the increasing trend seen in Figure 3, the position X condition interaction was significant, $F(2,64) = 7.58$, $p < .005$[4]. Further paired t-tests comparing repeated with nonrepeated conditions at each position revealed relatively faster responding in the repeated condition during the first third, $t(32) = -2.093$, $p < .05$, no difference between the conditions during the middle third, $t(32) = .59$, $p = .56$, and relatively slower responding in the repeated condition during the final third, $t(32) = 3.69$, $p = .001$. In other words, early in the list, participants responded faster when the cue was the label of the dominant category, but by the end of the list, participants responded slower when the cue was the label of the dominant category. Thus, early in the list there appears to be semantic facilitation, but by the end of the list, participants were slower for the repeated category, as expected if semantic satiation occurred.

The apparent semantic satiation effect seen with reaction time might in fact be a change in bias if there was a corresponding change in accuracy (see Table 3). However, the condition X position interaction was not significant, $F(2, 64) = 2.38$, $p = .11$. Therefore, a speed-accuracy tradeoff cannot explain the RT interaction between repetition status and position.

These results suggest that after 7–9 repetitions of the categorical cue, semantic satiation occurred. This demonstrates that the speeded category matching task with a mixed list paradigm provides a well controlled method for studying semantic satiation. In particular, unlike previous semantic satiation studies, this paradigm equates the repeated and nonrepeated conditions in terms of fatigue and attention by using a mixed design. This paradigm also measures semantic satiation with the same task that induces satiation, thus eliminating any concern that the results arise from task switching. However, the design and results of this experiment are compatible with all three accounts of semantic satiation. Furthermore, as explained next, there is a specific memory based strategy that might also explain these results.

A careful analysis for the ordering of events within a block reveals that participants might have adopted a memory based strategy that could possibly explain relatively slower responses in the repeated condition. In the design of Experiment 1a, the mismatch trials were constructed by swapping exemplars between the repeated and nonrepeated conditions (see Table 1, Experiment 1a, row 2 and 4). However, if a mismatch trial in the repeated condition occurred before the associated exemplar-swapped mismatch trial in the nonrepeated condition, participants could have known from the cue word that the trial was to be a mismatch trial. In

[4]The interaction between list position and repetition status was still significant, $F(2,84) = 5.42$, $p < .01$, when all participants were included.

other words, they could potentially consult their memory for a previously seen exemplar from the non-dominant category, and then once they viewed the related category label as the cue word on a later trial, they would know that a mismatch exemplar would appear. Because this strategy is only effective for the later trials of the block (i.e., the appropriate mismatch repeated trial has to have already occurred), this might explain the relative slowing as due to a speedup in the nonrepeated condition. This is a fairly elaborate strategy and it relies upon a consultation with memory, but nonetheless, this is a conceivable alternative explanation. This strategy should have produced a 3-way interaction with match status, although no 3-way interaction was found, which provides some evidence against this alternative. In any case, Experiment 1b served to replicate Experiment 1a with a modified design that eliminated the possibility of this elaborate strategy by no longer swapping exemplars in the mismatch conditions.

4. Experiment 1b: Category matching, repeated cue (16 categories)

Experiment 1b sought to replicate Experiment 1a with a slightly different design in which there could be no strategy based on memory for previously seen exemplars. Unlike Experiment 1a, the repeated mismatched trials were constructed by using exemplars from additional categories. This change necessitated the use of 16 categories rather than 11.

4.1. Method

4.1.1. Participants—A total of 41 students in University of California, San Diego voluntarily participated in this experiment in return for extra credit in an introductory psychology. These participants were different from those participated in Experiment 1a.

4.1.2. Materials—All the materials used in this experiment were the same as Experiment 1a, except for the inclusion of 5 additional categories (McEvoy & Nelson, 1982; Van Overschelde, Rawson, & Dunlosky, 2004). The categories are listed in Appendix Table A2.

4.1.3. Design and procedure—All experimental design and procedures were the same as in the Experiment 1a, except as noted. There were 16 blocks in one set and each set was repeated 3 times, for a total of 48 blocks in the experiment. The 5 mismatch trials in the repeated condition were created by pairing the repeated category label with 5 exemplars from categories that otherwise did not appear in the block. However, as with Experiment 1a, the 5 mismatch trials in nonrepeated condition were created with 5 exemplars from repeated category (see Table 1). This is important in order that a target exemplar from the dominant category is non-diagnostic (i.e., the correct response to an exemplar from the focal category is just as likely to be 'match' as 'mismatch').

4.2. Results and Discussion

Seven participants were excluded based on the 90% accuracy criterion, leaving 34 participants for further analyses. A repeated measures three-way ANOVA on correct median RT was applied on the factors of position, repetition status, and match status. Match status did not interact with the other factors ($F < 1$). Therefore, match status was collapsed to increase power in the following analyses.

Figure 3 (also see Table 2) shows median correct reaction time differences between the repeated and nonrepeated conditions as a function of number of position (number of repetitions). A repeated measures two-way ANOVA revealed a significant main effect of position due to a general slowing with increasing position, $F(2, 66) = 9.99$, $p < .001$. More importantly, the position X condition interaction was significant, $F(2, 66) = 15.59$, $p <.001$. Paired t-tests comparing the repeated and nonrepeated conditions at a given position revealed a facilitation for the first third, $t(33) = -2.11$, $p < .05$. However, this effect disappeared during the middle third, $t(33) = -.14$, $p = .89$, and was reversed by the final third such that there were slower responses in the repeated condition, $t(33) = 4.29$, p <001.

A similar repeated measures two-way ANOVA on accuracy revealed a main effect of condition, with participants responding more accurately in the repeated condition, $F(1,33) = 52.31$, $p < .001$. However, the condition X position interaction was not significant ($F < 1$). Therefore, a speed-accuracy trade-off cannot explain the interaction found with reaction times (see Table 3).

In summary, Experiment 1b replicated all the findings of Experiment 1a even though the alternative memory based explanation for the relative slow down in the repeated condition was eliminated. Thus, this paradigm appears to provide a well controlled and robust method for measuring semantic satiation. In both experiments, there was a transition from response benefits to response deficits with increasing numbers of repetitions of the categorical cue. Unlike previous semantic satiation experiments, these experiments equated attention and fatigue between the repeated and nonrepeated conditions. Furthermore, there was only one task, which eliminated concern for task switching effects and also allowed measurement of the full time course of semantic satiation. However, these experiments used the same category cue on all repeated trials, and so while the results validated the category matching task, they cannot differentiate between *lexical satiation*, *meaning satiation*, or *associative satiation*, which all predicted a satiation effect considering that both the lexical entry and the associated meaning repeated.

5. Experiment 2: Category matching, novel cue

Experiment 1 used the same category cue on all trials in the repeated condition and, as predicted by all three accounts, responses in the repeated condition were slower by the final third of the block. To differentiate between these accounts, Experiment 2 used the same design and again used a dominant category that repeated across trials within a block. However, unlike Experiment 1, none of the words in Experiment 2 repeated within a block, and the category that was to be matched was indicated on each trial by a new exemplar. In other words, rather than viewing the category label, participants needed to infer the category for the matching task based on an exemplar. Thus, the meaning of the dominant category was repeatedly accessed, but this access occurred in response to a new exemplar on each trial. With this design, the theory of *meaning satiation* is potentially falsified. According that account, a satiation effect similar to Experiment 1 should be found due to the repeated access of the same category meaning. However, both *lexical satiation* and *associative satiation* predict that there should not be any satiation because no lexical item repeats.

5.1. Method

5.1.1. Participants—A total of 40 students in University of California, San Diego voluntarily participated in this experiment in return for extra credit in introductory psychology course. These students were different from who participated in Experiment 1.

5.1.2. Materials—Sixteen different category were selected with 20 exemplars in each list (McEvoy & Nelson, 1982; Van Overschelde, Rawson, & Dunlosky, 2004). The categories are listed in Appendix Table A3.

5.1.3. Design and procedure—The procedure was identical to that in Experiment 1b, except that the material used as the cue word on each trial were also exemplars instead of category labels. That is, in each trial, two exemplars appeared with one appearing above the midline, and then a second appearing below the midline 1,000 ms later. At that time, both remained on screen until participants responded. The task was to judge whether the two exemplars belonged to the same category. For category cues, 10 trials in the block used 10 different exemplars from the repeated category (repeated condition) while the other 10 trials used 10 different exemplars from 10 different categories (nonrepeated condition). The mismatched trials in the repeated condition were created by pairing 5 exemplars from the repeated category with 5 exemplars from 5 different categories that otherwise did not appear in the block (see Table 1). The mismatched trials in the nonrepeated condition were created by pairing 5 exemplars drawn without replacement from the repeated category with 5 different exemplars from other categories. Each of sixteen blocks used a different category for the repeated category and this formed one set. All 320 exemplars were used twice in one set. Three sets were included in the experiment.

5.2. Results and Discussion

Six participants were excluded based on the 90% accuracy criterion, leaving 34 participants for further analyses. A repeated measures three-way ANOVA on correct median RT revealed that match status did not interact with the repetition status by position interaction ($F < 1$). Therefore, the results were collapsed over match status to increase power in the following analyses.

Figure 3 (also see Table 2) shows the median correct reaction time difference between the repeated and nonrepeated conditions as a function of number of repetitions. A repeated measures two-way ANOVA revealed a main effect of repetition status due to faster responses in the repeated than in the nonrepeated condition, $F(1,33) = 9.98$, $p < .005$, and a main effect of position due to a slowing in general with increasing position, $F(2, 66) = 15.50$, $p <.001$. However, there was no interaction between position and condition ($F < 1$), suggesting that semantic satiation did not occur.

The accuracy results are shown in Table 3. A similar repeated measures two-way ANOVA found a main effect of condition, with participants making fewer errors in repeated condition, $F(1,33) = 41.73$, $p < .001$. There was no interaction between position and condition ($F < 1$), and so a speed-accuracy tradeoff could not explain the apparent lack of a semantic satiation effect in the reaction time results.

In summary, neither reaction time nor accuracy changed as the number of repetitions increased in Experiment 2. Therefore, these results falsify an account of the satiation in Experiment 1 in terms of *meaning satiation*: Although the same category meaning was repeated on 10 trials, there was no response deficit in Experiment 2. Instead, a response benefit was observed regardless of the number of repetitions. However, it is still not clear from these results whether the semantic satiation in Experiment 1 was due to *lexical satiation* or due to *associative satiation*. Experiment 3 sought to differentiate between these alternatives by using lexical repetitions, as in Experiment 1, but with a task that did not require meaning access.

6. Experiment 3: Word matching, repeated cue

The theory of *lexical satiation* and the theory of *associative satiation* both predicted the lack of satiation that was found in Experiment 2. According to both of these accounts, satiation does not occur unless a lexical item is repeated. However, these two accounts differ in terms of the level at which this satiation can be observed. According to *lexical satiation*, there should be a satiation effect when responding based on meaning, but this should also be true when giving a lexical response (e.g., simply word matching). In contrast, according to *associative satiation*, the lexical response is not satiated, but the association to meaning has been lost, and so only by repeating a lexical entry in a meaning based task will semantic satiation be observed (such as occurred in Experiment 1). In Experiment 3, participants were asked to respond to exemplars at the lexical level (word matching between cue and target rather than category matching) to differentiate between these two accounts. The theory of *lexical satiation* predicts that a simple word matching task should also produce slower RTs with increasing repetitions, just as was observed for Experiment 1. In contrast, the theory of *associative satiation* predicts a lack of satiation when responses are based on lexical access rather than meaning access.

6.1. Method

6.1.1. Participants—A total of 40 students in University of California, San Diego voluntarily participated in this experiment in return for extra credit in introductory psychology course. These students were different from who participated in Experiment 1 and 2.

6.1.2. Materials—Sixteen four-letter exemplars were selected from 16 different categories used in Experiment 2 (one exemplar per category used consistently throughout the experiment and for all participants), by best matching Kucera-Francis written frequency ($M = 37.4$, $SD = 17.1$). The words are listed in Appendix Table A4.

6.1.3. Design and procedure—The procedure was identical to Experiment 2, except that the task was word matching rather than category matching. One of the 16 exemplar words was randomly selected without replacement as the repeated word in a given block and used as the cue on 10 trials (repeated condition). The other 10 trials used the chosen exemplars from 10 other categories (nonrepeated condition). Match trials used the same word for cue and target. Mismatch trials in the repeated condition presented a target that was an exemplar from a category that did not appear on any other trial. Mismatch trials in the nonrepeated condition presented the same repeating exemplar used as the cue in the repeated condition (see Table 1). The task was to judge whether the two exemplars were the same or different. In theory, this task could have been accomplished based on category membership, although reaction times were much faster than either Experiment 1 or 2, suggesting that participants engaged in simple orthographic or phonetic matching without waiting for a match decision based on meaning.

6.2. Results and Discussion

One participant was excluded based on the 90% accuracy criterion, leaving 39 participants for further analyses. A repeated measures three-way ANOVA on correct median RT revealed that match status did not interact with the repetition status by position interaction ($F < 1$). Therefore, the results were collapsed over match status to increase power in the following analyses.

Figure 3 (see also Table 2) shows the median reaction time difference between the repeated and nonrepeated conditions as a function of number of repetitions. A repeated measures two-way ANOVA revealed a main effect of repetition status due to faster responses in the repeated condition than in the nonrepeated condition, $F(1,38) = 21.11$, $p < .001$ and a main effect of position due to a slowing in general with increasing position, $F(2, 76) = 13.89$, $p < .001$. However, there was no interaction between position and condition ($F < 1$), suggesting that semantic satiation did not occur.

The accuracy results are shown in Table 3. A similar repeated measures two-way ANOVA found a main effect of condition, with participants making fewer errors in repeated condition, $F(1,38) = 4.35$, $p < .05$. There was no interaction between position and condition, $F(2,76) = 2.73$, $p = .072$, and so a speed-accuracy tradeoff could not explain the apparent lack of a semantic satiation effect in the reaction time results.

Therefore, just as in Experiment 2, neither reaction time nor accuracy changed with increasing repetitions. This stands in contrast to Experiment 1, in which a repeated cue word produced slower RTs. We assume that participants were responding based on a lexical match rather than a meaning based categorical match, and that this difference explains the difference between

Experiment 1 versus Experiment 3. An examination of Table 2 supports this hypothesis of the difference between Experiment 1 versus Experiment 3, revealing that responses were approximately 200 ms faster in Experiment 3. According to the theory of *lexical satiation*, Experiment 3 should have produced a satiation effect because it should have become difficult to access the lexical response of the repeated cue word. Instead, as in Experiment 2, there was a benefit for the repeated condition and that benefit was unchanged with increasing numbers of repetitions. Thus, only the theory of *associative satiation* can explain all three experiments because by this theory, semantic satiation only occurs when repeating the same word in a meaning based task, such as Experiment 1.

7. General Discussion

Three experiments examined the question of semantic interference in a reading task that involved speeded matching between a cue and a subsequently presented target word. According to the ROUSE theory, information is parsed from moment to moment by discounting previously identified objects so as to minimize perceptual source confusion. Discounting is a policy that is useful in general, but it produces a deficit in processing repetitions. As applied to semantic processing, this theory says that when a word repeats with little delay between presentations, the perceptual evidence of the repetition is discounted, which makes semantic access difficult. A neural implementation of this theory proposed discounting through synaptic depression, which results in the temporary loss of connectivity between sending and receiving neurons. Thus, discounting of previously read words is due to a loss of association between the lexical representation and its meaning. This loss of association stands in contrast to theories in which semantic access is difficult due to the direct loss of semantic processing or the direct loss of the lexical processing. On this account, the phenomenon of semantic satiation is due to *associative satiation* and behavioral measurement of semantic satiation requires a semantic task that repeats the same lexical item.

Experiment 1 used a newly developed task for measuring semantic satiation that equated for attention and fatigue by using a mixed list design that included both repeated category and nonrepeated category trials in a random order. This paradigm removes any task switching by using the same task both to induce and measure semantic satiation. On each trial, a category cue word appeared for one second, followed by a target word for a speeded category matching decision. Because one second was previously shown to maximize short-term repetition priming deficits in a perceptual identification task (Huber, 2008; Huber, Shiffrin, Lyle, & Ruys, 2001; Huber, Shiffrin, Lyle, & Quach, 2002; Huber, Shiffrin, Quach, & Lyle, 2002; Weidemann, Huber, & Shiffrin, 2005; Weidemann, Huber, & Shiffrin, 2008), this cue duration served to equate in terms of perceptual effects. In other words, in terms of short-term perceptual processes, a first repetition was expected to be the same as a ninth repetition. Thus, any differences as a function of increasing repetition would reflect slower acting non-perceptual processes, such as with semantic satiation. Blocks consisted of 20 trials with 10 repeated and 10 nonrepeated conditions, allowing measurement for between 1 and 9 previous presentations of the repeated category cue. Breaking these 9 prior repetitions into thirds, the first third revealed facilitation for the repeated condition, the second third revealed no difference, and the final third revealed slower responses for the repeated condition, suggesting that semantic satiation occurred. There was no interaction between these effects and the match versus mismatch status of the target word, which suggests that the effect is primarily due to the cue word that repeated across trials. The effect was then replicated in a slightly different design that eliminated a strategy that might have explained the relative slow down in the repeated condition as arising from a speed up in the nonrepeated condition.

Theorists previously proposed that semantic satiation is due to *meaning satiation* (inability to process repeated meaning) or due to *lexical satiation* (inability to process a repeated lexical representation). Because the design of Experiment 1 used a repeated word and responses based on access of that repeated word's meaning, the results of Experiment 1 supported both of these accounts, as well as an account based on *associative satiation*. Experiment 2 used a modified category matching task that presented exemplars as cues rather than the category label. Because a different exemplar appeared on every trial, only the category meaning repeated, but no lexical item repeated. According to *meaning satiation*, there should still have been a satiation effect and yet none was found. Experiment 3 used a modified task that repeated lexical items like Experiment 1, but changed the task to simple word matching rather than category matching. According to *lexical satiation*, there should still have been a satiation effect and yet none was found. Thus, amongst these three theories, only *associative satiation* can explain the results of all three experiments. This is because only *associative satiation* requires both a semantic task (meaning access) and a repeated lexical item.

7.1. An explanation based on ROUSE

As summarized above, these results are inconsistent with the theory of *meaning satiation* (disconfirmed by Experiment 2) and *lexical satiation* (disconfirmed by Experiment 3), but are the data across all three experiments consistent with *associative satiation*? In particular, it is not clear whether the theory of *associative satiation* explains the observed facilitations and it is not clear that it explains the lack of interaction of these effects with the match status of the target. In this section, we explain the mechanism of the ROUSE model in greater detail, revealing that these aspects of the data were expected.

Experiment 1 revealed a gradual transition from facilitated responding (positive priming) for the repeated category to slower responding (negative priming) for the repeated category. The eventual slower responding is assumed to reflect semantic satiation, but what account for facilitated responding early in the list? In the domain of short-term perceptual priming, the ROUSE model was developed to handle similar transitions from positive to negative priming. ROUSE assumes that lingering prime activation produces positive priming (Huber, Shiffrin, Lyle, & Ruys, 2001). Offsetting this lingering activation, negative priming is due habituation that leads to sluggish re-activation according to the neural ROUSE model (Huber & O'Reilly, 2003). Because habituation is a slower process that is driven by ongoing activation, it takes time to accrue. With short-term repetition priming in a perceptual task, the transition from positive to negative priming is complete after 1,000 ms of prime viewing (e.g., Huber, 2008). In modeling this result, the neural ROUSE model used habituation in the association between orthography and the lexical representation. In the current situation, the transition from positive to negative priming took place over many seconds, as might be expected with habituation in the association between the lexical representation and semantics. In summary, the positive to negative priming transitions seen with short-term priming and semantic satiation are both explained in a similar same manner, although the former occurs more quickly due to fast acting orthographic-to-lexical habituation whereas the latter occurs more slowly due to slow acting lexical-to-semantic habituation.

The theory of *associative satiation* predicted satiation for Experiment 1 as well as the absence of satiation for Experiment 2 and 3. But what explains the observed facilitations seen in Experiments 2 and 3? This requires consideration of the decision rule used in the same/different task. In a series of experiments, we examined repetition priming for the word matching task employed in Experiment 3 (Davelaar, Huber, Tian, & Weidemann, submitted). In different conditions, either the cue word or the target word repeated a word from the last trial. We found that mismatch trials were faster when the cue was primed but slower when the target was primed. As with the current studies, this was explained with the ROUSE model by assuming that priming produces habituation. Habituation explains this pattern of data if the decision rule is novelty detection, such as by monitoring the lexical response to the target to see whether the target produces additional activation as compared to the cue. If the cue and target are different words, then the target produces a boost of additional lexical activation, and this boost signals a 'different' response, rather than a 'same' response. However, if the cue and target are the same, then there is no boost of activation in response to presentation of the target. If priming from a previous trial produces orthographic-to-lexical habituation, then there is less lexical activation for a primed word on the next trial. Thus, when the cue is primed, it is easier to quickly detect a target that differs from the cue because there is a larger difference in activation with the onset of the target. A primed target also produces a reduced level of lexical activation. However, in this case, the reduced activation works against novelty detection, making it difficult to detect the boost of activation for a primed target that follows a different cue. In Experiment 3, the same word repeated across the list, appearing as the cue in the repeated condition, which aids this lexical novelty detection, and appearing as the target in the nonrepeated condition, which hurts this lexical novelty detection. On this account, the facilitation seen throughout the list is explained by habituation in the orthographic-to-lexical association combined with lexical novelty detection.

A decision rule based on novelty detection also explains facilitation in Experiment 2. However, in this case, the novelty detection was in terms of the semantic activation rather than lexical activation. Thus, the decision was to respond 'different' if the target word produced a sufficient burst of new meaning. In the design of Experiment 2, there were no repetitions of the same word. Therefore, there was no habituation. Nevertheless, the same meaning occurred through the list (e.g., the inferred category FRUIT), producing a higher baseline of semantic activation for the meaning of the repeated category. With this constant additional activation, novelty detection in the repeated condition was unaffected (i.e., a mismatching target from some other category would still produce additional semantic activation above and beyond this higher baseline level). In contrast, this constant additional activation was detrimental to novelty detection in the nonrepeated condition because a mismatch trial consists of presenting an exemplar from the repeated category. Because the meaning of the repeated category was already active, an exemplar from the repeated category would not produce much additional boost of semantic activation, giving the mistaken impression that the target matched the cue. Thus, the facilitation in the repeated condition is explained as a deficit in the nonrepeated condition. On this account, the facilitation seen throughout the list is explained by lingering semantic activation combined with semantic novelty detection.

We now summarize these theoretical interpretations. The early list facilitation in Experiment 1 and the constant facilitation in Experiment 2 were due to lingering semantic activation, which made detection of novel semantics difficult in the nonrepeated mismatch because the meaning of the target was already active. The eventual semantic satiation in Experiment 1 was due to habituation in the lexical-to-semantic association. Slower responses occurred because the repeated cue word produced less semantic activation, and so there was a boost of new semantic activation for a matching target, which would give the mistaken impression of novelty. Finally, the facilitation in Experiment 3 was due to habituation in the orthographic-to-lexical association, which made novelty detection of the lexical response easier in the repeated condition (cue primed) but more difficult in the nonrepeated condition (target primed). The key assumptions of this account are that orthographic-to-lexical habituation is fast (maximized with a single presentation) whereas lexical-to-semantic habituation is slow (requiring at least 7 prior presentations), and that accurate responding is achieved through novelty detection of the target word by measuring the boost of semantic activation (category matching task in Experiments 1 and 2) or the boost of lexical activation (word matching task in Experiment 3).

Note that the semantic satiation of Experiment 1 is explained specifically with the repeated match condition. In this condition, the matching target mistakenly appears to indicate a new category due to the habituated response to the cue. Yet in the reported results, there was no interaction between the match status of the target and list position. In other words, both the match trials and the mismatch trials slowed down with semantic satiation. However, to avoid errors, participants should set their novelty detection response threshold to progressively more conservative levels as semantic satiation builds. Indeed, the adjustment of response thresholds is a common observation in reaction time studies. For instance, Jones and colleagues found that response bias constantly shifts in a go/no-go task due to response conflict from the last few trials (Jones, Cho, Nystrom, Cohen, & Braver, 2002). But shouldn't the nonrepeated condition have been affected by a shift in the response threshold? Because the cue words appeared for 1 second, it is reasonable to assume that there were separate thresholds repeated versus nonrepeated cue words (e.g., the system could learn to be more conservative selectively in response to the repeated cue). Therefore, assuming that people adapt to avoid errors, it is sensible that there was just as much of a performance change in the repeated mismatch condition as occurred in the repeated match condition.

7.2. Concerns and Alternative Explanations

In comparing across experiments, one concern is that the findings of Experiment 2 and Experiment 3 rely on a null result for the interaction between position and repetition status. In other words, perhaps there was a slow down with increasing list position in those experiments, but there was insufficient power to observe the effect. However, all three experiments used similar numbers of participants and identical numbers of trials per participant, resulting in equivalent power to observe interactions between trial number and condition. Therefore, under the assumption that there is just one cause of semantic satiation (a, b, or c in Figure 1), and considering that the interaction in Experiment 1 was replicated (i.e., it appears to be a robust effect), it seems unlikely that there was an interaction of a similar magnitude in Experiments 2 or 3. Furthermore, although Experiments 2 and 3 included sufficient power to observe a reliable facilitation in the repeated condition, this facilitation remained constant across the entire list.

A 1,000 ms cue duration was used to equate for short-term perceptual priming effects. However, use of a long duration cue may have allowed participants to adopt more strategic forms of responding. More specifically, for the category matching experiments (Experiments 1 and 2), perhaps participants generated category exemplars in response to the cue word. For instance, they might see the cue word FRUIT and generate the set APPLE, PEAR, and BANANA prior to viewing the target. If the target word was amongst this set of generated exemplars, then they could quickly respond 'same', but otherwise they would engage in a more time consuming cue-target comparison. By itself, this expectancy set hypothesis does not explain semantic satiation. However, viewing previous exemplars from the repeated category may have made it increasingly difficult to generate new exemplars. This would have occurred if previously viewed exemplars more easily spring to mind, serving to block generation of new exemplars in the expectancy set.

There are several pieces of evidence against this expectancy set hypothesis. For one, this account doesn't explain facilitation early in the list. In contrast, the ROUSE model supposes that satiation exists precisely to offset the lingering activation that underlies this facilitation. For another, this account doesn't explain the lack of interaction with the match status of the target. In contrast, the supposition of novelty detection in the ROUSE model can explain this because responses are determined from a single underlying measure (degree of novelty). With a single measure, adaptation of the response threshold affects the match and mismatch conditions conversely. But beyond these theoretical gaps, the most problematic piece of evidence for the expectancy set hypothesis is the failure to find satiation in Experiment 2. If previously viewed exemplars make it difficult to populate the expectancy set with new exemplars, this should have been particularly true in Experiment 2 considering that 15 exemplars from the repeated category were viewed across the block of trials rather than the 10 that appeared in Experiment 1. Rather than a stronger satiation effect, Experiment 2 did not produce any satiation.

To further investigate the issue of response strategies, we recently performed a magnetoencephalography (MEG) experiment using the same design as Experiment 1b. Because MEG has millisecond temporal resolution, this allowed us to determine which time points in the cue-target sequence of a trial were affected by list position. Besides replicating the behavioral results, the question of interest was whether neural satiation occurs in response to the cue or the target, and whether neural satiation occurs as part of lexical processing or as part of the post-lexical decision (such as with a strategy). According to the ROUSE model, the lexical-to-semantic association to the repeated cue word is responsible for the semantic satiation effect. In keeping with this assumption, both the M170 and the M400 to the repeated cue word became progressively smaller with each additional third of the list. In contrast, none of the neural responses to the target word decreased in magnitude with list position. Instead, the M400 to the target in the repeated match condition increased with list position, as was expected under the novelty detection hypothesis. According to the novelty detection hypothesis, the matching target produces a larger than expected boost of semantic activation towards the end of the list due to the lowered baseline semantic activation in response to a repeated cue word. Thus, the effect appears to be due to reduced lexical-semantic processing to the cue word rather than a post-lexical decision strategy.

7.3. Relationship to Other Lexical-Semantic Tasks

The current paradigm is different than traditional methods for studying semantic satiation. In Experiment 1, the same cue word repeated 10 times across a block of trials, but these repetitions were interrupted by target words, responses, and trials that used different category cues. In contrast, traditional studies of semantic satiation have used a continuous series of 30 repetitions (e.g., Smith & Klein, 1990). However, semantic satiation is presumably due to some sort of slow accrual. If semantic satiation was a fast process, it would not require 10 or 30 repetitions. Therefore, in a continuous series of repetitions, there is both the effect from the most recent repetition as well as lingering effects from previous repetitions. In the current paradigm, we did not include any immediate repetitions (except for in Experiment 3, which produced no satiation). This situation was by design. We sought to study the slow processes that underlie semantic satiation while eliminating or controlling faster processing such as perceptual priming. Semantic satiation paradigms that use continuous repetitions presumably include both fast perceptual effects as well as slower processes that accrue over multiple presentations. Thus, the *associative satiation* effect we observed with the current paradigm should contribute to the results of continuous repetition experiments even if it’s not the complete explanation of those data.

Our experiments used long duration cues, but semantic deficits have also been found with repetitions of subliminal primes. Wentura and Frings (2005) presented the same category label followed by a mask after each presentation for 20 repetitions. Despite these repetitions, participants were unaware of the primes. Collectively, the duration of these 20 repetitions was equal to the prime duration in another condition that presented the prime just once. These prime presentations were followed by a target word to which a lexical decision was given. The single prime presentation condition produced the usual priming facilitation in terms of faster reaction times to related target words but the repeated subliminal presentation condition actually produced a reliable negative priming effect, with slower reaction times for related target words. The neural dynamics contained in the ROUSE model may help explain this puzzling set of results. Each prime presentation may induce some degree of activation and also some modest degree of habituation. However, activation and habituation operate on different time scales, with activation fading more quickly as compared to the recovery time of habituation. Therefore, this repeated subliminal presentation procedure may be ideally suited to slowly build up lingering habituation (*associative satiation*), which produces negative priming, without producing too much lingering activation, which would otherwise produce position priming.

Similar performance deficit with repetitions have been found in other semantic tasks that were not specifically designed to address semantic satiation. In a study conducted by Brown, Zoccoli and Leahy (2005), participants recalled 12 exemplars from the same category using the first letter of each exemplar as a cue. They found that retrieval success declined across the 12 successive recall attempts. They concluded that each retrieved exemplar served to inhibit access of subsequent exemplars from the same category. It might appear that this violates the theory of *associative satiation* considering that only the category meaning repeated (similar to Experiment 2). However, in their studies, they also repeated the same category label on each trial. According to the theory of *associative satiation*, it is possible that the repetitions of the category label was the cause of the semantic satiation and that the progressive retrieval failure resulted from increasingly less category activation in response to the category label. Finally, note that this paradigm did not use a mixed design and so general changes in fatigue or attention may provide an alternative explanation.

Another study similar to Experiment 2 is that of Neely, Shmidt, and Roediger (1983). They performed three episodic recognition experiments that manipulated the test sequence to examine the effect of recently tested category exemplars. Similar to Experiment 2, they manipulated the number of exemplars from the same category and exemplars did not repeat within the testing session. Accuracy was very good and RT was the key measure of interest for the speeded recognition responses. Similar to our semantic satiation experiments, they separately examined RT to test items that were targets (analogous to the match condition) versus test items that were lures (analogous to the mismatch condition). They observed that an increased number of recently viewed category exemplars produced slower responses to targets but faster responses to lures. This may seem to contradict the results of Experiment 2, which revealed faster responding for the repeated conditions. However, the key difference between the Neely et al. study and Experiment 2 is that the former tested episodic recognition (i.e., long-term familiarity) whereas the latter tested cue-target category matching (i.e., short-term novelty). In a recent series of experiments, we extended the neural ROUSE model to long-term familiarity by assuming that semantic processing serves as the input to the episodic familiarity representation (Huber, Clark, Curran, & Winkielman, 2008). If this is correct, it may be that semantic-to-familiarity habituation produced the gradually accruing RT effects in the Neely et al. experiments. More specifically, this habituation would produce less familiarity for categorical test items regardless of whether they were targets or lures. This lessened familiarity might explain why responses to targets were slower (less familiarity makes it difficult to respond ‘old’) whereas responses to lures were faster (less familiarity makes it easier to respond ‘new’).

8. Conclusions

The ROUSE theory of source confusion and discounting helps explain how the reading system can maintain meaning across a sentence while reducing confusion between previously viewed words and subsequent words that are lexically similar. To reduce source confusion, previously viewed words are temporarily discounted. A neural implementation of ROUSE further assumed that this discounting occurs through habituation in the connection (association) between a lexical item and its meaning. However, this solution is not without a cost. Specifically, this makes it difficult to access the meaning of a repeated word. Therefore, the negative effects of this discounting process should be found in a semantic task that involves repetitions of the same lexical item. In its application to semantic satiation, we termed this theory *associative satiation*, and we performed a series of 3 experiments that documented its existence in a well controlled manner and ruled out several previously proposed alternative accounts of semantic satiation. More generally, we hypothesize that associative habituation is a ubiquitous process in identification that serves to minimize confusion between items that appear close in time.

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Appendix

This Appendix lists all the words used in all four experiments.

Table A1

Categories Cues (underlined) and Exemplars used in Experiment 1a.

VEGETABLE	INSECT	SPORT	MAMMAL	FRUIT	SPICE
CARROT	ANT	FOOTBALL	DOG	APPLE	SALT
LETTUCE	SPIDER	BASKETBALL	CAT	ORANGE	PEPPER
BROCCOLI	BEE	SOCCER	HORSE	BANANA	GARLIC
CUCUMBER	MOSQUITO	BASEBALL	LION	GRAPE	SUGAR
PEAS	BEETLE	TENNIS	BEAR	PEAR	OREGANO
CORN	GRASSHOPPER	HOCKEY	TIGER	PEACH	CINNAMON
POTATO	BUTTERFLY	SWIMMING	COW	STRAWBERRY	PAPRIKA
CELERY	WASP	GOLF	ELEPHANT	KIWI	BASIL
ONION	ROACH	VOLLEYBALL	DEER	PINEAPPLE	VANILLA
SPINACH	MOTH	LACROSSE	PIG	WATERMELON	MUSTARD
SQUASH	GNAT	RUGBY	GIRAFFE	PLUM	VINEGAR
BEAN	COCKROACH	SOFTBALL	RABBIT	GRAPEFRUIT	LEMON
CAULIFLOWER	CATERPILLAR	SKIING	GOAT	MANGO	THYME
CABBAGE	CENTIPEDE	RUNNING	ZEBRA	CHERRY	CURRY
RADISH	CRICKET	GYMNASTICS	MOOSE	CANTALOUPE	NUTMEG
ASPARAGUS	WORM	POLO	SHEEP	RASPBERRY	PARSLEY
BEET	MANTIS	RACQUETBALL	RACCOON	TANGERINE	CHILI
POTATOES	DRAGONFLY	WRESTLING	FOX	NECTARINE	ROSEMARY
TURNIP	FLEA	BOWLING	DONKEY	PAPAYA	CHIVES
ZUCCHINI	HORNET	BADMINTON	ELK	APRICOT	MARJORAM

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FLOWER	BIRD	BEVERAGE	VEHICLE	OCCUPATION
ROSE	EAGLE	BEER	CAR	SECRETARY
DAISY	ROBIN	VODKA	BUS	MANAGER
TULIP	BLUEJAY	WINE	TRUCK	COOK
LILY	CARDINAL	RUM	AIRPLANE	POLICEMAN
CARNATION	HAWK	WHISKEY	PLANE	ATHLETE
DAFFODIL	PARROT	TEQUILA	TRAIN	BANKER
DANDELION	SPARROW	GIN	BICYCLE	CARPENTER
PANSY	PIGEON	MARGARITA	VAN	JANITOR
ORCHID	SEAGULL	CHAMPAGNE	BOAT	THERAPIST
PETUNIA	DOVE	SCOTCH	SHIP	SCIENTIST
IRIS	PARAKEET	BOURBON	MOTORCYCLE	DOCTOR
VIOLET	FALCON	WATER	SUV	TEACHER
LILAC	CANARY	COKE	SUBWAY	LAWYER
COLUMBINE	OWL	MILK	TAXI	NURSE
GERANIUM	DUCK	JUICE	CAB	FIGHTER
PEONY	FINCH	SODA	SCOOTER	PROFESSOR
AZALEA	WOODPECKER	TEA	HELICOPTER	ACCOUNTANT
BEGONIA	FLAMINGO	COFFEE	JEEP	PSYCHOLOGIST
CHRYSANTHEMUM	ORIOLE	LEMONADE	MOPED	DENTIST
GARDENIA	SWALLOW	PUNCH	JET	ENGINEER

Table A2

Category Cues (underlined) and Exemplars used in Experiment 1b.

<u>EMOTION</u>	<u>COLOR</u>	<u>UTENSIL</u>	<u>FLAVORING</u>	<u>OCCUPATION</u>	<u>BIRD</u>	<u>SPORT</u>	<u>WEATHER</u>
LOVE	BLUE	KNIFE	SALT	DOCTOR	EAGLE	FOOTBALL	TORNADO
HAPPINESS	RED	FORK	PEPPER	TEACHER	ROBIN	BASKETBALL	HURRICANE
SADNESS	GREEN	SPOON	GARLIC	LAWYER	BLUEJAY	SOCCER	RAIN
FEAR	YELLOW	SPATULA	SUGAR	FIREMAN	CARDINAL	BASEBALL	SNOW
SORROW	PURPLE	PAN	CHILI	PROFESSOR	HAWK	TENNIS	HAIL
ANGER	ORANGE	POT	SPICE	ACCOUNTANT	CROW	HOCKEY	FLOOD
DEPRESSION	BLACK	WHISK	CINNAMON	DENTIST	WOODPECKER	SWIMMING	LIGHTNING
MAD	WHITE	BLENDER	PAPRIKA	ENGINEER	PARROT	GOLF	BLIZZARD
BITTERNESS	PINK	BOWL	KETCHUP	SECRETARY	SPARROW	VOLLEYBALL	FOG
CONFUSION	BROWN	LADLE	BUTTER	MANAGER	PIGEON	BOXING	SLEET
EXCITEMENT	GRAY	PLATE	BASIL	COOK	SEAGULL	KARATE	MONSOON
JEALOUSY	VIOLET	CHOPSTICKS	VANILLA	POLICEMAN	DOVE	RUGBY	THUNDER
JOY	INDIGO	TONGS	MUSTARD	ATHLETE	PARAKEET	SOFTBALL	WIND
PITY	MAGENTA	OPENER	SESAME	BANKER	FALCON	SKIING	STORM
CRYING	TURQUOISE	MIXER	VINEGAR	CARPENTER	CANARY	SURFING	TYPHOON
LAUGHTER	MAROON	OVEN	GINGER	JANITOR	OWL	RUNNING	DROUGHT
TEARS	TEAL	COLANDER	OIL	THERAPIST	FLAMINGO	GYMNASTICS	CLOUD
SMILE	TAN	CUP	THYME	SURGEON	ORIOLE	DIVING	SUNSHINE
TENSION	AQUA	STOVE	CURRY	SALESMAN	RAVEN	WRESTLING	GALE
SHOCK	FUCHSIA	MICROWAVE	NUTMEG	ARCHITECT	DUCK	BOWLING	DUST

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CLOTHING	FISH	ELEMENT	INSTRUMENT	VEHICLE	VEGETABLE	INSECT
SHIRT	SALMON	OXYGEN	DRUM	CAR	CARROT	FLY
PANTS	TROUT	HYDROGEN	GUITAR	BUS	LETTUCE	ANT
SOCKS	EEL	CARBON	FLUTE	TRUCK	BROCCOLI	TERMITE
UNDERWEAR	BASS	HELIUM	PIANO	AIRPLANE	TOMATO	BEE
SHOES	TILAPIA	NITROGEN	TRUMPET	TRAIN	CUCUMBER	MOSQUITO
HAT	TUNA	GOLD	CLARINET	BICYCLE	PEAS	BEETLE
SHORTS	SHARK	IRON	SAXOPHONE	VAN	CORN	BUG
JACKET	FLOUNDER	SILVER	VIOLIN	BOAT	POTATO	GRASSHOPPER
SWEATER	HERRING	SODIUM	TROMBONE	SHIP	CELERY	BUTTERFLY
SKIRT	CARP	SULFUR	TUBA	MOTORCYCLE	BEANS	WASP
COAT	COD	ZINC	CELLO	SKATEBOARD	SPINACH	HORNET
DRESS	GUPPY	COPPER	OBOE	SUBWAY	SQUASH	MOTH
GLOVES	HALIBUT	CHLORINE	BASS	TAXI	CAULIFLOWER	GNAT
SCARF	PERCH	NEON	HARP	SCOOTER	CABBAGE	ROACH
BLOUSE	TROUT	CALCIUM	HORN	HELICOPTER	RADISH	CATERPILLAR
TIE	MARLIN	ALUMINUM	KEYBOARD	JEEP	ASPARAGUS	WEEVIL
BELT	MINNOW	BORON	PICCOLO	MOPED	TURNIP	CRICKET
TOP	PIKE	LITHIUM	BANJO	SUV	ZUCCHINI	MANTIS
BOXERS	SNAPPER	MERCURY	HARMONICA	JET	ONION	DRAGONFLY
JEANS	PIRANHA	MAGNESIUM	TAMBOURINE	CAB	BEET	FLEA

Table A3

Exemplars used in Experiment 2.

type of emotion	color	kitchen utensil	part of human body	occupation	natural earth formation	sport	weather phenomenon
LOVE	BLUE	KNIFE	LEG	DOCTOR	MOUNTAIN	FOOTBALL	TORNADO
HAPPINESS	RED	FORK	ARM	TEACHER	RIVER	BASKETBALL	HURRICANE
SADNESS	GREEN	SPOON	FOOT	LAWYER	OCEAN	SOCCER	RAIN
FEAR	YELLOW	SPATULA	FINGER	FIREMAN	VOLCANO	BASEBALL	SNOW
SORROW	PURPLE	PAN	HEAD	PROFESSOR	LAKE	TENNIS	HAIL
ANGER	ORANGE	POT	TOE	ACCOUNTANT	VALLEY	HOCKEY	FLOOD
DEPRESSION	BLACK	WHISK	EYE	DENTIST	HILL	SWIMMING	LIGHTNING
MAD	WHITE	BLENDER	HAND	ENGINEER	ROCK	GOLF	BLIZZARD
BITTERNESS	PINK	BOWL	NOSE	SECRETARY	CANYON	VOLLEYBALL	EARTHQUAKE
CONFUSION	BROWN	LADLE	EAR	MANAGER	PLATEAU	BOXING	SLEET
EXCITEMENT	GRAY	PLATE	MOUTH	COOK	CRATER	KARATE	MONSOON
JEALOUSY	VIOLET	CHOPSTICKS	STOMACH	POLICEMAN	PLAIN	RUGBY	THUNDER
JOY	INDIGO	TONGS	HEART	ATHLETE	CAVE	SOFTBALL	WIND
PITY	MAGENTA	OPENER	KNEE	BANKER	GLACIER	SKIING	STORM
CRYING	TURQUOISE	MIXER	NECK	CARPENTER	ISLAND	SURFING	TYPHOON
LAUGHTER	MAROON	OVEN	BRAIN	JANITOR	STREAM	RUNNING	DROUGHT
TEARS	TEAL	COLANDER	HAIR	THERAPIST	CLIFF	GYMNASTICS	CLOUD
SMILE	TAN	CUP	ELBOW	SURGEON	DESERT	DIVING	SUNSHINE
TENSION	AQUA	STOVE	SHOULDER	SALESMAN	BEACH	WRESTLING	GALE
SHOCK	FUCHSIA	MICROWAVE	CHEST	ARCHITECT	WATERFALL	BOWLING	DUST

article of clothing	part of a building	chemical element	musical instrument	transportation vehicle	vegetable	insect
SHIRT	WINDOW	OXYGEN	DRUM	CAR	CARROT	FLY
PANTS	DOOR	HYDROGEN	GUITAR	BUS	LETTUCE	ANT
SOCKS	FLOOR	CARBON	FLUTE	TRUCK	BROCCOLI	SPIDER
UNDERWEAR	WALL	HELIUM	PIANO	PLANE	TOMATO	BEE
SHOES	ROOF	NITROGEN	TRUMPET	TRAIN	CUCUMBER	MOSQUITO
HAT	STAIRS	GOLD	CLARINET	BICYCLE	PEAS	BEETLE
SHORTS	ELEVATOR	IRON	SAXOPHONE	VAN	CORN	BUG
JACKET	ROOM	SILVER	VIOLIN	BOAT	POTATO	GRASSHOPPER
SWEATER	CEILING	SODIUM	TROMBONE	SHIP	CELERY	BUTTERFLY
SKIRT	BASEMENT	SULFUR	TUBA	MOTORCYCLE	BEANS	WASP
COAT	BATHROOM	ZINC	CELLO	SKATEBOARD	SPINACH	ROACH
DRESS	OFFICE	COPPER	OBOE	SUBWAY	SQUASH	MOTH
GLOVES	HALL	CHLORINE	BASS	TAXI	CAULIFLOWER	GNAT
SCARF	LOBBY	NEON	HARP	SCOOTER	CABBAGE	COCKROACH
BLOUSE	BRICK	CALCIUM	HORN	HELICOPTER	RADISH	CATERPILLAR
TIE	FOUNDATION	ALUMINUM	KEYBOARD	JEEP	ASPARAGUS	CENTIPEDE
BELT	ENTRANCE	BORON	PICCOLO	MOPED	TURNIP	CRICKET
TOP	ATTIC	LITHIUM	BANJO	MINIVAN	ZUCCHINI	WORM
BOXERS	CARPET	MERCURY	HARMONICA	FORD	ONION	DRAGONFLY
JEANS	CELLAR	MAGNESIUM	TAMBOURINE	CAB	BEET	FLEA

Table A4

Exemplars used in Experiment 3

Exemplar	Category
CORN	Vegetable
WASP	insect
GOLF	sport
BEAR	mammal
TAXI	vehicle
COOK	occupation
PITY	emotion
PINK	color
BOWL	utensil
KNEE	Body part
LAKE	earth
SNOW	weather
COAT	clothing
ROOF	building
IRON	chemical
HORN	instrument

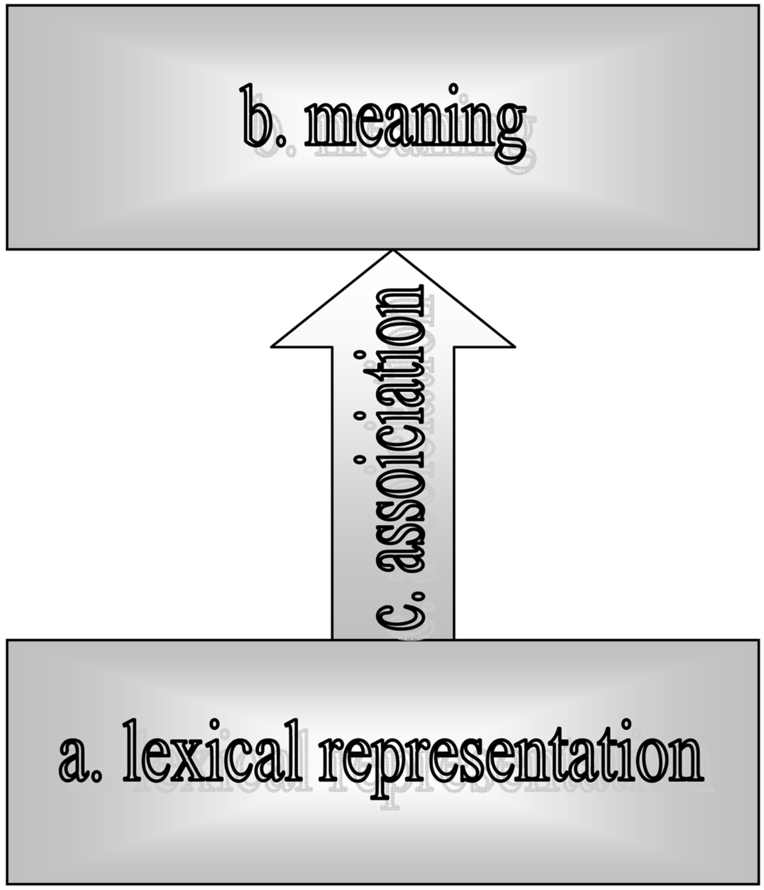

Figure 1.
Illustration of three theoretical accounts of semantic satiation: a. *lexical satiation*: repetitions produce satiation in the orthographic representation, causing reading difficulty for that word; b. *meaning satiation*: repetitions produce satiation in the semantic representation, causing an inability to access that meaning regardless of the manner in which access is attempted; and c. *associative satiation*: repetitions produce satiation in the association between the repeated lexical item and its meaning, causing an inability to access meaning through the particular repeated word.

Trial NO.	Repetition Status	Match Status	Experiment 1	Experiment 2	Experiment 3
1	R	D	VEGETABLE SALMON	CARROT PANTS	CORN IRON
2	N	D	BIRD CARROT	TORNADO BASKETBALL	COAT SNOW
3	R	S	VEGETABLE SPINACH	SPINACH LETTUCE	CORN CORN
4	R	S	VEGETABLE CABBAGE	BROCCOLI CORN	CORN CORN
5	N	S	SPORT FOOTBALL	SALT PEPPER	GOLF GOLF
• • •	• • •	• • •	• • •	• • •	• • •
18	N	D	COLOR BROCCOLI	EAGLE KNIFE	BOWL KNEE
19	N	S	VECHICLE TRUCK	BLUE RED	BEAR BEAR
20	R	D	VEGETABLE OXYGEN	CELERY DOCTOR	CORN TAXI

Figure 2.

Experimental designs of Experiments 1–3. This figure provides examples of a single block of 20 trials, although only 8 trials are shown. The second column is the repetition status of each trial, where R and N stand for the repeated condition and the nonrepeated condition respectively. The third column is the match status for cue and target on that trial, where S stands for ‘yes’ responses (Same = match), while D stand for ‘no’ responses (Different = mismatch). Two words are presented in each trial as shown in the last three columns. First, the cue word appeared in the center of the screen above the middle line for 1000 ms (the cue is the upper of the two words shown) followed by the target word below the middle line. At that point, both words remained on the screen until participants responded. In Experiment 1, the cue word was always the category label and the second word was always a new exemplar. In Experiment 2, both words were always new exemplars (category repetition but no repeated words). In Experiment 3, exemplars were selected and used for cues and targets, with the cue and target presenting the same word twice for match trials (repeated cue words, but no need to access category). The matching task in each experiment is therefore slightly different: in Experiment 1 the cue provides the name of the category, in Experiment 2, the category must be inferred by the cue, and in Experiment 3 the matching is of the word rather than the category.

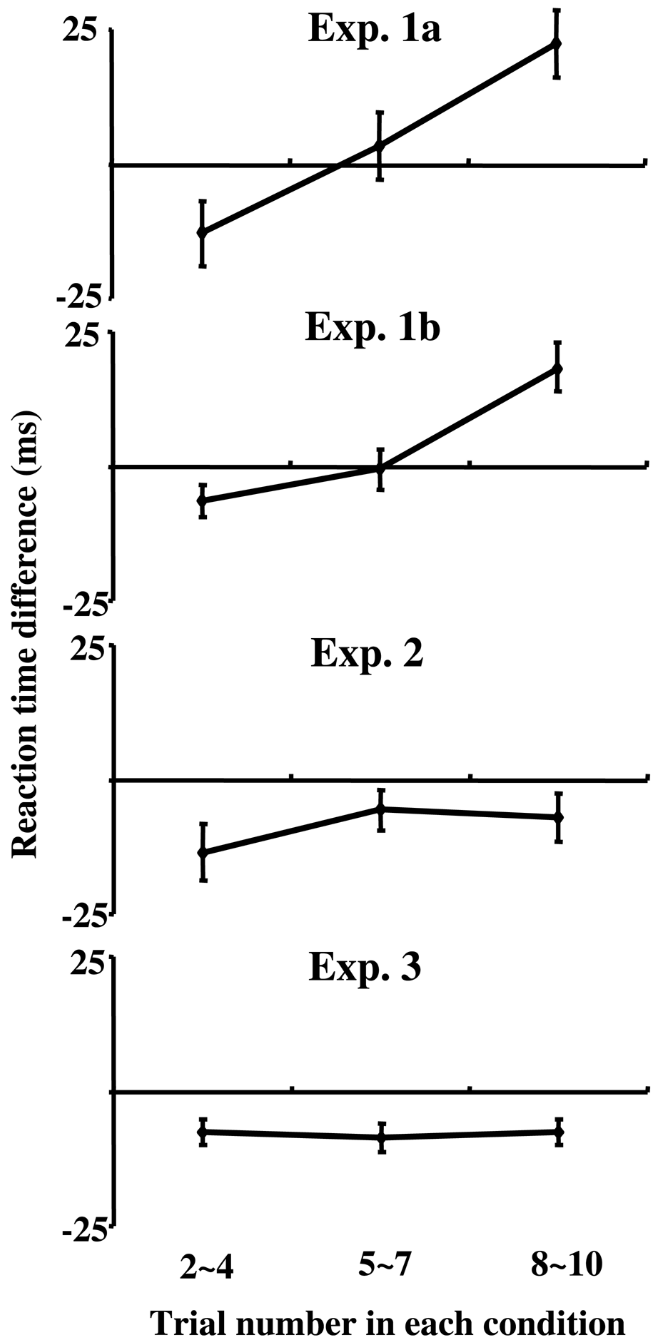

Figure 3.

Reaction time results as a function of within condition trial number (position) in Experiment 1–3. All results are collapsed over match versus mismatch trials, which did not interact with the position by repetition status interactions in any experiment. Trial number is not list position. Instead, trial number is the n^{th} occurrence of the repeated or nonrepeated condition within the list of 20 total trials, where n can take on values 1–10. Trial number 1 is not shown because it is not yet known which category is repeating at that point within the list (thus, there is no difference between the conditions). The remaining 9 trial numbers are broken into thirds. These results show reaction time differences between correct median RT to repeated conditions minus correct median RT to nonrepeated conditions. Experiments 1a and 1b both show a transition from benefits to deficits for the repeated condition as a function of increasing trial number. In contrast, Experiments 2 and 3 only show benefits for the repeated condition regardless of trial number.

Table 1

Cue-target trial types.

	Experiment 1a	Experiment 1b	Experiment 2	Experiment 3
Repeated match	A-a	A-a	a1-a2	a-a
Repeated mismatch	A-b	A-b	a3-b1	a-b
Nonrepeated match	C-c	C-c	c1-c2	c-c
Nonrepeated mismatch	B-a	D-a	d1-a4	d-a

Note. Upper case indicates category label, lower case indicates category exemplar, different letters indicate different categories, and different numbers indicated different exemplars within the category.

Table 2

Reaction Times for Correct Responses (in ms).

Experiment	Condition	Trial 2 – 4		Trial 5 – 7		Trial 8 – 10	
		Mean	SEM	Mean	SEM	Mean	SEM
1a	Repeated match	595.02	14.20	608.20	17.37	619.79	16.88
	Repeated mismatch	632.24	15.06	649.80	17.50	658.71	18.83
	Nonrepeated match	603.73	17.48	613.23	17.05	609.06	16.03
	Nonrepeated mismatch	646.44	19.80	637.32	17.60	629.15	15.12
1b	Repeated match	578.77	12.29	585.66	11.10	603.94	11.98
	Repeated mismatch	601.84	11.45	620.54	13.01	632.75	13.62
	Nonrepeated match	585.96	11.70	593.53	11.17	588.81	11.16
	Nonrepeated mismatch	611.85	13.20	618.24	13.41	615.37	13.35
2	Repeated match	555.43	12.00	577.49	14.94	584.82	13.96
	Repeated mismatch	598.56	12.88	612.38	13.41	623.97	14.35
	Nonrepeated match	574.62	15.03	585.46	13.18	594.87	15.57
	Nonrepeated mismatch	607.02	15.34	622.40	16.98	627.41	17.17
3	Repeated match	412.94	6.96	418.80	6.43	422.24	7.29
	Repeated mismatch	424.15	8.01	427.53	7.96	434.12	8.15
	Nonrepeated match	419.76	7.42	422.34	7.17	425.90	7.15
	Nonrepeated mismatch	431.03	8.19	439.40	8.74	446.05	9.35

Note. SEM = Standard Error of the Mean.

Table 3

Accuracy (proportion correct).

Experiment	Condition	Trial 2 – 4		Trial 5 – 7		Trial 8 – 10	
		Mean	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
1a	Repeated match	.94	.007	.95	.007	.94	.007
	Repeated mismatch	.94	.008	.95	.007	.94	.009
	Nonrepeated match	.94	.009	.93	.007	.93	.009
	Nonrepeated mismatch	.92	.009	.91	.008	.93	.007
1b	Repeated match	.93	.006	.94	.006	.95	.006
	Repeated mismatch	.96	.005	.96	.005	.97	.004
	Nonrepeated match	.93	.008	.93	.006	.94	.006
	Nonrepeated mismatch	.91	.008	.93	.006	.92	.011
2	Repeated match	.94	.007	.95	.006	.95	.005
	Repeated mismatch	.95	.006	.95	.004	.95	.005
	Nonrepeated match	.91	.008	.92	.007	.92	.008
	Nonrepeated mismatch	.93	.006	.93	.007	.94	.006
3	Repeated match	.92	.010	.93	.010	.93	.009
	Repeated mismatch	.94	.006	.94	.007	.94	.009
	Nonrepeated match	.90	.010	.90	.011	.90	.010
	Nonrepeated mismatch	.92	.007	.92	.008	.93	.008

Note. SEM = Standard Error of the Mean.