BACKWARD ASSOCIATIVE PRIMING RELIES ON AN AUTOMATIC SEMANTIC MATCHING PROCESS

by

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ABSTRACT

Backward (BA) priming, which is the facilitated recognition of targets that have a backward association with the prime (e.g., *baby-stork)*, is said to occur due to a semantic matching process that is only engaged in the LDT at long SOAs (Neely, Keefe, & Ross, 1989). However, BA priming occurs at short SOAs and in other tasks (Kahan, Neely, & Forsythe, 1999), suggesting that it may rely on an automatic process. A lexical decision task was administered in which a nonword relatedness proportion (NWRP) was created, such that 50% of nonwords were related to their primes (e.g., *boy-girk*), and participants were warned that checking for a relation will not be helpful for task performance. For unmasked (but not masked) primes, BA priming occurred even when conditions (i.e., high NWRP and warning) decreased the utility of a semantic matching strategy. This suggests that BA priming relies on an automatic semantic matching process that requires a conscious prime. Furthermore, analyses of integrative priming (e.g., *log-house*) suggest that INT priming relies on a hybrid prospective/retrospective process.

BACKWARD ASSOCIATIVE PRIMING RELIES ON AN AUTOMATIC SEMANTIC MATCHING PROCESS

It is well established that context is essential for language comprehension. For instance, when reading, the context provided by surrounding words can be crucial to determining the meaning of an unknown word (Nagy, Anderson, & Herman, 1987). The associations between concepts can be especially helpful in facilitating understanding. For instance, in a lexical decision task (LDT) or pronunciation task, participants are faster to recognize a word (e.g., *dog*) when it is preceded in context by a related concept (e.g., *cat*), relative to an unrelated concept (e.g., *table*). This phenomenon is known as the semantic priming effect, which occurs in any cognitive task involving recognition or retrieval from semantic memory (for reviews, see Hutchison, 2003; McNamara, 2005). Thus, understanding semantic priming is important for appreciating the role of semantic context in performance.

Neely, Keefe, and Ross' Three Process Model of Priming

The Three Process Model (Neely, Keefe, & Ross, 1989; Neely, 1991) attributes priming to three processes: (1) automatic spreading activation (ASA), (2) expectancy generation, and (3) semantic matching. Given that some priming effects presumably rely on a combination of these processes, they are not mutually exclusive. Furthermore, the three processes vary in directionality (whether the process occurs before or after target activation) and controllability (whether the process is automatic or strategic).

Consequently, there are several classes of priming, consisting of all combinations of directionality (prospective, retrospective) and controllability (automatic, strategic). In the upcoming sections, I will describe the three processes and evaluate the evidence for each.

ASA, which explains priming as an unconscious and rapid "spread of activation" from the prime to associated concepts, is frequently evoked as an explanation for automatic priming. According to the theory, activating a prime concept lowers the perceptual threshold of recognition for related concepts (Collins & Loftus, 1975). Activation decays over a delay and as concepts become more distant in the network. Thus, *cat* has greater activation when preceded by *dog* compared to *table,* as *cat* and *dog* are more related than *cat* and *table*, and the link between *cat* and *dog* has greater accessibility from frequent use.

In contrast to ASA, expectancy generation relies on anticipating what target words might plausibly follow the prime (Neely, 1977; Neely, 1991). For instance, subjects might reasonably predict that *bone*, *cat*, and *house* could follow the presentation of the prime *dog*. If the target item is in the expectancy set, responses are speeded, whereas responses could be slowed if the expectancy set does not contain the target, depending upon the size of the generated set (Becker, 1980; 1985). Given that expectancy involves using the prime to predict targets, expectancy generation must occur prospectively (before the target is activated).

There is strong evidence that expectancy generation is modulated by the relatedness proportion (RP), defined as the proportion of word target trials in which the prime and target share a relation (Neely et al., 1989). If there is enough time for expectancy to occur, priming effects increase as a function of RP (de Groot, 1984; den Heyer, Briand, & Dannenbring, 1983; Stolz & Neely, 1995; Tweedy, Lapinski, & Schvaneveldt, 1977, see Hutchison, 2007, for a review). Furthermore, the relationship between RP and the magnitude of priming suggests that participants increase expectancy generation as more primes validly predict targets, consistent with a strategic expectancy process.

In addition to these two prospective processes (spreading activation and expectancy), Neely and Keefe (1989) described a retrospective process that occurs in the LDT, a task which requires subjects to respond whether the target item is a word or nonword (NW). In this process, known as *semantic matching*, participants assess the prime and target for a semantic relation in order to assist their binary LDT response. Given that only word targets are truly related to their primes, detecting a relation indicates that the target will be a word. Similarly, the absence of a relation biases a NW response for the target, because most unrelated prime-target pairs contain NW targets. This strategy also slows responses to word targets that follow semantically unrelated primes (e.g., *brother-supper*), boosting the overall priming effect (de Groot, 1984; Neely, 1991).

The role of semantic matching in priming suggests that priming effects in the LDT rely partially on the conditional probability that a target is a nonword, given that it is unrelated to the prime. This is known as the nonword ratio (NWR; Neely et al., 1989). Mathematically, NWR can be described as the ratio of NW targets to total unrelated targets. Consider how the NWR affects a typical trial in a standard LDT, a task in which participants indicate if the target item is a word or a nonword (for a schematic, refer to Figure 1). Imagine an LDT with a stimulus list containing 100 word targets and 100 NW targets. Under these conditions, half of the word targets are related to the prime, and thus the RP is .5. However, because all NW targets are unrelated to the prime, the target is a NW in two-thirds (100/150) of the instances where the prime and target are not related. Thus, when no prime-target relation is found, there is a 67% chance that the target is a NW.

However, it is difficult to increase the NWR without also raising the RP, as they are typically confounded. To demonstrate how the confound might occur, imagine that you have 16 trials: 8 with NW targets, 4 with related word targets, and 4 with unrelated word targets. As 4 of 8 word targets have related primes and 8 of 12 unrelated trials have nonword targets, this yields an RP of .5, and an NWR of .67. To raise the RP to .75, you could convert two of the unrelated word targets into related word targets. However, this would also increase the NWR to .8, because now 8 out of 10 unrelated trials contain nonword targets.

Neely et al. (1989) unconfounded RP and NWR by increasing or decreasing the number of NW targets while keeping RP constant. Their results revealed that NWR and RP both contribute to priming and that the typical confounded RP effect in LDT was due to a combination of both the increased NWR and increased RP. Given this consistent increase in priming that occurs with increased NWR, and the fact that a long SOA is supposedly required to utilize this increase in NWR, semantic matching is thought to be a strategic process.

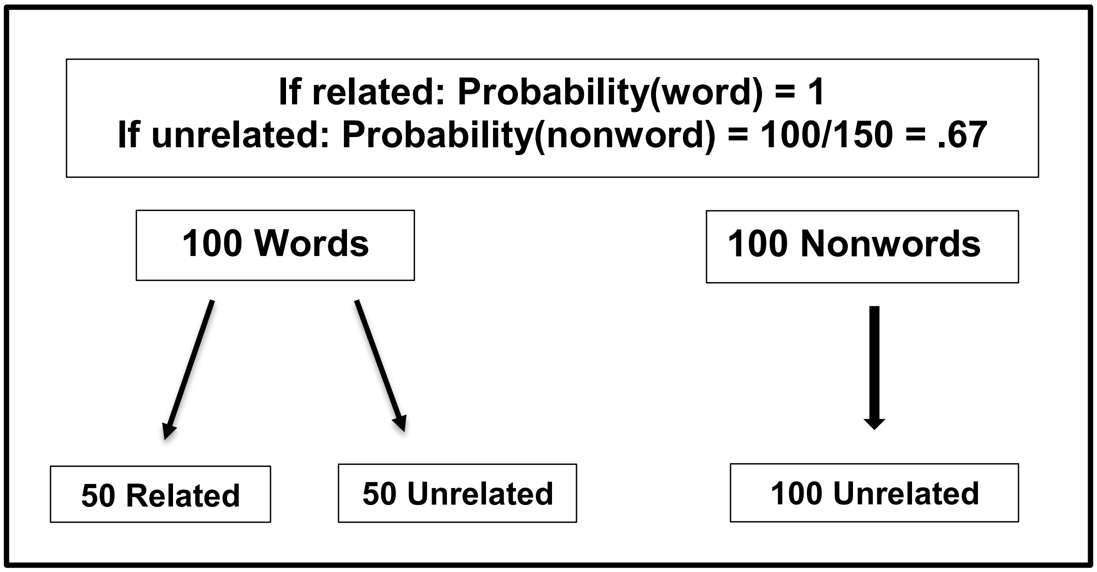

Figure 1. How NWR Predicts Lexical Decision in Standard LDT

Evidence for the Three Process Model

As illustrated by the previous section, three different processes can contribute to semantic priming. To review, there are two strategic process (expectancy generation and semantic matching), and one automatic process (ASA). Evidence that each of these three processes contribute to priming come from studies that found priming under conditions in which one of the processes is presumably isolated.

Automatic Spreading Activation

Many studies tested for the existence of ASA by testing if priming can occur merely by indirect association. To accomplish this, they used mediated priming, a class of priming in which targets are related to the prime via an intervening concept (e.g., LION-STRIPES). Combining the results from several studies, mediated priming rarely occurs when there are strong associations between both the prime and the mediator (e.g., LION and TIGER) and the mediator and target (e.g., TIGER and STRIPES; Balota & Lorch, 1986; de Groot, 1984; McNamara & Altarriba, 1988). Note that the strength of association between primes and their targets is determined by the percentage of respondents that would respond with the target item (*cat*) as the first word that comes to mind when provided with a cue (*dog*; Hutchison, 2003). In most semantic priming studies, associative items come from databases that norm items for associative strength.

Because *stripes* is unlikely to be generated when *lion* is presented (lions do not have stripes), an expectancy generation process is unlikely to explain mediated priming. Furthermore, mediated priming has also been found in tasks that exclude semantic matching. For instance, McNamara and Altarriba (1988) found mediated priming in a sequential (continuous) LDT, in which a response is required for both primes and targets. This procedure makes it difficult to check back for a relation, which should reduce the ability to use relatedness to predict the LDT response. Indeed, when stimuli are presented one at a time (as in a sequential LDT), there is only a .37 probability of the target being a NW when the item on the preceding trial is unrelated. Given that mediated priming still occurs when a semantic matching or expectancy strategy are unlikely to occur (or be helpful), mediated priming is best explained by automatic activation that spreads from the prime to the mediator, and then from the mediator to the target (but see Jones, 2010 for an alternative semantic matching account of mediated priming).

In addition to being evoked as the mechanism for mediated priming, ASA is also suggested by the "irrational" nature of priming in some tasks. Priming often occurs even when it is not useful to the task goal. For instance, when participants were presented with word fragments that required completion with the letter a or e (for instance, sh_ve; completed as *shave*), fragment completion was slower if it was preceded by a prime that was semantically related to a prohibited fragment solution (e.g., push; Heyman, Hutchison, & Storms, 2016). Given that primes were never related to a valid completion, they should be ignored if priming is strategic. Moreover, this inhibitory priming effect suggests that priming can occur without intention. This “irrational” nature of activation is consistent with an automatic mechanism (i.e., ASA) that occurs unintentionally, regardless of task demands.

Expectancy Generation

In contrast to an automatic process like ASA, expectancy generation is a supposedly strategic process that increases priming as long as the RP is high, and there is enough time between the onset of the prime and the onset of the target (i.e., the stimulus onset asynchrony, SOA) to permit such generation. However, if expectancy generation is indeed strategic, it should be a flexible process that can be engaged intentionally when needed in the task. To test this possibility, Hutchison (2007) manipulated RP within-subjects and within-block by presenting primes in either green or red ink, with the prime color corresponding to the probability that the target will be related (i.e., 25% probability of a relation for red, 75% probability for green). An RP effect was found, suggesting that participants were able to use the color of the prime to decide whether to engage expectancy generation for that trial, consistent with a strategic process.

Evidence for a strategic expectancy process is bolstered by data showing that expectancy is modulated by an individual's degree of attentional control (AC; Hutchison, 2007). AC is a measure derived from a battery of attentional (e.g., Stroop) and working memory tasks (e.g., Operation Span). Given that expectancy requires maintaining concepts that could plausibly follow the prime in memory, it logically follows that AC might modulate the ability to use the strategy effectively. In the Hutchison (2007) study, RP increased linearly with AC, suggesting that high-AC individuals (who are better at generating and maintaining information) more effectively utilize expectancy generation, consistent with a strategic process.

Furthermore, there is also a relationship between AC and types of priming that supposedly rely on expectancy. The Three Process Model claims that priming for forward associated (FA, e.g., *lollipop-candy*) pairs, which have a strong prime-to-target association but a weak or null target-to-prime association, is partially due to expectancy. In contrast, priming for backward associated (BA; e.g., *baby-stork*) pairs, which contain a strong target-to-prime association strength but a weak or null prime-to-target association strength, should not rely on expectancy (because stork is not likely to be predicted to follow baby). In line with this assertion, FA, but not BA, priming attenuated when participants were under high working memory load (remembering a complex dot matrix pattern; Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2015). Furthermore, individuals high in AC had significantly higher FA priming compared to individuals low in AC (Hutchison, Heap, Neely, & Thomas, 2014). Adding to this line of evidence, a link between AC and expectancy has also been replicated in the Stroop task (Ortells, Álvarez, Noguera, Carmona, and de Fockert, 2017; Ortells, de Focket, Romera, & Fernández, 2018).

Taken together, the evidence suggests that expectancy generation is in fact strategic. First, expectancy generation is said to take time (Neely, 1977), and strategies are said to be time-consuming. Second, even when RP varies trial by trial, expectancy generation occurs. This suggests it can be engaged flexibly as needed for the task. Finally, FA priming (which relies on partially on expectancy) decreases when participants are expending attentional resources on another task. This indicates that expectancy generation relies on AC, consistent with a strategic process.

Semantic Matching

In addition to processes that exert their influence before target activation (e.g., expectancy), priming can also be influenced by a semantic matching process that occurs after the target is presented. A critical piece of evidence for semantic matching is that it provides a suitable explanation for BA priming. Because BA priming relies on activation that flows from the target back to the prime (stork gives more activation to baby than baby gives to stork), it cannot rely on a forward acting process such as ASA or expectancy. Although other models of priming have been evoked to explain BA priming (e.g., compound cue; Ratcliff & McKoon, 1988), semantic matching is the most commonly evoked explanation (Hutchison, 2003; Neely, 1991).

Semantic matching is frequently referred to in the literature as “strategic semantic matching” and, in fact, some evidence suggests that this process is indeed strategic. For instance, Neely (1977) identified a *nonword facilitation effect,* described as faster responding to a NW following an unrelated prime relative to a neutral prime (e.g., XXXX). This nonword facilitation effect explains how NWR contributes to performance in the lexical decision task. Recall that boosting the NWR increases performance by increasing the utility of a strategy that biases a nonword response when a prime-target relation is absent. The ability to engage semantic matching to a greater degree when it is helpful to the task suggests a strategic process.

However, nonword facilitation is said to occur only at long SOAs (Favreau & Segalowitz, 1983; Neely, 1977; Neely & Keefe, 1989; Neely, 1991), suggesting that time is required for semantic matching to occur. Given that BA priming relies on semantic matching, it can be used to test predictions related to the process. This can be combined with manipulating the SOA, which differentiates between automatic and strategic processes; if a process occurs at a short SOA, it is probably not strategic, because strategies should be time consuming. Consistent with *strategic* semantic matching, many studies confirmed that BA priming does occur at long SOAs (>450 ms; Kahan et al., 1999; Seidenberg, Waters, Sanders, Langer; 1984; Shelton & Martin, 1992).

However, I am only aware of two studies that have tested if BA priming occurs in a standard lexical decision task at a short SOA (<300 ms). Thompson-Schill, Kurtz, and Gabrieli (1998) observed 17 ms of BA priming in two separate experiments, yet failed to report the contrasts. Kahan et al. (1999) found 30 ms of reliable BA priming at a 150 ms SOA. This latter finding challenges the notion that semantic matching is strategic.

Two Problems for the Three Process Model:
Backward and Integrative Priming

Although the Three Process Model accounts for many findings in the literature, there are issues that require attention. For instance, there is some debate about the mechanism for BA priming. The Three Process Model claims that BA priming relies on a process that is engaged only when it aids performance in the LDT. Yet, such a slow-acting and strategic semantic matching process cannot account for BA priming that occurs at short SOAs and in other tasks (e.g., Kahan et al., 1999). Thus, there are some BA priming results that are incompatible with the semantic matching process described in the model.

Is BA Priming Truly Strategic? Given the inconsistent data for BA priming, it may be premature to say that it relies on a strategic semantic matching process. Semantic matching has long been thought to be a strategic (Neely et al., 1989) and time-consuming (Neely & Keefe, 1989) process that is used based on whether it will improve performance in the LDT. Indeed, the argument for a strategic semantic matching process hinges largely on the assertion that BA priming is said to only occur at long SOAs in the LDT. However, BA priming has been found at short SOAs (200 ms or less; Chwilla, Hagoort, Brown, 1998; Kahan et al., 1999; Peterson & Simpson, 1989; Thompson-Schill, Kurtz, & Gabrieli, 1998) and in pronunciation tasks (Kahan et al., 1999; Peterson & Simpson, 1989). Thus, semantic matching can occur rapidly, and occurs even when it is not helpful in making a binary lexical decision.

Furthermore, if NWR reflects strategy use, participants under high cognitive load or with low AC should exhibit smaller priming effects for BA priming, given that strategies consume attentional resources. Yet Hutchison et al. (2014) found that low-AC individuals, in fact, had a marginal advantage over high-AC individuals for BA priming in the slowest RTs. Adding to this argument, research examining attentional demands also challenges the assertion that BA priming is strategic. Simply put, if BA priming is strategic, BA priming should rely on attentional control (AC; Hutchison, 2007), which reflects an individual's ability to maintain information in memory in the face of interference. However, no significant difference in BA priming was found between low-AC and high-AC participants (Hutchison et al., 2014). Furthermore, BA priming does not dissipate when participants are engaged in a secondary task (Heyman et al., 2015). The fact that BA priming does not rely on AC suggests it is an automatic process. Consequently, it is unknown whether the semantic matching process is strategic, as previous findings from the priming literature suggest (i.e., Neely et al., 1989), or automatic (as findings from AC studies suggest).

What is the Mechanism for Integrative Priming? Another issue with the Three Process Model is its failure to provide an explanation for integrative (INT) priming. INT priming (Estes & Jones, 2009; Jones, Wurm, Calcaterra, & Ofen, 2017) is described as faster responding to target words (e.g., *hat*) that are preceded by a prime that can plausibly be combined with it to form a subtype (e.g., *plastic*), relative to a concept that cannot be plausibly combined (e.g., *binder*). Integrative concepts can be combined in many ways, including temporally (e.g., *summer vacation),* causally (e.g., *rope burn*), or spatially (e.g., *park bench*). Unlike traditional semantic priming, which is said to rely either on association strength (e.g., *salt-pepper*) or feature overlap (e.g., *cow-sheep*), INT priming occurs due to *relational integration*, which is said to occur automatically during lexical processing and facilitate recognition of the target. Relational integration occurs when the word pair both elicits priming and reflects a subclass of the target item. For instance, a *dog park* denotes a subclass of parks that are dog-friendly, differentiating it from other parks that may not be as suitable for (or allow) dogs.

In a seminal study, Estes and Jones (2009) established the INT priming effect, confirming that relational integration influences lexical processing. Furthermore, they found evidence suggesting that INT priming is automatic, as it was equal at both low (.25) and high (.75) RP and occurred regardless of whether lists included many or few integrative items. In addition, integration has been found in a Stroop priming task (Mather, et al., 2014, Experiment 2). In that study, participants were presented with primes, which shared (or did not share) an integrative relation with their targets. Considering the goal of the Stroop task is to name the color, attending to prime words are never helpful for performing well in the task. Thus, if INT priming is strategic, it should not occur in tasks in which integration decreases task performance. Indeed, color naming was slower and less accurate following integrative primes relative to unrelated primes, suggesting that integration occurs automatically.

Taken together, the null RP effect and Stroop priming results suggest an uncontrollable automatic mechanism for integrative priming. However, it may be premature to describe INT priming as a strictly automatic process. Only a handful of studies on INT priming have been conducted to date, and to my knowledge, no study has examined a relationship between INT priming and NWRP. If INT priming is affected by high NWRP or the presence of a warning, it would suggest that INT priming can be controllable under some conditions, inconsistent with a purely automatic account of integrative priming. Furthermore, the one study that has addressed the controllability of INT priming (e.g., Estes & Jones, 2009; Experiments 3-4) used exclusively integrative stimuli as the critical items. With that in mind, it remains possible that integration will not occur automatically when a high proportion of items in the study cannot be successfully integrated (as would be the case in the current study). This would challenge the notion that INT priming occurs entirely due to *automatic* relational integration.

Even if the automaticity of INT priming were to be assumed, ASA is the only automatic process in the Three Process Model, and thus is the only potential explanation from the model. Yet an ASA explanation is unlikely, as INT priming occurs in absence of a prime-target association or semantic similarity between concepts. In fact, most integrative pairs (e.g., *leaf nest*) have a weak or null associative strength. For instance, *steel* primes *scissors*, yet neither concept strongly evokes each other. Given that priming due to ASA requires a prime-target association, ASA cannot account for INT priming. Consequently, none of the three processes in the model constitute a suitable mechanism for INT priming.

Present Study

The present study examines two processes that impact lexical processing; semantic matching, and relational integration. Much of the priming literature suggests that semantic matching is a strategic process. If it is, it should be controllable, and employed only when it benefits in assisting a binary LDT response. However, if semantic matching still occurs when these criteria do not exist, that would suggest that it occurs automatically. To test whether semantic matching is controllable, I created a condition in which half of the NWs are "related" to the target (e.g., *ketchup-mastard*) by replacing a single letter in the related target to create a nonword in which the target is the only orthographic neighbor. Given that nonwords activate their orthographically similar word neighbors (Davis & Lupker, 2006, Forster & Hector, 2002), seeing *mastard* should activate *mustard*, allowing participants to detect its relation to ketchup.

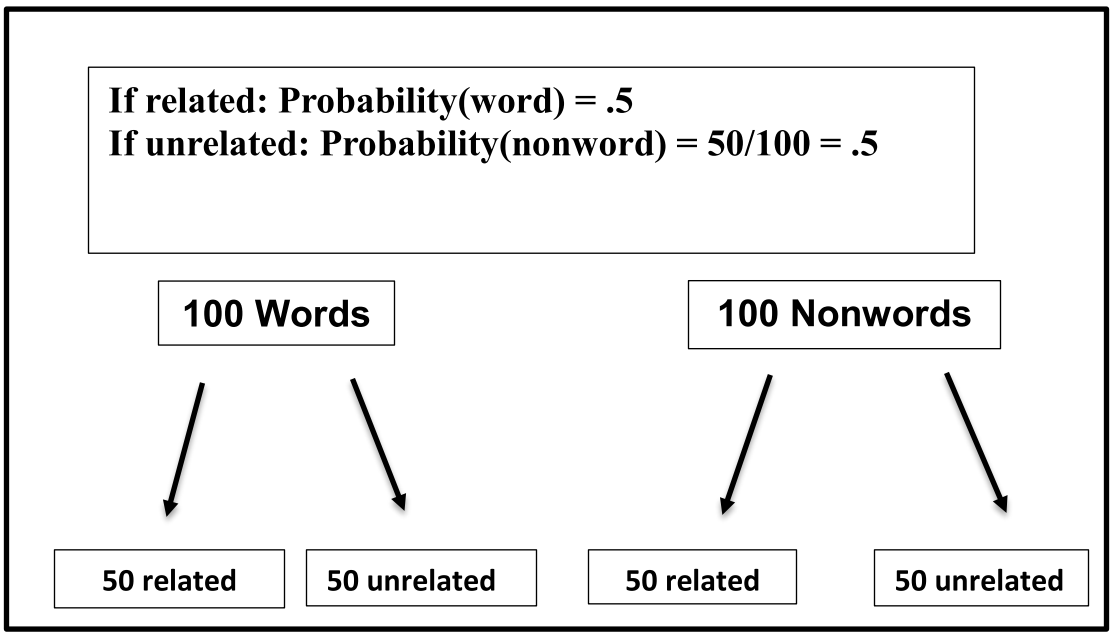

Figure 2. How High NWRP Predicts NWR in the Standard LDT

This results in a nonword relatedness proportion (NWRP), or the probability that a target is a NW, given that it is related to the prime. To illustrate how raising the NWRP affects NWR in the LDT, refer to Figure 2. Put simply, high NWRP decreases the utility of a semantic matching strategy, making it no longer helpful in predicting if a target is a word or not.

Recall that semantic matching is the only process in the Three Process Model that can explain BA priming. Consequently, if semantic matching is a strategic process, BA priming should decrease under high NWRP conditions that should decrease the utility of the strategy. However, if BA priming is unaffected by high NWRP, finding BA priming under such conditions means that semantic matching occurs even when it does not boost performance in the LDT, suggesting it is uncontrollable.

Furthermore, if semantic matching is a strategic process, it should not be used when instructions discourage use of the strategy. To test this, I also included a third condition that includes both a high NWRP and a warning that checking back for a relation will not be helpful for task performance. If BA priming occurs despite both high NWRP and a warning that checking for a relation will not be helpful, this would strongly suggest that semantic matching occurs unintentionally, and thus automatically. Importantly, if BA priming is due to an automatic process, that would explain past studies that found BA priming at short SOAs, and in tasks like pronunciation that do not require a binary response.

As discussed in the previous section, creating "related" nonwords will allow us to test if semantic matching is uncontrollable. If semantic matching is uncontrollable, then searching for a relation between a nonword (e.g., *mastard*) and the preceding prime (e.g., *ketchup*) would slow responses for NW targets. Thus, any automatic semantic matching would hinder performance in the LDT, resulting in inhibitory NW priming for the 50% NWRP condition. However, if semantic matching is strategic, it should not occur when it is not useful, and no inhibitory NW priming should occur.

Given that an automatic semantic matching process should lead to both positive BA priming and negative NW priming, there should be a correlation between these two types of priming. To test this, I will conduct correlational analyses to examine the relationship between NW priming and BA priming. This is important because the processes for NW priming and BA priming are similar in that they both require inferring a relation between the prime and target after the target is presented. However, because NW priming is inhibitory and BA priming is facilitative, the correlation should be negative. Alternatively, if no significant correlation is found between BA and NW, this could suggest that BA and NW priming rely on different processes (assuming adequate reliability of both types of priming), suggesting that BA priming is not automatic.

This allows us to test assumptions of the Complementary Role Activation (Mather, Jones, & Estes, 2014) model of INT priming. According to this model, INT priming could occur prospectively, retrospectively, or both. In the prospective process, the prime activates (e.g., *glass*) its most typical role, which activates its complementary roles (e.g., *glass* is a material). Thus, *glass* would facilitate recognition of *jar* and *boat,* but not *smile* or *bag* (a *jar* could be made of *glass* but not a bag). Alternatively, INT priming could occur retrospectively, in which the prime and target are considered together. Once it is presented, the target is checked for how well it complements the prime (i.e., could a *jar* be made out of *glass*?). Consequently, the size of the INT priming effect is modulated by the speed in which the complementary roles are identified.

Turning to relational integration, the present study also allows us to test how manipulations that discourage strategic semantic matching affect INT priming. If INT is unaffected by the presence of related NWs on the stimulus list, that would confirm that INT priming does not rely on a strategic semantic matching process. However, if INT priming decreases under high NWRP, this would be consistent with a strategic semantic matching process contributing to INT priming. Furthermore, if INT priming is decreased by conditions of high NWRP and a warning that seeking a relation will not be helpful, this would suggest that integration can be under participant control when participants are made aware that integration does not aid task performance.

The correlational analyses can also examine the relationship between INT priming and other types of priming (e.g., FA priming) that have a known mechanism. Such correlations could provide information about the directionality of INT priming. It is well established that FA priming relies on prospective processes, BA priming relies on retrospective processes, and symmetric (SYM) priming relies on both (Neely, 1991). If INT priming is more correlated with FA priming, this would suggest that INT priming relies on a prospective process. However, if it is more correlated with BA priming, this suggests that INT priming relies on a retrospective process. Finally, INT priming could also occur from a combination of both prospective and retrospective processes, indicated by a correlation between INT priming and all three types of associative priming. Furthermore, these correlations may vary depending on the presence of high NWRP and/or warning. Given that INT priming should not rely on NWRP if it is due to an automatic process, these analyses could help determine the controllability of INT priming.

EXPERIMENT 1

Methods

Participants

A total of 192 English-speaking subjects at Montana State University participated as part of a requirement for an introductory psychology course. Data from six subjects were removed due to committing errors on at least 40% of words or NW trials. The final analysis included data from 186 subjects.

Design

The experiment was a mixed-factor design with relatedness and item-type (FA, BA, SYM, INT) manipulated within-subjects, and NWRP condition manipulated between-subjects (0% NWRP vs. 50% NWRP vs. 50% + warning NWRP). Stimuli were randomized from trial to trial for the entirety of the experiment. However, asymmetric (FA, BA, and SYM) items were placed in a separate block from INT block items. This is essential to the design, because many items that share an integrative relation (e.g., *rope burn*) lack association strength or feature overlap, and thus would be classified as unrelated in a list with a large proportion of asymmetric items. Other parameters (e.g., SOA and NWRP) were held constant between blocks. The dependent variables were reaction time (RT), reflected by speed of responding, and accuracy, which reflects error rate. A priming effect is defined by the difference between the unrelated RT and related RT for that target item.

Stimuli

The critical stimuli were 40 FA (e.g., *peel-orange*), 40 BA (e.g., *fire-blaze*), and 40 SYM (e.g., *black-white*) prime-target pairs selected from Thomas, Neely, & O'Connor (2012). Forty INT (e.g., *oak-desk*) pairs were selected from Jones et al. (2017). Stimuli were selected to ensure that association strength was equated for FA, BA, and SYM items. INT stimuli lacked forward and backward association strength, and consisted of 20 locative pairs (e.g., *island house*) and 20 compositional pairs (e.g., *plastic hat*). Targets were equated for length, baseline RT, and logarithmic contextual diversity (logCD) using values from the English Lexicon Project (Balota et al., 2007). Contextual diversity reflects the number of contexts in which a word is experienced. LogCD was used as the word frequency measure, because it better predicts RTs than standard word frequency, which reflects the number of experiences with a word (Adelman, Brown, & Quesada, 2006). Related non-words were created by selecting symmetrically associated filler pairs (e.g., *ketchup-mustard*) and changing one letter of the target (e.g., *ketchup-mastard*) with the constraint that the changed target did not create another word or pseudohomophone (e.g., *brane*). In the unrelated NW condition, related nonword targets were randomly repaired with other primes. To ensure counterbalancing of block order, relatedness and NWRP condition, 12 lists were created.

Procedure

Participants were run in groups of 1-2 in a quiet room and seated approximately 60 cm from a computer monitor. For each trial, subjects were instructed that they would see a fixation point (+), followed by an UPPERCASE word that is read silently. Next, they were told that they would see a white lowercase target letter string which would be either a word (apple) or a nonword (flirp). Participants were instructed to press the key labeled "W" (the M key on a standard keyboard) to indicate a word response and the key labeled "NW" (the Z key) for nonword responses, and to indicate their responses quickly and accurately. In the warning condition, instructions also informed participants that 50% of the nonword targets would be related to the prime (e.g, *boy-girk*), and hence searching for a relation between the prime and target would not help determine whether the target item is a word or not. Before critical trials began, a set of eight practice trials were administered. All stimuli were centered on the graphics monitor, using E-Prime 2 software (Schneider, Eschman, & Zuccolotto, 2002). The refresh rate of the stimuli was 59.495 ms. Items were presented randomly. Each trial started with a 600 ms fixation (+), followed by a prime displayed for 150 ms. Then a blank screen was presented for 650 ms, resulting in a stimulus onset asynchrony (SOA) of 800 ms. Rest breaks were self-paced and given after every 40 trials. Half the word targets were related to the prime in all conditions (e.g., *demon-devil*); however, in the 50% NWRP and 50% NWRP plus warning conditions, half of the NW targets were also related to the prime (e.g., *ketchup-mastard*). No primes or targets appeared more than once in the study.

<u>Preliminary Data Analysis</u>

Only correct responses were included in RT analyses. In line with previous studies (e.g., Hutchison et al., 2014), any reaction times that were below 100 ms or above 2000 ms were removed. Also, due to the tendency for positive skew in RT distributions, outliers were removed using a nonrecursive procedure described by Van Selst and

Jolicouer (1994). Through this procedure, 3.0% of correct RTs were removed. The semantic priming effect is calculated by taking the difference between the RTs or accuracies in the related and unrelated conditions.

Results

Associated Items

Table 1 presents the mean RT and error data for each prime type and in each NWRP condition. A 2 (Relatedness: related, unrelated) x 3 (Item-type: forward, backward, symmetric) x 3 (NWRP condition: 0%, 50%, 50% with warning) mixed ANOVA was conducted. In RTs, a main effect of relatedness was found, $F(1, 189) = 183.14$, $MSE = 2739.60$, $\eta^2_p = .49$, $p < .001$, indicating faster responses for targets that followed related primes compared to unrelated primes. A main effect of Item-type was also found, $F(2, 378) = 180.80$, $MSE = 2585.85$, $\eta^2_p = .49$, $p < .001$, indicating that overall RTs were faster for FA pairs compared to BA. Furthermore, there was a significant Item-type x Relatedness interaction, $F(2, 378) = 7.97$, $MSE = 2393.80$, $\eta^2_p = .04$, $p < .001$, indicating greater priming for SYM (53 ± 10 ms) and BA (46 ± 12 ms) compared to FA (26 ± 9 ms) pairs (± = 95% CIs). However, there was no three-way interaction, $F < 1$, $p = .773$ indicating that the advantage for SYM and BA priming did not differ across levels of NWRP.

Table 1. Mean Reaction Time (RT) and Percentage Error for the Priming Task: Related and Unrelated FA, BA, SYM, and NW pairs as a Function of NWRP

	NWRP					
	0% NWRP		50% NWRP		50% NWRP + warning	
Variable	*M*	%err	*M*	%err	*M*	%err
NW Unrelated	-	-	750 (20)	6.2 (0.7)	759 (20)	5.7 (0.7)
NW Related	-	-	756 (20)	7.4 (0.8)	772 (20)	7.5 (0.8)
NW Priming	-	-	**-6** (5)	**-1.1**✧ (0.6)	**-13*** (5)	**-1.7*** (0.7)
FA Unrelated	637 (17)	3.5 (0.6)	651 (18)	3.9 (0.6)	643 (18)	3.9 (0.6)
FA Related	612 (17)	1.9 (0.5)	621 (17)	2.7 (0.5)	620 (17)	1.5 (0.5)
FA Priming	**25*** (4)	**1.6*** (0.7)	**30*** (8)	**1.3** (0.7)	**23*** (8)	**2.4*** (0.7)
BA Unrelated	718 (20)	11.3 (1.1)	725 (20)	11.3 (1.1)	726 (20)	12.1 (1.1)
BA Related	675 (17)	7.0 (0.9)	684 (17)	5.8 (0.9)	673 (17)	6.9 (0.9)
BA Priming	**43*** (10)	**4.3*** (1.2)	**41*** (10)	**5.5*** (1.2)	**54*** (10)	**5.2*** (1.2)
SYM Unrelated	675 (19)	6.8 (0.8)	690 (19)	6.8 (0.8)	690 (19)	6.3 (0.8)
SYM Related	629 (17)	3.3 (0.7)	632 (17)	3.0 (0.7)	634 (17)	3.6 (0.7)
SYM Priming	**46*** (8)	**3.5*** (0.9)	**58*** (8)	**3.8*** (0.9)	**56*** (8)	**2.7*** (0.9)

Note. FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; NWRP = Non-Word Relatedness Proportion. Standard error appears in parenthesis. As there are no related nonwords at 0% NWRP, there is no NW priming effect to measure. Bold font indicates unrelated-related conditions.
✧$p < .10$. *$p < .05$

For error analyses, there was a main effect of relatedness, $F(1, 189) = 93.081$, $MSE = .004$, $\eta^2_p = .330$, $p < .001$, indicating less errors for related targets compared to unrelated targets. There was also a main effect of Item-type, $F(2, 378) = 122.97$, $MSE = .003$, $\eta^2_p = .394$, $p < .001$, indicated by less errors for FA primes than BA primes. As in RTs, a significant Item-type x Relatedness interaction was found, $F(2, 378) = 9.87$, $MSE = .003$, $\eta^2_p = .050$, $p < .001$, indicating greater priming for SYM (3.4 ± 0.9%) and BA (5.0 ± 1.4%) pairs compared to FA (1.8 ± 0.7%). As in RTs, there was no three-way interaction, $F < 1$, $p = .644$, indicating that the advantage for SYM and BA did not differ across levels of NWRP. Importantly, the error data exhibited the same pattern as RTs.

For nonword RTs, related NWs (764 ± 28 ms) were recognized significantly slower than unrelated NWs (755 ± 28 ms), which was confirmed by a main effect of relatedness, $F(1, 126) = 7.108$, $MSE = 796.10$, $\eta^2_p = .053$, $p = .009$. This inhibitory effect of related NWs demonstrates the presence of semantic matching despite its reduced utility. However, the Relatedness x Warning interaction did not reach significance, $F = 1.297$, $p = .257$. Thus, NW priming was equivalent regardless of whether a warning was presented. The error effect mimicked the RT effects. There was once again a main effect of relatedness, $F(1, 126) = 10.222$, $MSE = .001$, $\eta^2_p = .075$, $p = .002$. Participants made also more errors in the related condition than in the unrelated condition. Finally, the Relatedness x Warning interaction was not significant, $F < 1$, $p = .510$, indicating that NW inhibitory priming did not differ across warning conditions.

Integrative Items

Table 2 presents the mean RT and error data for INT primes and NW primes in the integrative block. A separate 2 (Relatedness: related, unrelated) x 3 (NWRP condition: 0%, 50%, 50% with warning) mixed ANOVA was conducted. Crucially, there was a main effect of relatedness, $F(1, 189) = 8.25$, $MSE = 1791.81$, $\eta^2_p = .042$, $p = .005$, replicating the integrative priming effect found in past studies (e.g., Estes & Jones, 2009). There was no significant interaction between NWRP and Relatedness, $F < 1$, $p = .678$, indicating that the magnitude of INT priming did not significantly differ across the NWRP conditions. However, a pairwise comparison showed that INT priming was significant in the 0% NWRP condition ($p = .034$), marginal in the 50% NWRP condition ($p = .061$), and nonsignificant in the 50% with warning condition ($p = .342$).

Table 2. Mean Reaction Time (RT) and Percentage Error for the Priming Task: Related and Unrelated FA, BA, SYM, and NW pairs as a Function of NWRP

	NWRP					
	0% NWRP		50% NWRP		50% NWRP + warning	
Variable	*M*	%err	*M*	%err	*M*	%err
NW Unrelated	-	-	697 (21)	5.7 (0.8)	718 (21)	5.4 (0.8)
NW Related	-	-	710 (19)	6.0 (0.7)	707 (19)	5.1 (0.7)
NW Priming	-	-	**-13*** (6)	**-0.3** (0.9)	**11** (6)	**0.3** (0.9)
INT Unrelated	663 (21)	6.0 (0.7)	672 (21)	4.8 (0.7)	673 (21)	4.9 (0.7)
INT Related	648 (19)	4.8 (0.7)	658 (19)	3.6 (0.7)	666 (19)	3.6 (0.7)
INT Priming	**16*** (7)	**1.2** (0.8)	**14**✧ (7)	**1.2** (0.8)	**7** (7)	**1.3** (0.8)

Note. FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; NWRP = Non-Word Relatedness Proportion. Standard error appears in parenthesis. As there are no related nonwords at 0% NWRP, there is no NW priming effect to measure. Bold font indicates unrelated-related conditions.

✧$p < .10$. *$p < .05$

In errors, there was a main effect of relatedness, $F(1, 189) = 7.234$, $MSE = .002$, $\eta^2_p = .037$, $p = .008$, indicating that less errors were made in the related condition compared to the unrelated condition. As with RTs, the NWRP x Relatedness interaction was not significant, $F < 1$, $p = .992$, indicating no significant differences in INT priming between the three NWRP groups. This suggests that INT priming is unaffected by NWRP. Although the overall priming effect was significant, a pairwise comparison revealed no significant INT priming in the zero percent condition ($p = .121$), the 50% NWRP condition ($p = .146$), or the 50% NWRP + warning condition ($p = .103$).

For nonwords, separate 2 (Relatedness: related, unrelated) x 2 (Warning: warning, no warning) ANOVAs were conducted, comparing priming in the 50% NWRP and 50% NWRP with warning conditions. As there are no related nonwords at 0% NWRP, there is no NW priming effect to measure. There was no main effect of relatedness, $F < 1$, $p = .779$, indicating no inhibitory NW priming in the INT block. However, there was a significant Relatedness x Warning interaction, $F(1, 126) = 7.004$, $MSE = 1317.91$, $\eta^2_p = .053$, $p < .009$. Pairwise comparisons revealed that NW inhibitory priming occurred in the 50% NWRP condition ($p = .040$), but was numerically positive, yet non-significant ($p = .097$) in the 50% plus warning condition. Thus, NW priming occurred under high NWRP, but it attenuated under warning. In errors, there was no main effect of relatedness, $F < 1$, $p = .917$, nor was there a significant Relatedness x Group interaction, $F < 1$, $p = .647$. This indicates no difference in errors for related and unrelated targets in this block, and no difference across NWRP conditions.

Correlations

In addition to RT and error analyses, intercorrelations between several different types of priming (e.g., FA, BA, SYM) were conducted, following the logic that prime types that rely on the same processes should be correlated. These results can be found in Tables 3 and 4. To avoid spurious correlations that could result from individual differences in baseline RT, correlational data was analyzed using *z scores* (Hutchison, Balota, Cortese, & Watson, 2008). Thus, any RT findings described here refer to RTs first converted to *z scores.* The correlational analyses support the notion that BA priming relies on an automatic process. Specifically, there was a negative correlation between BA and NW priming in both the associative and integrative block, for both RTs and errors, irrespective of warning. This negative correlation also occurred in the 50% NWRP with warning condition, but only in errors. Given that a semantic matching process is responsible for inferring a relation in NW priming, a negative correlation between BA and NW priming suggests that BA priming relies on a similar process.

Table 3: Correlation Matrix for Z-score Priming in Experiment 1

0% NWRP	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	-.007	--				
3. SYM_prime	-.019	-.023	--			
4. NW_prime	--	--	--	--		
5. INT_prime	.047	.239✧	.070	--	--	
6. NW_INT_prime	--	--	--	--	--	--
50% NWRP	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	-.120	--				
3. SYM_prime	.315*	.114	--			
4. NW_prime	-.371**	.054	-.038	--		
5. INT_prime	.190	.044	.405**	-.014	--	
6. NW_INT_prime	-.237	.164	.131	.007	-.184	--
50% NWRP + warning	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	-.172	--				
3. SYM_prime	.439**	-.323**	--			
4. NW_prime	-.490**	.148	-.124	--		
5. INT_prime	.226	-.260*	.431**	.053	--	
6. NW_INT_prime	-.126	-.305*	.077	.070	-.028	--

Note. RTs = Reaction Times FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; INT = Integrative items; NW = Nonword; NW_INT= Nonword items in the INT block. ✧p < .10 *p < .05. **p < .01. There are no related NWs in the 0% NWRP condition, thus NW priming cannot be assessed.

Along with this significant negative correlation between BA and NW priming, there were also correlations between BA priming and other types of priming. In RTs, BA and SYM priming were positively correlated in both the 50% NWRP and 50% NWRP plus warning condition, suggesting that these two types of priming rely on a similar process when NWRP is high.

Table 4: Correlation Matrix for Errors in Experiment 1

0% NWRP	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	-.118	--				
3. SYM_prime	.129	-.065	--			
4. NW_prime	--	--	--	--		
5. INT_prime	-.197	.046	.031	--	--	
6. NW_INT_prime	--	--	--	--	--	--
50% NWRP	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	.247*	--				
3. SYM_prime	.124	.141	--			
4. NW_prime	-.167	-.317*	-.038	--		
5. INT_prime	.051	.023	.405**	-.014	--	
6. NW_INT_prime	-.301*	-.120	.131	.007	-.184	--
50% NWRP + warning	1	2	3	4	5	6
1. BA_prime	--					
2. FA_ prime	.269*	--				
3. SYM_prime	.161	.201	--			
4. NW_prime	-.308*	-.129	-.027	--		
5. INT_prime	-.065	-.178	.094	.040	--	
6. NW_INT_prime	.094	-.011	.206	-.001	-.015	--

Note. RTs = Reaction Times FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; INT = Integrative items; NW = Nonword; NW_INT= Nonword items in the INT block. $^*p < .05$. $^{**}p < .01$.There are no related NWs in the 0% NWRP condition, thus NW priming cannot be assessed.

In addition to providing information about the process for BA priming, these findings offer new insights about the nature of INT priming. In RTs, INT priming was positively correlated with SYM priming in both the 50% NWRP and 50% NWRP with warning conditions, suggests that INT priming could occur due to a combination of prospective and retrospective processes. There was also an unexpected pattern suggesting that INT priming relies on different processes depending on the NWRP. In the 0% NWRP condition, INT and FA priming were (marginally) correlated, whereas in the 50% NWRP and 50% NWRP plus warning conditions, INT priming was correlated with BA and SYM priming. This suggests that raising the NWRP can cause a shift away from prospective processes.

Discussion

Associative Items

I predicted that participants would detect an association between the prime and a related NW target. If semantic matching is used, this would bias a word response and slow responses to NWs targets. In line with this reasoning, there was a reliable NW priming effect, in which responses for related NW targets (i.e., *mastard* for the prime *ketchup*) were slower than NW unrelated targets (e.g., *camdle*). This NW priming effect serves as an important manipulation check, confirming that subjects did in fact notice related NWs. The ability to infer a relation between primes and related NW targets is necessary for my NWRP manipulation to prevent the bias towards responding nonword when a relation is absent. Given the NW inhibitory priming, I can conclude that raising the NWRP decreased the utility of semantic matching for associative items.

For word targets, a reliable semantic priming effect was found for all four prime types (BA, FA, SYM, INT) in all three NWRP (0%, 50%, 50% plus warning) conditions, for both RTs and errors. Crucially, BA priming remained stable across conditions, suggesting that BA priming is unaffected by NWRP. Of further interest, there was no significant difference in associative priming between the 50% NWRP and 50% NWRP plus warning condition, suggesting that the process for BA priming was unaffected by a warning that checking back will not be helpful. Thus, BA priming did not attenuate under conditions (i.e., high NWRP or high NWRP plus warning) in which inferring a relation no longer predicts target lexicality.

This pattern of results is inconsistent with a strategic semantic matching account, which would predict a *decrease* in BA priming in the 50% NWRP and 50% NWRP with warning conditions. However, BA priming remained intact despite the decrease in utility of this strategy. This suggests that BA priming occurs even when semantic matching is nondiagnostic of the target's lexicality, and thus is an automatic process. If BA priming relied on a controllable (i.e., strategic) process, it should not have occurred when semantic matching is not diagnostic of the correct target response, and especially not when participants are also explicitly warned such a strategy would not be useful. Yet, it seems that a search for a relation is conducted under these conditions of it not being helpful to the task. This uncontrollability is also consistent with an automatic process.

By showing that BA priming can occur even when semantic matching does not aid in performance on the LDT, these findings are consistent with past studies that have suggested a non-strategic retrospective integration process as the mechanism for BA priming (Chwilla et al., 1998; de Groot, 1984). Importantly, an automatic semantic matching process can account for BA priming that occurs at short SOAs, and in tasks that do not require a binary response (e.g., pronunciation; Kahan et al., 1999). Furthermore, the correlational analyses provided additional evidence that BA priming relies on an automatic process. NW inhibitory priming correlated with BA positive priming, suggesting the same automatic process for these two types of relations. Finally, the positive correlation between BA and SYM, which occurred for RTs only in the 50%

NWRP and 50% NWRP with warning conditions, suggests that SYM priming relies more on retrospective processes when the prime-target relations should be more salient (as in the high NWRP conditions).

Integrative Items

Experiment 1 provided valuable insight about the mechanisms for INT priming. In line with previous studies (e.g., Estes & Jones, 2009), a reliable integrative priming effect was found. Of greater importance, INT priming is seemingly unaffected by NWRP. Considering that INT priming is also insensitive to RP (Estes & Jones, 2009), the evidence provides confirmation that INT priming is automatic, as suggested by Mather et al. (2014). However, the results also suggest that NW priming in the INT block is sensitive to warning. Although significant NW inhibitory priming was found in the 50% NWRP condition, it was numerically positive (and non-significant) when a warning was provided. This suggests NW priming can be affected by a warning, at least when presented in a list where most targets are not associated with the prime. Given that NW targets were generated from symmetrically associated fillers, semantic matching could have been useful in this block, as detecting a prime-target association predicted a NW target response. It is possible that participants became aware of this strategy, which could explain why INT priming became numerically positive under warning,

Turning to the correlational data, a link was found between SYM and INT priming, suggesting that priming for these relations relies on a similar process (or processes). Recall that SYM priming relies on a combination of prospective (expectancy) and retrospective (semantic matching/automatic integration) processes, suggesting a similar combination of processes for INT priming. This is consistent with the Complementary Role Activation model (Mather et al., 2014), which left open the possibility that INT priming relies on “hybrid” prospective/retrospective processes. In further support of a hybrid process, the correlations for INT priming are influenced by NWRP and/or warning. This suggests that the presence of high NWRP shifted participants away from prospective mechanisms. It could be that INT priming in the standard LDT mostly occurs prospectively, but under high NWRP, relations between primes and their targets are more salient (as even many nonwords are related to their prime), possibly encouraging the use of a retrospective strategy in which the prime and target are considered is checked for whether they can be plausibly integrated.

EXPERIMENT 2

Taken together, results from Experiment 1 suggest that BA priming is best explained by an automatic semantic matching process. They also suggest that INT priming relies on a hybrid prospective/retrospective process, consistent with Complementary Role Activation theory. However, it is still unknown whether semantic matching relies on a visible prime. To address this issue, Experiment 2 will utilize masked priming. Masked primes are presented briefly and overlaid with a forward and backward mask, to limit perceptibility of the prime (for a review, see Kinoshita & Lupker, 2004). If semantic matching is an unconscious process, it should occur even when the prime is masked, and thus masked BA priming should occur. However, if it is a conscious process, participants should not check back to a prime that cannot be fully perceived.

Furthermore, the SOA and prime duration were lowered make the conditions in Experiment 2 more conducive to automatic priming. This could provide additional evidence against strategic semantic matching. Once again, if BA priming relies on a strategic process, it should not occur under conditions that reduce the utility of the strategy (i.e., high NWRP), or under conditions in which participants have an inadequate amount of time to use the strategy (i.e., brief SOA and prime duration).

Finally, the use of masked primes affords an opportunity to test a key prediction of ASA. ASA predicts that FA priming should occur even when primes are masked, because it partially relies on unconscious activation (McNamara, 2005; Neely, 1991). Given that, and the past studies which have found masked priming in the LDT, I expect to find both masked and unmasked FA priming. However, recent studies have questioned whether masked priming really relies on ASA. For instance, de Wit and Kinoshita (2015) found that masked priming magnitude varies with the task, inconsistent with ASA, which would predict equivalent masked priming in both tasks. Specifically, masked priming did not occur in the LDT but occurred reliably in a semantic categorization task, a task in which participants indicated whether targets are members of a certain category (e.g., living vs. non-living things). This suggests that participants use semantic information differently in the two tasks. Furthermore, there should be no RP effect if activation spreads automatically. Yet an effect of RP was found in the semantic categorization task, suggesting that priming in that task is not due to ASA. This RP effect, and the task difference in masked priming, suggest that masked priming does not occur due to ASA, and may not occur in the LDT at all.

Methods

Participants

A total of 151 English-speaking subjects from Montana State University participated as part of a requirement for an introductory psychology course. Four participants were removed for committing 40% errors on word or NW trials in either asymmetric or the integrative block. Thus, the final analyses included 147 participants.

Design

Experiment 2 utilized a mixed-design. Relatedness and Item-type (FA, BA, SYM) were manipulated within subjects, whereas masking was manipulated between subjects (masked vs. unmasked). All participants were tested under 50% NWRP. Again, items were presented randomly from trial to trial. The critical dependent variables were RT and error rate.

<u>Stimuli</u>

The same associative stimuli as Experiment 1 were used. In the masked condition, primes were overlaid with a forward and backward visual mask to prevent conscious identification of the target. Masks were alternated from forward (e.g., X#X#X#X#X) to backward (e.g., #X#X#X#X#) to further limit identification.

<u>Procedure</u>

The procedure was the same as Experiment 1, except for three important changes. First, integrative items were removed. Considering that masked priming is said to occur via ASA, it is unlikely that masked priming will be found for INT items, given that they lack association. Second, the warning condition was removed, as it is not needed to examine whether semantic matching is a conscious process. Finally, the SOA was shortened from 800 ms to 200, and prime durations were shortened to from 150 ms to 28 ms. I also equated the SOA in the masked and unmasked conditions. In masked trials, forward masks were presented for 500 ms, the prime was presented for 28 ms, backward masks were presented for 100 ms, and a black screen was presented for 72 ms. For unmasked trials, the prime was presented for 28 ms, followed by a 172 ms blank screen, allowing for conscious identification of the prime, while keeping the SOA at 200 ms. Participants were given the same instructions as Experiment 1, except that they were told a visual mask (#X#X#X#X) would follow the fixation.

Preliminary Data Analysis

Data were treated in the same fashion as Experiment 1. Through the Van Selst & Jolicouer (1994) procedure, 3.0% of correct RTs were removed.

Results

Table 5 presents mean RTs and error rates for each prime type, in both the masked and unmasked condition. To analyze both RTs and errors, a 2 (Relatedness: related, unrelated) x 3 (Item-type: forward, backward, symmetric) x 2 (Mask: visible, masked) mixed ANOVA was conducted. The RT data show a main effect of Relatedness, $F(1, 145) = 4.510$, $MSE = 3514.57$, $\eta^2_p = .030$, $p = .035$. Overall, related targets were responded to faster than unrelated targets. There was also a Mask x Relatedness interaction, $F(1, 145) = 14.353$, $MSE = 3514.57$, $\eta^2_p = .090$, $p < .001$, indicating that priming was significant in the unmasked (24 ± 11 ms) condition, $p < .001$, but not in the masked (-7 ± 12 ms) condition, $p = .243$. Finally, there was a significant three-way interaction, $F(2, 290) = 4.116$, $MSE = 2288.70$, $\eta^2_p = .028$, $p = .017$, indicating greater BA (30 ± 22 ms, $p = .007$) and SYM (35 ± 16 ms, $p < .001$) priming than FA (5 ± 13 ms, $p = .381$) priming for unmasked primes, but not for masked primes. Furthermore, a pairwise comparison found that masked priming was non-significant for all three prime-types. For errors, there was a main effect of Relatedness, $F(1, 145) = 4.510$, $MSE = .003$, $\eta^2_p = .036$, $p = .021$, as expected. This indicates more accurate responding to related targets relative to unrelated targets. There was also a trend toward greater priming in the unmasked condition than in the masked condition, indicated by a marginal Mask x Relatedness interaction, $F(1, 145) = 3.058$, $MSE = .003$, $\eta^2_p = .021$, $p = .082$. However, pairwise comparisons revealed that priming was significant for unmasked primes (*p* = .004), but not for masked primes (*p* = .684). There was also an Item-Type x Relatedness interaction, $F(2, 290) = 4.50$, $MSE = .002$, $\eta^2_p = .030$, $p = .012$. Collapsed across mask conditions, BA (1.7 ± 1.6%, $p = .034$) and SYM (1.3 ± 0.9%, $p = .010$) priming were larger than FA (-0.5 ± 0.6%) priming, which was non-significant ($p = .124$).

Table 5. Mean Reaction Time (RT) and Percentage Error for the Priming Task: Related and Unrelated FA, BA, SYM, and NW pairs as a Function of Mask

Condition	Unmasked		Masked	
Variable	*M*	%err	*M*	%err
NW Unrelated	848 (19)	7.0 (0.7)	850 (19)	6.1 (0.7)
NW Related	849 (19)	8.5 (0.8)	855 (19)	6.0 (0.8)
NW Priming	**-1** (5)	**-1.5*** (0.7)	**-5** (5)	**0.1** (0.7)
FA Unrelated	693 (14)	2.2 (0.4)	667 (14)	1.2 (0.4)
FA Related	688 (16)	2.8 (0.4)	669 (16)	1.7 (0.4)
FA Priming	**5** (6)	**-0.6** (0.7)	**2** (6)	**-0.5** (0.7)
BA Unrelated	789 (17)	10.1 (1.1)	750 (18)	6.9 (1.1)
BA Related	759 (18)	7.2 (0.7)	763 (17)	6.4 (0.7)
BA Priming	**30*** (11)	**2.9*** (1.1)	**-13** (11)	**0.5** (1.2)
SYM Unrelated	738 (15)	5.4 (0.7)	711 (19)	3.3 (0.7)
SYM Related	702 (16)	3.5 (0.5)	719 (17)	2.8 (0.6)
SYM Priming	**36*** (8)	**1.9*** (0.7)	**-8** (8)	**0.5** (0.9)

Note. FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; Standard error appears in parenthesis. Bold font indicates unrelated-related conditions.
✧$p < .10$. *$p < .05$.

In contrast to RTs, no three-way interaction was found, $F(2, 290) = 1.284$, $MSE = .002$, $\eta^2_p = .009$, $p = .279$. This suggests that priming magnitude did not differ between unmasked and masked primes. However, pairwise comparisons revealed the same pattern as in RTs. BA (2.9 ± 2.2% $p = .011$) and SYM (2.0 ± 1.3%, $p = .007$) priming, but not FA (-0.6 ± 1.0%, $p = .219$) priming, occurred in the unmasked condition. Conversely, no priming of any type occurred in the masked condition (*p*-values were non-significant for all three prime-types).

For NW RTs, a separate two-way ANOVA was conducted to compare priming effects for masked and unmasked targets. Unlike word targets, there was no main effect of relatedness, $F(1, 145) = 1.070$, $MSE = .750.40$; $\eta^2_p = .003$, $p = .303$, indicating no NW priming. In addition, there was no Mask x Relatedness interaction ($F < 1$). NW priming magnitude did not differ in the masked and unmasked conditions. For NW errors, there was no main effect of relatedness in errors, $F(1, 145) = 1.964$, $MSE = .002$, $\eta^2_p = .013$, $p = .163$, and a Mask x Relatedness interaction did not reach significance, $F(1, 145) = 2.713$, $MSE = .002$, $\eta^2_p = .018$, $p = .102$. However, pairwise comparisons revealed inhibitory priming in errors for unmasked targets ($p = .032$), but not masked targets ($p = .862$). This suggests that NW priming relies on a consciously identifiable prime.

Discussion

Experiment 2 provided additional evidence that BA priming relies on an automatic process. As in Experiment 1, BA (and SYM) priming occurred under high NWRP when primes were unmasked. This is inconsistent with strategic semantic matching, which predicts that semantic matching (and thus BA and SYM priming) should decrease when checking for a relation does not reliably predict if the target is a word or NW. Furthermore, BA priming occurred at 200 ms, inconsistent with the assertion that semantic matching is a slow-acting process. However, when primes were masked, no priming of any type occurred, suggesting that BA priming relies on a consciously identifiable prime. Consequently, BA priming is best attributed to an automatic process that relies on a visible prime. Put differently, participants check for a prime-target relation automatically, but only when participants are consciously aware of the prime. Finally, Experiment 2 examined if masked FA priming occurs in the LDT at a short SOA. Recall that the Three Process Model predicts that FA priming should occur under these conditions due to ASA. However, no masked FA priming was observed, inconsistent with ASA. Thus, masked priming is left without an explanation that is consistent with the Three Process Model.

EXPERIMENT 3

The findings in Experiment 2 suggest that BA priming relies on an automatic process that requires conscious awareness of the prime. However, the 28 ms prime durations may have too short for unconscious processing (and thus ASA). Thus, to increase potential processing of the primes, the prime duration was bumped to 38 ms in this experiment. Furthermore, a post-trial visibility check was added in which participants assess each prime's visibility. This procedure can test whether subjective awareness of the prime is necessary for BA (and other types of priming) to occur. If BA priming occurs under masked conditions (i.e., prime rated as unseen in the visibility check), this would suggest that semantic matching does not rely on conscious identification of the prime. However, if BA priming occurs only for subjectively aware primes (i.e., rated as fully perceivable in the visibility check), this suggests a conscious process, consistent with the findings in Experiment 2. Given that SYM priming is also presumed to partially rely on semantic matching, my predictions for BA priming also apply to SYM priming. As for FA priming, given that it did not occur in Experiment 2, it should not occur in Experiment 3 for unseen primes.

Methods

Participants

A total of 81 English-speaking subjects from Montana State University participated in the study, which was completed as part of a requirement for an introductory psychology course. Data from six subjects were removed due to committing errors on 40% of word or NW trials. Thus, the final analysis included data from 75 subjects.

Design

Experiment 3 utilized a within-subjects design. Relatedness and Item-type (FA, BA, SYM) were manipulated within subjects. All participants were tested under 50% NWRP, and all stimuli were masked. Again, items were presented randomly. The critical dependent variables were RT and error rate. The same stimuli from Experiment 2 were used.

Procedure

The SOA (200 ms) and masking procedure from Experiment 2 were maintained, allowing us to compare results across experiments. All primes are masked and presented for 38 ms. Also, a visibility check was also added to each trial, designed to probe the participant's subjective judgment of the prime's visibility (using a perceptual awareness scale, PAS; Overgaard, Rote, Mouridsen, & Ramsøy, 2006; Wierzchon, Paulewicz, Asanowicz, Timmermans, & Cleeremans, 2014). Participants rated the extent they could see the prime word under the mask, using the following scale; (1) I could not perceive anything; (2) I perceived a brief glimpse of something in between the two pattern masks; (3) I could perceive the outline of a word (but no letters); (4) I could perceive at least one (or several) letters quite clearly; (5) I could perceive most letters clearly; (6) I perceived the word entirely. To ensure that participants were actively engaging in the PAS, 5 catch trials were added. Because I did immediately think to include these at the start of the study, only 64 participants received these trials. For all catch trials, no prime was presented under the mask, and thus participants should indicate a 1 for these trials.

Preliminary Data Analysis

Data were analyzed in a similar fashion as Experiment 1 and 2. First, RTs below 100 ms were removed. Through the Van Selst and Jolicouer (1994) procedure, 2.5% of correct RTs were removed. In a slight deviation from Experiment 1 and 2, the top bound of the cutoff to eliminate RTs was set as 3000 (as opposed to 2000 in the other studies). This was because overall RTs were slower than in the other two experiments (see Table 6 for overall RTs for all 3 experiments). This could be from adding the PAS, as it required participants to make two responses (one for the target lexicality and one for the prime visibility) on each trial. The semantic priming effect was calculated by subtracting mean RT or percent error for related targets and from the mean RT or percent error for unrelated targets.

Table 6: RTs (± = 95% CIs) for Experiments 1, 2, and 3

Experiment	RT – Related Condition	RT – Unrelated Condition
1	642 ± 24	684 ± 20
2	739 ± 22	725 ± 21
3 (All Trials)	1075 ± 71	1112 ± 75
3 (PAS 1-5)	1191 ± 89	1191 ± 81

Results

Before reporting the data, it is important to point out that some participants rated all primes a 6 on the PAS, indicating that they could see every prime. With that in mind, there is an unequal number of subjects in the overall and unseen groups. The top of Table 7 notes the number of participants analyzed for overall and unseen primes.

Overall Data

For analyses of all trials, a 2 (Relatedness: related, unrelated) x 3 (Item-type: forward, backward, symmetric) mixed ANOVA was conducted. Table 7 presents the mean RT and error data for each prime type in each visibility condition. The RT data show a main effect of relatedness, $F(1, 67) = 13.239$, $MSE = 10423.46$, $\eta^2_p = .165$, $p = .001$, indicating faster responses for related targets compared to unrelated targets. There was also a main effect of type, $F(2, 134) = 6.132$, $MSE = 10152.32$, $\eta^2_p = .084$, $p = .003$, indicating that FA (1100 ± 84 ms) items were responded to faster than BA (1143 ± 82 ms) or SYM (1127 ± 88 ms) items. Although no Item-type by Relatedness interaction was found ($F < 1$, $p = .407$), the results exhibited the same pattern as Experiment 2. BA ($p = .001$) and SYM ($p = .009$) priming occurred reliably, whereas FA priming was marginal ($p = .077$; recall that it was non-significant in Experiment 2). No other main effects or significant interactions were found.

For errors, there was a main effect of relatedness, $F(1, 67) = 18.667$, $MSE = .002$, $\eta^2_p = .218$, $p < .001$, indicated by less errors for related items compared to unrelated items. There was also a main effect of type, $F(2, 134) = 26.875$, $MSE = .002$, $\eta^2_p = .286$, $p < .001$, indicating significantly more errors for BA (6.6 ± 1.5%) items compared to FA (2.7 ± 0.9%) or SYM (3.9 ± 1.0%) items, which did not differ. Finally, there was also an Item-type x Relatedness interaction, $F(1, 67) = 6.269$, $MSE = .002$, $\eta^2_p = .086$, $p = .205$, indicating that the magnitude for BA and FA priming differed from SYM priming.

Furthermore, a pairwise comparison found significant BA (p = .001) and FA (p = .004) priming, but no significant SYM priming (p = .499).

Analyses were also conducted on nonwords. In RTs, there was a marginal effect of relatedness, $F(1, 67) = 8.776$, $MSE = 10423.46$, $\eta^2_p = .116$, $p = .086$, indicating a trend toward slower responding to related NWs compared to unrelated NWs. For nonword errors, there was a main of relatedness, $F(1, 67) = 13.239$, $MSE = .001$, $\eta^2_p = .165$, $p =$ .004, indicating more errors for related NW targets compared to unrelated NW targets. This pattern mirrors the pattern found in Experiments 1 and 2.

Unseen Primes (Rated 1-5 on PAS)

To analyze unseen primes, I conducted a 2 (Relatedness: related, unrelated) x 3 (Item-type: forward, backward, symmetric) mixed ANOVA on primes that were rated 1-5 on the PAS. There was no main effect of relatedness, $F < 1$, $p = .977$, indicating no significant difference in RTs for related and unrelated primes. There was a marginal effect of type, $F(2, 100) = 2.941$, $MSE = 47081.95$, $\eta^2_p = .056$, $p = .057$. There was a trend towards faster responding for FA (1158 ± 75 ms) items compared to BA (1232 ± 102 ms) and SYM (1202 ± 102 ms), which did not differ (p = .204). However, there was no significant Item-type by Relatedness interaction ($F < 1$, $p = .924$). In contrast to the visible prime results, no significant priming was found for any of the three prime types (FA, BA, and SYM).

The error results converge with these findings. No main effect of relatedness was found, $F(1, 50) = 1.650$, $MSE = .007$, $\eta^2_p = .032$, $p = .205$, indicating no difference in errors for related and unrelated items. There was also a main effect of type,

$F(2, 100) = 10.414$, $MSE = .006$, $\eta^2_p = .172$, $p < .001$, indicating more errors for BA items compared to FA or SYM items. BA (8.5 ± 2.5%) items had significantly more errors than FA (4.0 ± 1.8%) and SYM (4.0 ± 1.7%) targets, whereas errors for FA and SYM items did not differ ($p = .404$). Also, there was no Item-type by Relatedness interaction ($F < 1$, $p = .614$), suggesting no difference in priming magnitude between the three prime types. In fact, no significant priming was found for any of the three prime types (FA, BA, and SYM).

Table 7: Mean Reaction Time (RT) and Percentage Error for the Priming Task:
Related and Unrelated FA, BA, SYM, and NW pairs for Visible and Unseen Primes

Condition	All Trials (n =68)		Unseen (1-5 on PAS; n = 51)	
Variable	*M*	%err	*M*	%err
NW Unrelated	1201 (35)	5.4 (0.6)	1220 (35)	8.5 (1.4)
NW Related	1215 (35)	7.3 (0.8)	1227 (35)	7.9 (1.2)
NW Priming	**-15**✧ (9)	**-1.9*** (0.7)	**-7** (15)	**-0.6** (1.0)
FA Unrelated	1085 (37)	4.0 (0.4)	1161 (54)	5.3 (2.5)
FA Related	1061 (38)	1.4 (0.9)	1150 (43)	2.7 (0.9)
FA Priming	**24**✧ (13)	**2.6*** (0.9)	**-11** (62)	**2.6**✧ (1.5)
BA Unrelated	1139 (35)	8.2 (1.1)	1223 (53)	8.8 (1.3)
BA Related	1093 (38)	5.0 (0.7)	1234 (52)	8.2 (1.9)
BA Priming	**46*** (14)	**3.2*** (1.1)	**11** (28)	**0.6** (2.2)
SYM Unrelated	1072 (37)	4.1 (0.7)	1203 (51)	4.9 (1.1)
SYM Related	1113 (41)	3.7 (0.5)	1200 (17)	4.6 (1.0)
SYM Priming	**41*** (15)	**0.4*** (0.7)	**3** (24)	**0.3** (1.3)

Note. FA = Forward Associates; BA = Backward Associates; SYM = Symmetric Associates; Standard error appears in parenthesis. Bold font indicates
unrelated-related conditions.
✧$p < .10$. *$p < .05$

For NWs, there was no main effect of relatedness in RTs ($p = .661$) or errors ($p = .554$), indicating that related and unrelated primes did not differ in RT or response accuracy. This result matches what was found in Experiment 2 and suggests that NW inhibitory priming does not occur when primes are not consciously identifiable.

Discussion

Experiment 3 obtained additional evidence that BA priming relies on an automatic process. Again, BA priming occurred under high NWRP and at a short SOA, inconsistent with a strategic process. Another goal of the experiment was to search for additional evidence that BA priming requires a consciously identifiable prime. To compare conscious and unconscious primes, a post-trial visibility check was added to the LDT. The pattern in the overall data mirrored the pattern in Experiment 2. BA and SYM priming occurred reliably when primes were visible (i.e., rated a 6 on the PAS), but disappeared when primes were not consciously identified (i.e., rated 1-5 on the PAS). Hence, the automatic process for BA priming relies on a prime that participants can fully and consciously identify.

Turning to FA priming, it was marginal in RTs and significant in errors for visible primes. However, for unseen primes, FA priming was absent in RTs, and numerically positive but nonsignificant ($p = .090$) in errors. This is problematic for an ASA account, as ASA should presumably occur even when the prime cannot be consciously identified by subjects. Indeed, it is possible that the masked priming effect is not due to unconscious activation, but instead from some primes reaching consciousness. This could occur from inadequate prime masking or prime durations that are too long (de Wit & Kinoshita, 2015). Considering that the PAS can distinguish between unconscious and conscious primes, future investigations of masked priming would benefit from using this procedure, rather than assuming that short prime durations and masks are successful at preventing identification of the prime.

Although these results are exciting in that they present challenges to strategic semantic matching and ASA, there are a few important caveats to discuss. First, RTs were overall slower in Experiment 3. It is possible that the visibility check caused participants to maintain the prime's visibility rating for the PAS until after their LDT response, slowing their LDT RTs. Second, I compared the main analyses (consisting of all trials) to analyses of trials rated 1-5 on the PAS (i.e., unseen primes), resulting in less subjects in the 1-5 data set compared to in all trials (and lost statistical power). Thus, it remains possible that priming differed for participants who perceived at least some primes as unseen. To ensure that this did not occur, I conducted an analysis looking only at the 51 subjects who rated at least some primes as unseen, comparing their priming effects for unseen and for all trials. In this analysis for RTs, there was again a main effect of relatedness, $F(1, 55) = 9.971$, $MSE = 10134.96$, $\eta^2_p = .153$, $p = .003$, demonstrating faster RTs for related primes compared to unrelated. This replicated the pattern from the overall analysis. Furthermore, the pairwise comparison revealed the same pattern as the overall analysis. BA (44 ± 33 ms, $p = .008$) and SYM (40 ± 35 ms, $p = .026$) priming were significant, but whereas FA priming was numerically positive but non-significant (24 ± 26 ms, $p = .106$). The pattern was similar in errors. Less errors were made on related items compared to unrelated items, $F(1, 55) = 15.791$, $MSE = .002$, $\eta^2_p = .223$, $p < .001$, consistent with the overall analysis. A pairwise comparison revealed significant BA priming (3.4 ± 1.0%, $p = .002$), and FA priming ($p = .007$; it was marginal in the original analysis), and numerically positive but non-significant SYM priming (0.2 ± 0.7%, $p =$

.743). Thus, the pattern of BA priming replicated in the reduced sample, suggesting that the difference between visible and unseen trials was not merely due to subject differences.

GENERAL DISCUSSION

According to the Three Process Model, BA priming is explained by a strategic semantic matching process in which participants check back for a relation and diagnostically use relatedness to determine if the target is a word or nonword. Yet other studies have viewed searching for a relation as an automatic process that occurs regardless of the utility of a semantic matching strategy (de Groot, 1984; Chwilla et al., 1998). To adjudicate this issue, the present study examined if BA priming would occur under high NWRP (Experiments 1-3), when a warning against checking back is present (in Experiment 1), when a short SOA is used (Experiments 2 & 3), and when primes are masked (Experiments 2 & 3). When NWRP is high, utilizing relatedness to determine if the target is a word (or not) is no more effective than chance guessing the target's lexicality. Furthermore, a strategy should only be used when it aids performance. So if semantic matching is strategic, it should not be utilized if a warning states that it will not be helpful. Consequently, if BA priming is due to strategic semantic matching, it should not occur when the NWRP is high and especially not when subjects are warned that checking back will not be helpful. Alternatively, if BA priming is due to an automatic semantic matching process, BA priming should not be affected under high NWRP or warning conditions.

In support of an automatic process for semantic matching, BA priming was found in the LDT at 50% NWRP, with a short 200 ms SOA, and with brief prime durations, conditions that should reduce the diagnosticity of a semantic matching strategy. BA priming was also insensitive to warnings, as there was no difference in BA priming for the

50% NWRP and 50% NWRP with warning conditions. These findings suggest that BA priming is unaffected by both high NWRP and instructions not to check back, suggesting that it relies on an uncontrollable (and thus automatic) process. If the process for BA priming were strategic, it should not be employed when it is not helpful to the task (e.g., high NWRP, warning).

Additional evidence for automatic semantic matching was found in the correlational analyses. Given that NW inhibitory priming likely relies on an automatic semantic matching process, a negative correlation between NW and BA priming indicated that both types of priming rely on the same process. Furthermore, BA and NW priming were negatively correlated in both the 50% NWRP condition and the 50% NWRP with warning conditions, in RTs and errors. This suggests that BA and NW priming both rely on an automatic semantic matching process.

Whether a warning was provided or not, BA priming remained stable when semantic matching is nondiagnostic of target lexicality in the LDT. Building on this finding, Experiments 2 and 3 examined if semantic matching requires a consciously identified prime. To test this, comparisons were made between masked and unmasked priming. In both studies, BA priming did not occur when primes were unseen (i.e., in the masked condition in Experiment 2, and primes rated less than 6 on PAS in Experiment 3), indicating that semantic matching relies on a consciously identifiable prime.

Semantic Matching – A Continuum of Automaticity

One way to interpret the results here is to conclude that semantic matching relies on a strictly automatic process. Admittedly, this interpretation is quite tempting. After all, BA priming was unaffected by high NWRP, which should decrease the utility of the semantic matching strategy. This automaticity was confirmed by the presence of inhibitory NW priming, suggesting that related nonwords (that are the closest orthographic neighbors of the word; e.g., *mastard*) are processed automatically in a similar fashion to words (i.e., BA and NW rely on similar processes). If BA priming were strategic, however, then participants under high NWRP would have ceased their attempts to find a relation between primes and their targets, as searching for a relation would slow responses in half of the trials. In fact, BA priming remained intact even when high NWRP was combined with a warning that checking back will not be helpful. If semantic matching were controllable, the combination of these two manipulations should decrease performance by discouraging a search for a prime-target relation.

Furthermore, many past results are validated by an automatic semantic matching process. If the process for BA priming is automatic, it would explain why there are no links between BA priming and AC, suggesting that BA priming is modulated by a resource free (and thus automatic) process (Heyman et al., 2015; Hutchison et al., 2014). An automatic semantic matching process would also explain the handful of studies that found BA priming at a short SOA (e.g., Chwilla et al., 1998; Kahan et al., 1999; Thomson-Schill et al., 1998), and in pronunciation (Kahan et al., 1999; Thomas et al., 2012). However, despite many studies that suggest an uncontrollable semantic matching process, it is premature to conclude that semantic matching is never strategic. If that were the case, there would be no explanation for the consistent increase in priming that occurs as semantic matching becomes more useful (i.e., as the NWR increases; Neely at al., 1989). This suggests that retrospective semantic matching is an adaptive processer that engages processes based on the task (Aschenbrenner & Yap, 2019).

Indeed, there is evidence in the study showing that semantic matching is a flexible process that can switch from automatic to strategic depending on the task parameters. In Experiment 1, NW priming in the INT block switched from inhibitory to numerically positive under warning. This indicates that when most of the items are unrelated (as they would be in the INT block), participants began to use the presence of a relation to bias a *nonword* response for the target. Considering the results demonstrating that semantic matching can operate automatically under conditions where it is nondiagnostic, but also can be engaged strategically when checking for a relation assists in a binary LDT response (e.g., in the standard LDT or in the INT block of this study), the controllability of the semantic matching could be viewed as a continuum that permits the process to operate automatically under certain conditions (e.g., short SOA, high NWRP, pronunciation), and strategically under others (e.g., high NWR, long SOAs, in the standard LDT).

Integrative Priming

Another goal of the study was to examine processes that might help explain integrative (INT) priming. Consistent with past studies (e.g., Estes & Jones, 2009; Jones et al., 2017), INT priming reliably occurred. Also, INT priming was unaffected by high NWRP, suggesting that it relies on an automatic process. This is consistent with past studies that attributed INT priming to *automatic* relational integration. However, INT priming was no longer significant when there was a warning against checking back for a relation. This suggests a warning was effective at preventing integration, suggesting that

INT priming may rely partially on a controllable (i.e., strategic) process. It is possible that relational integration as a process can be automatic or strategic process, in a similar fashion to semantic matching.

There was also evidence suggesting that INT priming relies on different processes when the NWRP is high versus when it is not. At 0% NWRP, INT and FA priming were marginally correlated, but in the 50% NWRP and 50% NWRP with warning conditions, this correlation decreased, and INT was significantly correlated with BA and SYM priming. This suggests that high NWRP might have caused participants to shift away from prospective processes. However, when forward acting processes are disabled, priming can still occur retrospectively, as the targets are spontaneously assessed for how plausibly it fits the role activated the prime, in a similar vein to automatic semantic matching. Thus, these findings suggest a hybrid retrospective/prospective process for INT priming, consistent with Complementary Role Activation theory.

Masked Priming

In addition to providing insights about BA and INT and priming, these findings also highlight another problem with the Three Process Model, which is the growing number of studies that present challenges to ASA. Recall that ASA relies on an unconscious spread of activation from the prime to the target, and thus should be able to account for masked priming. However, no (significant) masked priming FA priming occurred for "truly unseen" primes (i.e., the masked condition in Experiment 2 and primes rated 1-5 on the PAS in Experiment 3). This is inconsistent with ASA's prediction that masked FA priming should occur in the LDT. However, these findings are consistent with studies which found a task dependency effect for masked priming, such that it occurred in the LDT, but not in a semantic categorization task (deWit & Kinoshita, 2015). Furthermore, these results are consistent with Heyman et al. (2015), who found that FA priming disappears under cognitive load. If FA priming relies solely on expectancy, which relies on AC, it follows that FA priming should be wiped out when high cognitive load prevents engagement of the strategy.

The current results also bolster findings from past studies that suggest masked priming is influenced by response criteria. For instance, Bengson and Hutchison (2007) found evidence for this by conducting a masked priming task in which participants completed word stems (e.g., *mo*___) with a word that is unrelated to their preceding prime (e.g. *cash*). Thus, the task required excluding the prime. When participants were instructed to "report the prime if you saw it," masked priming (exclusion failure) occurred. However, when participants were instructed to "give your best guess," regarding the prime's identity, masked priming disappeared. This suggests that masked priming is in part due to individual differences in prime-report. These findings are consistent with Experiment 3, which found that masked priming occurred only for conscious primes.

Implications for Other Models

In addition to contending with the Three Process Model, the data here can address assumptions made by other models of priming. Another well-studied theory of priming is the Cue-Combination Theory (Ratcliff & McKoon, 1988), in which subjects use a "compound cue" (consisting of the prime and target but biased towards the target) to retrieve both concepts from memory and then assess the familiarity of the target. Because words are more familiar than NWs, subjects will be faster to determine that a familiar target is a word. However, if a target is highly unfamiliar, non-word responses are speeded. Furthermore, if it is "moderately familiar", more processing is needed, resulting in slower RTs. Thus, priming is a result of higher familiarity for related prime-target pairs compared to unrelated.

One strength of Cue-Combination Theory is that it nicely accounts for BA priming in the LDT. In contrast to strategic semantic matching, cue-combination is automatic and directionless (Ratcliff & McKoon, 1988), meaning that regardless of the direction of presentation, related prime-target pairs will be assessed as more familiar than unrelated prime-target pairs (Neely, 1991). At first glance, the theory seems to provide a potential explanation for the results here. However, compound cue theory is incapable of explaining BA priming in tasks other than the LDT, because there is no a priori reason to believe that prime-target familiarity would be helpful in correctly pronouncing the target.

The compound cue model also has trouble accounting for the INT and FA priming results. Integrative targets could be classified as unrelated (e.g., *lobby-fountain*), and thus might not be judged as more familiar than an unrelated target (e.g., *plastic-idea*). In fact, most INT items (e.g., *paper-hat*) would be classified as unrelated in many tasks. Thus, it is unlikely that a cue-combination process underlies INT priming. Similarly, compound cue theory has trouble accounting for masked priming, if it really exists. Although the theory claims that masked primes could be part of a compound cue (Neely, 1991; Ratcliff & McKoon, 1988), it is unknown how participants could assess the familiarity of a subliminal prime.

Another model of priming to discuss is the Evidence Accumulation and Source Confusion Model. This model borrows assumptions from the Bayesian Reader Account (Norris & Kinoshita, 2008), as well as the ROUSE (Responding Optimally with Unknown Source of Evidence; Huber, Shiffrin, Lyle, & Ruys, 2001) model of priming. This theory characterizes semantic priming as a task-dependent process, in which the task goal determines which representations and decision processes are required for priming. Thus, priming effects are a result of accumulating enough evidence to arrive at the correct response on a given trial, and evidence contributed by the prime is assessed against the target. Priming increases as a function of the congruency between the evidence accumulated from the prime and the information needed to arrive at a correct target response.

However, the Source Confusion/Evidence Accumulation model is challenged by studies that found "irrational" priming. If priming is an adaptive process, then an explanation is needed for instances when priming occurs even when it hinders task performance. For instance, items (e.g., *sh_ve)* in a speeded word fragment task were completed slower if preceded by a prime that was semantically related to a prohibited fragment solution (e.g., *push*; Heyman et al., 2016). More importantly, priming is in irrational in the current study, as determining prime-target relatedness did not help predict a correct response. Given that priming occurs when participants are attempting to avoid it (such as in the Heyman et al. study), and when it is not helpful for performance (such as in the current study), priming cannot rely on a purely rational account suggested by the source confusion model.

Future Directions

More evidence is needed to confirm that BA priming is due to an automatic, and not strategic, semantic matching process. One potential way forward is with go/no-go priming (Gomez, Ratcliff, & Perea, 2007; Perea, Rosa, & Gomez, 2002). In the go/no-go paradigm, subjects respond only to word targets, withholding responses on NW targets. Thus, inferring a prime-target relation will not be helpful in this task. If BA priming remains intact in this task, it would provide additional evidence that participants automatically search for a relation even when it is does not facilitate performance in the LDT, providing strong evidence that integration occurs automatically. Thus, go/no-go priming could be another way to test if semantic matching is automatic or strategic.

Another way to approach is this issue is testing if semantic matching can be strategically induced. To address this question, participants could be trained to practice checking back for a relation. If BA priming relies on semantic matching, it should increase when participants are informed of the strategy and given practice at using it. To “train” participants in semantic matching, a variant of the LDT could be administered in which two primes are presented, one of which is related to the prime. Participants would then indicate if the target is related to the prime presented either in the top or bottom position. This should encourage participants to check back for a relation, increasing utility of the semantic matching strategy. The Three Process Model predicts that BA priming will increase under these conditions, as participants should get more out of the strategy.

Finally, further utilization of NWRP manipulations can test predictions in the semantic matching model. At a NWRP of 75%, a majority of NWs are “related” to the target. Thus, utilizing a strategic semantic matching strategy will “reverse” the probabilities in a standard LDT. Under these conditions, finding a relation means that the target has a 40% (50/125) chance of being a word, whereas the absence of such a relation indicates a 67% (50/75) chance of being a word. If the process for BA is truly strategic, participants should be able to rely on prime-target relatedness to predict target lexicality, even when finding a relation biases a NW target response (under standard conditions, a relation predicts a word response). However, if BA priming does not increase from 0% NWRP to 75% NWRP, this would suggest that BA priming is insensitive to NWRP, and thus relation checking occurs independent of its utility. If the latter is found, it would be consistent with the findings in Experiments 1 through 3, and provide additional confirmation that semantic matching can occur automatically. On the other hand, if BA priming increases under 75% NWRP, it would provide additional evidence that the semantic matching can occur strategically if doing so reliably improves performance.

Conclusion

BA priming is often explained as a strategic semantic matching process (Neely et al., 1989; Thomas et al., 2012). Yet BA priming did not decrease under conditions in which the utility of semantic matching decreased (i.e., high NWRP and warning), inconsistent with a strategic account. Thus, BA priming is best described as an automatic process, in which participants spontaneously check back for a relation regardless of how it affects task performance.

As for INT priming, its magnitude was unaffected by NWRP, consistent with its automaticity. However, in the correlational analyses, increasing the NWRP changed which types of priming are correlated with INT priming. At low RP, there was a trend towards a correlation between FA and INT priming, whereas at high RP, BA and SYM priming were correlated with INT priming and negatively correlated with FA priming under warning. This suggests that increasing the NWRP causes participants to shift from prospective processes. This pattern comports with Complementary Role Activation theory, which left open that possibility that INT priming relies on a dual prospective/retrospective process.

Finally, masked priming (BA or otherwise) was found in the LDT when primes were not consciously identified. Thus, it can be concluded that BA priming relies on an automatic process that requires a fully identifiable prime. Furthermore, no masked FA priming was found when primes were unseen, inconsistent with an ASA account.

Importantly, the findings here (particularly the BA priming results) confirm observations often made about the process of reading. It makes sense that searching for relations between words to aid in comprehension would be an automatic process. The task of reading itself involves searching for meaning, and thus we probably do it without intention.

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