Visual Word Recognition: Evidence for Global and Local Control over Semantic Feedback

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

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Abstract

Two semantic priming experiments in the context of lexical decision are reported that examine the joint effects of stimulus quality, semantic context, and strength of association when all these factors are intermixed in a block of trials. A three-way interaction is seen in both experiments in which the typical interaction between semantic context and stimulus quality is eliminated when the strength of association between prime-target pairs is weak. The results support a role for a control mechanism that makes use of local information available within a trial, in addition to a global control mechanism that operates across a block of trials. The interaction between semantic context and stimulus quality when prime-target pairs are strongly related is attributed to the presence of feedback from the semantic system to the lexical system whereas additive effects of semantic context and stimulus quality is attributed to this feedback being eliminated such that semantic and lexical levels are functionally separate modules.

Acknowledgments

I extend a heartfelt thank you to Jennifer Stolz and Derek Besner for their guidance, encouragement, and support throughout the development of this work. I would also like to thank Jonathan Fugelsang for his constructive comments on the final draft of this thesis – the work is considerably improved for his efforts.

Dedication

To my family, without whom this wouldn't have been possible.

Table of Contents

List of Tables

List of Illustrations

Introduction

Numerous studies over the last three decades have found that semantic context can influence visual word processing (see McNamara, 2005 for an extensive treatment). In both reading aloud and lexical decision tasks, participants are faster and often more accurate when the target letter string is preceded by a related word (e.g., DOCTOR-NURSE) rather than an unrelated one (e.g., WOOD-NURSE). A variety of different accounts for this result have been proposed including automatic spreading activation, semantic matching, compound cueing, and expectancy (e.g., Becker, 1980; Meyer, Schvaneveldt, & Ruddy, 1975; McNamara, 2005; Neely, 1991). More recently, researchers have drawn on interactive activation models, including models with fixed connection weights and localist representations (such as the Dual-Route Cascaded model (DRC); see Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; see also Besner & Smith, 1992; Stolz & Neely, 1995) and models with learned connection weights and distributed representations (Parallel Distributed Processing, or PDP, models. e.g., Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg & Patterson, 1996; Rogers & McClelland, 2004; Plaut & Booth, 2000, 2006).

Main effects (such as the semantic context effect) are too often easily accounted for in a variety of frameworks. Some researchers have therefore turned to manipulations of multiple factors to determine which accounts are better able to also explain more complex patterns of data.

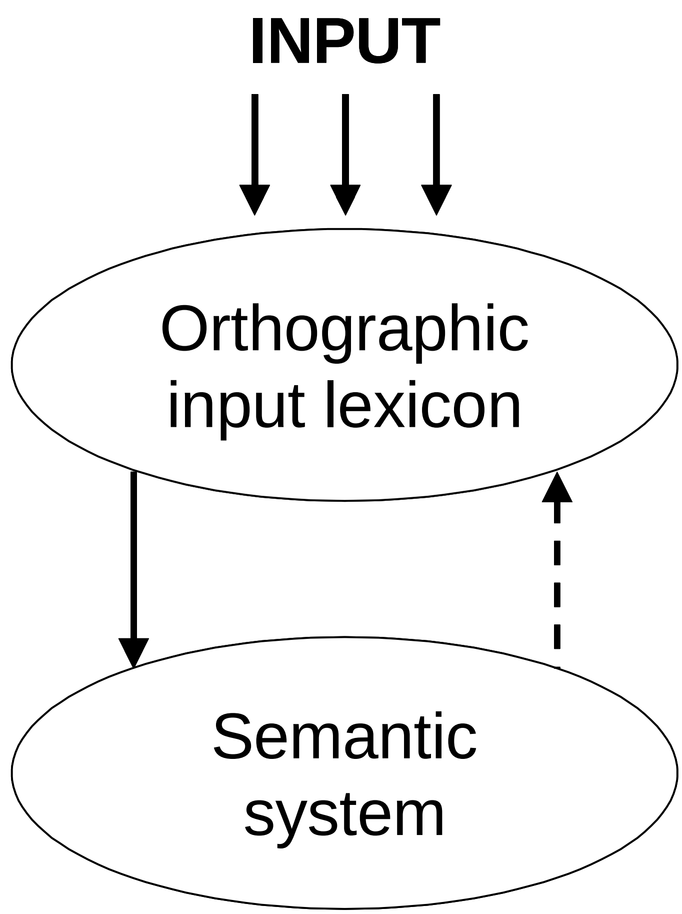
Of central interest here are the joint effects of semantic context and stimulus quality. Reductions in stimulus quality (such as contrast reduction or masking the stimuli) typically result in slower and often more error-prone responses to visual stimuli (Becker & Killion, 1977). The standard finding is that the semantic context effect is larger for degraded targets than for intact targets, and this holds true for both lexical decision and reading aloud (Becker & Killion, 1977; Besner & Smith, 1992; Borowsky & Besner, 1991, 1993; Meyer et al., 1975).

More recently, Stolz and Neely (1995) reported two factors associated with the elimination of this interaction: relatedness proportion (RP) and strength of association. The interaction is eliminated when the proportion of related trials is reduced from 50% of word trials to 25% of word trials (see Brown, Stolz, & Besner, 2006 for a replication), or when the strength of association between the related prime-target pairs is relatively weak[1].

Stolz and Neely (1995)'s Control Account of the Effect of Relatedness Proportion

Stolz and Neely (1995) assessed the ability of a variety of accounts to explain the pattern of data noted above and found none to be successful. They therefore proposed an explanation based on Besner and Smith's (1992; see also Borowsky & Besner, 1993) interactive activation account (see Figure 1). To produce a semantic context effect in this model, it is proposed that when a prime word (e.g., DOCTOR) is presented, its lexical entry (in the Orthographic Input Lexicon) is activated. This activation feeds forward to the semantic system activating the representation (a set of semantic features, or a category) for both the prime word (e.g., DOCTOR) and its associates (e.g., NURSE, NEEDLE). Stolz and Neely (1995) propose that this spread of activation from prime to associates is contained within the semantic system. Since then, Stolz and Besner (1996) have argued that it arises not from spreading activation within the semantic system, but from direct connections between words at the lexical level and associated concepts at the semantic level, an account I continue to prefer. Once activated in the semantic system, semantic representations for the prime word and all associates feed activation back to the orthographic input lexicon. The result is that the prime provides activation to the lexical entries for semantic associates via the semantic system, while avoiding the need for within-level spreading activation (remaining consistent with the earliest assumptions of the interactive activation framework. See McClelland & Rumelhart, 1988). This increased activation within the orthographic input lexicon and semantic system provides a benefit for associates of the prime. Thus, when the target falls within the set of associates it derives a processing benefit over unrelated targets, resulting in faster and more accurate responses.

Figure 1 - Aspects of the architecture in visual word recognition (reproduced from Stolz & Neely, 1995)



The interaction between semantic context and stimulus quality (such that the effect of semantic context is larger for degraded targets than for intact targets) arguably arises in part because a reduction in stimulus quality slows the rate of processing in the visual word recognition system. When the target is presented in degraded form, the slowed rate of processing combines with the semantic context effect in the orthographic input lexicon to amplify the benefit to primed targets relative to unprimed targets. There is some debate about where in the system stimulus quality has its effect, which I will revisit in a few moments. For the present purposes, it suffices to assume that the effects of stimulus quality are pre-semantic, that is, that stimulus quality only influences processing at the feature, letter, and/or lexical levels.

To account for the elimination of this interaction when relatedness proportion is low, Stolz and Neely (1995, following a suggestion by Besner) proposed a control mechanism that prevents feedback from the semantic system to the orthographic system (represented by the dotted arrow in Figure 1). Eliminating this feedback conserves activation in the semantic system, using it only when it is beneficial. When relatedness proportion is low, the feedback from the semantic system is not useful enough on most trials to justify allowing activation to spread from the semantic system to the lexical system. Additive effects of semantic priming and stimulus quality on RT are therefore seen because under this condition lexical and semantic processing are functionally separate modules. This account relies on two central assumptions. It assumes that the effect of stimulus quality does not progress beyond the lexical level (i.e., the effect does not extend to the semantic system), and that the lexical decision is made on the basis of activation within the semantic level.

An early locus of stimulus quality's effect.

As I stated previously, this account requires that the effect of stimulus quality manipulations be constrained to the early stages of processing (no further than the lexical level). This might seem to be a strong assumption, however it gains support from experiments manipulating stimulus quality and word frequency (thought to have its effect at the lexical level). The joint effects of these two factors are typically additive on RT (see Balota & Abrams, 1995; Becker & Killion, 1977; O'Malley, Reynolds & Besner, 2007; Plourde & Besner, 1997; Norris, 1984[2]; Stanners, Jastrzembski & Westbook, 1975; Wilding, 1988[2]; Yap & Balota, 2007).[3] This suggests that the effects of the two factors are in separate levels of processing, which would require that stimulus quality's effects be limited to the feature and letter processing levels (see also Brown et al., 2006; Reynolds & Besner, 2004; O'Malley, Reynolds, & Besner, 2007 for further constraints).

Locus of the word/nonword decision.

A second important assumption is that the word/nonword decision is carried out on the basis of activation in the semantic system at least some of the time rather than at the lexical level (e.g., Borowsky & Besner, 1993; Stolz & Neely, 1995; Stolz & Besner, 1996; Brown et al., 2006). Without this assumption, turning off feedback from the semantic system to the lexical system would result in no semantic priming effects at all.

This second assumption is common to at least one other account despite a very different kind of representational scheme (Plaut and Booth, 2000; 2006) but differs from another prominent theoretical account. Coltheart (2004) identified several patients with severe semantic damage who, despite this damage, still produce high accuracy in the context of the lexical decision task. Coltheart therefore argued that lexical decisions, at least for these patients, does not rely on semantic level information. It is important to point out that while this suggests that lexical decision *can* be made at the lexical level, it does not preclude participants with intact semantic systems from making word/nonword decisions at the semantic level.

If one would like to insist that the lexical decision is made on the basis of activation in the orthographic input lexicon, Ferguson, Robidoux, and Besner (2007) offer a possible alternative. They propose that instead of controlling feedback between the semantic system and the orthographic input lexicon, the control mechanism influences the feedback between the orthographic input lexicon and the letter level. This possibility would require that the effect of stimulus quality is restricted to pre-lexical levels (the letter and feature levels), and that the interaction between stimulus quality and context arises because the effect of the prime on the target eventually extends back to the letter level. However, if the context effect can find its way from semantics through the orthographic input lexicon to the letter level to produce an interaction with stimulus quality, this account predicts that the word frequency effect (thought to arise in the orthographic input lexicon) should also find its way to the letter and feature levels. If that were the case, I would expect word frequency and stimulus quality to interact, but in lexical decision these two factors are additive (Balota & Abrams, 1995; Becker & Killion, 1977; O'Malley et al., 2007; Plourde & Besner, 1997; Norris, 1984[2]; Stanners et al., 1975; Wilding, 1988[4]; Yap & Balota, 2007). For this reason, I believe that assuming the lexical decision is made at the semantic level is more consistent with current empirical results.

Stolz and Neely (1995)'s Time-Course Account of Strength of Association: Two Problems

While Stolz and Neely (1995) turned to a control mechanism to account for the effect of relatedness proportion manipulations on the interaction between stimulus quality and context, their account of the same effects for strength of association differed considerably. Here they argued that the additive effects of stimulus quality and context observed when trials were only weakly associated is due to the time-course of processing. When a trial includes a weakly related prime-target pairing, the spreading of activation from the prime to the target is slower than when the prime and target are strongly related. The end result, they argued, was that activation did not have sufficient time to reach the target's representation at the lexical level, thus eliminating the interaction between stimulus quality and context.

Two considerations seem to undermine this conclusion. First, it is not entirely clear why slower processing would eliminate the interaction entirely rather than simply reducing it. No matter how the priming arises within semantics, this benefit should eventually be found in the lexical system resulting in an interaction. A typical trial in the Stolz and Neely (1995) experiment lasted around 800 msecs (200 msec SOA, followed by 600 msecs of reaction time). It seems highly unlikely that activation would spread so slowly that in such a long period no effect of context would be felt in the lexical system, particularly given the robust context effects observed. However, even with 96 participants the interaction failed to materialize (Stolz & Neely, 1995).

A second consideration is that the Stolz and Neely (1995) account predicts that the priming effect for strong associates should be larger than that for weak associates in the bright (undegraded) stimulus quality condition. That is, the simple strength of association by context interaction should be significant such that strong associates receive more benefit from context than do weak associates. This effect is clearly not present in the data presented in Stolz and Neely (1995), again despite a powerful experiment with 96 participants. In their data, strong associates produced a 34 msec priming effect, while weak associates produced a 31 msec priming effect.

An Alternative Account of the Effect of Strength of Association

In light of these two problems with the time-course account of the effect of strength of association on the interaction between context and stimulus quality, it is worthwhile to reconsider the ability of a control mechanism that disables feedback from the semantic system to account for the effects of both relatedness proportion *and* strength of association. In the Stolz and Neely experiments (1995), participants were given separate blocks of weakly and strongly associated trials. As with relatedness proportion, I propose that the system monitors the utility of feedback from the semantic system to the orthographic input lexicon. When the associations are weak, the feedback is not considered useful (see the General Discussion for one reason this might be the case), and thus feedback is eliminated for both prime and target processing, producing additive effects of stimulus quality and strength of association.

An alternate possibility is that the time-course account is indeed correct, in which case the failure to find an interaction between context and strength of association (so that the priming effect is larger for strong associates than for weak associates) simply represents a Type II error. The two experiments presented here test this possibility and examine more closely the nature of the control mechanism (to foreshadow the results, I find the Stolz and Neely (1995) results unlikely to be attributable to a Type II error). First, though, I would like to draw attention to a difference between the relatedness proportion and strength of association manipulations in terms of their experimental manipulations.

Global and Local Factors

In a typical semantic priming experiment, relatedness proportion (high versus low) can only be defined across a series of trials (individual trials do not have a relatedness proportion). However, the same is not true of strength of association. Each individual trial has its own strength of association between the prime and target. Thus, relatedness proportion can be viewed as a global contextual factor and strength of association as a local contextual factor. Stolz and Neely (1995) treated strength of association as a global factor by presenting the different trial types (strong associates vs. week associates) in different blocks. The question addressed here concerns what happens when these trial types are intermixed. If the monitor responsible for implementing control operates only at the global level (as it must for relatedness proportion), then intermixing trials with differing strengths of association will either dilute the global strength of association enough for the monitor to turn semantic feedback off, or this feedback will be maintained and thus apply to all trials within the experiment regardless of whether the associates are weak or strong. In other words, mixing strong and weak associates when relatedness proportion is .5 should either produce an interaction between stimulus quality and semantic context for both levels of strength of association, or additive effects of these two factors. What it should not produce is a three-way interaction in which there is an interaction between stimulus quality and semantic priming for strong associates, but additive effects for weak associates. A three-way interaction would be evidence consistent with the claim that strength of association is a local contextual factor. That is, the control mechanism is relying on information available on a trial-by-trial basis to determine the utility of semantic level feedback.

The two experiments reported here test this assertion, first with the stimulus set used by Stolz and Neely (1995), and in Experiment 2 with a new stimulus set that corrects for a missing counterbalance in their original experiment. To anticipate the results, mixing strong and weak associates in the same block of trials yielded a three-way interaction such that there is an interaction between stimulus quality and semantic priming for strong associates but additive effects of these factors for weak associates. It is argued that these results force a modification to the control mechanism such that there is a distinction between global (across trials) and local (within trial) control over semantic feedback.

Experiment 1

Method

Participants.

Forty-five University of Waterloo undergraduate students took part in the experiment for payment or credit towards undergraduate psychology courses. All spoke English as a first language and all had normal or corrected-to-normal vision.

Design.

A 2 (context: related vs. unrelated) x 2 (stimulus quality: bright vs. dim) x 2 (association strength: strong vs. weak) repeated measures design was used. All three factors were within-subject and trials from all eight conditions were randomly intermixed. Half of all trials were word trials, while the remaining were nonword catch-trials. For both word and nonwords trials, there were equal numbers of clear and dim trials. For word trials, half of the trials were related prime-target pairs, while the other remaining were unrelated pairs (that is, the relatedness proportion was 0.5). Of the related pairs, half had strong associations between the prime and target, and the remaining trials were only weakly associated.

Stimulus materials and list construction.

The stimuli consisted of the 96 prime-target word pairs and 48 prime word-target nonword pairs used by Stolz and Neely (1995), and thus share the lexical characteristics of that set. The word list for Experiment 1 can be found in Appendix A. All stimuli appeared in a 12 point Fixedsys font face. The first word of each pair was the prime and always appeared in clearly visible lowercase letters. The second word was the target and appeared in lowercase letters that were clearly visible on half of the trials (RGB values: 200, 200, 200) and dim on the other half (RGB values: 63, 63, 63). The 96 word pairs were used to form eight lists, such that each list consisted of 24 strong-related-word pairs (12 bright, 12 dim), 24 weak-related-word pairs (12 bright, 12 dim), and 48 unrelated-word pairs (24 bright, 24 dim).

The combinations of cue and target words were rotated across subjects such that each target appeared equally often in clear and dim form and was preceded equally often by related and unrelated primes. The sequence of trials was randomized anew for each subject.

Procedure.

Subjects were tested individually and were seated approximately 57 cm from the computer monitor in a dimly lit room. Subjects read through instructions that were displayed on the computer monitor, and the experimenter then recapitulated them aloud. Each trial began with a fixation asterisk (*) at the center of the screen and displayed for 2000 ms. Following fixation, a prime appeared at fixation for 150 ms, followed by a blank ISI of 50 ms (producing a Stimulus Onset Asynchrony of 200 ms). A target was then presented at fixation until the participant produced a response (if the participant did not respond after 3000 ms, the trial would terminate itself). All subjects were directed to indicate the presence of a word by pressing a key with their right index finger, and that of a nonword using their left index finger. Subjects were instructed to respond as quickly and accurately as possible.

Stimuli were displayed on a standard 15-inch SVGA monitor controlled by E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) implemented on a Pentium-IV (1,800 MHz) computer. Response latencies were collected to the nearest millisecond.

Results

Data for three subjects were discarded due to excessive error rates on nonword trials (greater than 30% errors in the bright condition). Two more subjects were dropped from further analysis due to excessively large stimulus quality effects (more than 3.5 standard deviations from the sample mean), suggesting inordinate difficulty with the task on dim trials. For the remaining 40 subjects, errors accounted for 3.4% of word trials and are excluded from further analysis. Only correct responses to the target words were included in the analysis of the RT data. The remaining data were submitted to a recursive outlier analysis (Van Selst & Jolicoeur, 1994), which resulted in the further elimination of 2.0% of the data. Mean reaction times and percentage errors are presented in Table 1. Individual participant data for Experiment 1 can be found in Appendix B.

Table 1 - Experiment 1: Mean Reaction Time (ms) and Percentage Error (%) for Word Targets as a Function of Semantic Context, Strength of Association, and Stimulus Quality.

	Strong Associates				Weak Associates			
	Bright		Dim		Bright		Dim	
	RT	Error	RT	Error	RT	Error	RT	Error
Related	554	1.0	607	0.4	570	0.2	653	1.7
Unrelated	597	1.5	697	3.1	619	1.3	705	3.5
Difference	**43**	**0.5**	**90**	**2.7**	**49**	**1.1**	**52**	**1.8**

The mean RTs for each subject in each condition were submitted to a 2 x 2 x 2 within-subjects ANOVA. There are significant main effects of relatedness ($F(1, 39) = 51.5$, $MSE = 5355$, $p < .001$), stimulus quality ($F(1, 39) = 68.9$, $MSE = 7568$, $p < .001$), and strength of association ($F(1, 39) = 15.0$, $MSE = 2814$, $p < .001$). Of the second order interactions, only the one between stimulus quality and context is significant ($F(1,39) = 5.3$, $MSE = 2272$, $p < .05$). Strength of association does not interact with either stimulus quality ($F(1, 39) < 1$, $MSE = 1752$, $p > .4$) or context ($F(1, 39) = 1.9$, $p > .18$). Most importantly, the third order Stimulus Quality x Context x Strength of Association interaction is significant ($F(1, 39) = 4.4$, $MSE = 2247$, $p < .05$).

Finally, the time-course account of strength of association (Stolz & Neely, 1995) predicts a significant interaction between strength of association and context for bright trials. That is, the priming effect for strong associates should be larger than the priming effect for weak associates. I find no evidence for that interaction here ($F(1,39) < 1$, $MSE = 51.1$, $p > .8$). In fact, the trend for the means is in the opposite direction (the priming effect is slightly larger for the weak associates). The error data are not suitable for analysis due to a large number of zeroes in the subject data.

Given the significant three-way interaction such that strength of association modifies the interaction between stimulus quality and context, I computed planned t-tests of the two underlying interactions between stimulus quality and context (strong associates at +47 ms and weak associates at +3 ms.). It is clear that the interaction is present for the strong associates ($t(39) = 3.46$, $p < .001$), but there is no statistical evidence for an interaction with the weak associates ($t(39) < 1$, $p > .8$).

Discussion

Two results from Experiment 1 are particularly important. The first is that I have failed to produce the interaction between strength of association and context that is predicted by Stolz and Neely's (1995) time-course account of strength of association. This suggests that the absence of this interaction in Stolz and Neely's (1995) experiment is not simply a Type II error (Experiment 2 will once again demonstrates the same pattern).

The second, more theoretically important result is the significant three-way interaction between strength of association, stimulus quality, and context. As in Stolz & Neely's (1995) blocked design, the interaction between stimulus quality and context is eliminated for weakly associated cue-target pairs. Given that these trials are inter-mixed in the present experiment, this result is difficult to accommodate using only a global context monitor. Experiment 1 thus provides strong evidence that the control mechanism must be relying on local information (information available within the trial).

A Possible Counterbalance Problem

The stimuli in Experiment 1 are the same as those used by Stolz and Neely (1995) in their original experiment examining the joint effects of semantic context, stimulus quality and strength of association. An alternative explanation of the patterns of data found in Stolz and Neely (1995) and here in Experiment 1 is simply that it is the result of the particular word list that was used. Due to the way in which items were chosen for that experiment, individual targets were preceded only by strong or weak-associate prime words (i.e., not both). Thus, it may be that the targets used in the weak-associate pairings do not show the typical interaction between stimulus quality and semantic context, but that a different set of weak-associate prime-target pairings would show a different pattern. It may also be a quirk of this particular item list that the interaction between strength of association and context that is predicted by Stolz and Neely's (1995) time-course account is not detected.

To test the idea that it is the prime item that is driving the complex pattern of data observed here, and to rule out the possibility that the results are simply due to a list effect, a new list of stimuli were selected for Experiment 2. In this stimulus list, the same targets are preceded by both strong- and weak-associate primes, counterbalanced across participants. Since the same items now make up both the weak- and strong-associate target lists, any difference between strength of association conditions cannot be attributed to target-specific characteristics, as might be the case in Stolz and Neely (1995) and Experiment 1 here. On the other hand, if the three-way interaction found in Experiment 1 (and in Stolz & Neely, 1995) is once again observed using this new stimulus list, I can conclude that strength of association directly influences the interaction between stimulus quality and context. Furthermore, because trial types are inter-mixed here (as in Experiment 1), eliminating the interaction between stimulus quality and context in the weak-associates condition would support the hypothesis of a control mechanism that relies on both local and global information.

Experiment 2

Method

Participants.

Seventy-three University of Waterloo undergraduate students took part in the experiment for payment or credit towards undergraduate psychology courses. All spoke English as a first language and all had normal or corrected-to-normal vision.

Design.

The same repeated measures design as in Experiment 1 was used.

Stimulus materials and list construction.

In order to counterbalance targets across strength of association conditions, a new stimulus list was assembled using Nelson, McEvoy, and Schreiber's association norm database (1998). Ninety-six targets were selected that are the strongest associate to both a high- and low-association strength cue word (prime). For example, while PUSH is the strongest associate for both SHOVE and FORCE, it is much more strongly associated with SHOVE (0.94) than with FORCE (0.15). Thus I have one prime-target pairing for each of the strength of association lists, using the same target (SHOVE-PUSH for the strong associate list, and FORCE-PUSH for the weak associate list). This stimulus list appears in Appendix C. The same 48 prime-target nonwords pairs used in Experiment 1 were retained. All other features of the stimulus set were identical to those in Experiment 1.

Procedure.

The procedure was identical to that used in Experiment 1.

Results

Data for seven subjects were discarded from the analysis due to excessive error rates on non-word trials (greater than 30% in the bright condition). Two more subjects were identified as outliers (one in the main effect of stimulus quality, the other in the main effect for strength of association – all outliers scored more than 3.5 standard deviations from the mean on the relevant factor) and also dropped from further analysis. For the remaining 64 subjects, errors accounted for 1.4% of word trials and are excluded from further analysis. Only correct responses to the target words were included in the analysis of the RT data. The remaining data were submitted to a recursive outlier analysis (Van Selst & Jolicoeur, 1994), which resulted in the further elimination of 2.8% of the data. Mean reaction times and percentage errors for each condition are presented in Table 2. Individual participant data for Experiment 1 can be found in Appendix D.

Table 2 - Experiment 2: Mean Reaction Time (ms) and Percentage Error (%) for Targets as a Function of Semantic Context, Strength of Association, and Stimulus Quality.

	Strong Associates				Weak Associates			
	Clear		Dim		Clear		Dim	
	RT	Error	RT	Error	RT	Error	RT	Error
Related	530	0.7	583	1.6	528	0.7	602	2.1
Unrelated	553	0.7	634	2.5	549	0.8	618	2.5
Difference	**23**	**0.0**	**51**	**0.9**	**21**	**0.1**	**16**	**0.4**

The mean RTs for each subject in each condition were submitted to a 2 x 2 x 2 within-subject ANOVA. There are significant main effects of relatedness ($F(1, 63) = 52.4$, $MSE = 1871$, $p < .001$), and stimulus quality ($F(1, 63) = 172.7$, $MSE = 3562$, $p < .001$); but not of strength of association ($F(1, 63) < 1$, $p > .70$). Of the second order interactions, the interaction between context and strength of association is significant ($F(1, 63) = 4.4$, $MSE = 2519$, $p < .05$). The interaction between stimulus quality and context is marginally significant ($F(1, 63) = 2.9$, $MSE = 1698$, $p = .095$), while the interaction between strength of association and stimulus quality is not significant ($F(1, 63) < 1$, $p > .5$). Finally, the third order Stimulus Quality x Context x Strength of Association interaction is marginal ($F(1, 63) = 3.3$, $MSE = 2605$, $p = .073$). As before, Experiment 2 offers us the opportunity to test for the interaction between strength of association and context for bright trials that is predicted by the time-course account. Here again, I find no evidence for that interaction ($F(1,39) < 1$, $MSE= 69.1$, $p > .8$). The error data are not suitable for analysis due to a large number of zeroes in the subject data.

As in Experiment 1, I carried out planned t tests of the two interactions between stimulus quality and context (strong associates at +28 ms. and weak associates at -5 ms.)[5]. As in Experiment 1, it is clear that the interaction is present for the strong associate trials ($t(64) = 2.98$, $p < .01$), but not for the weak associate trials ($t(64) < 1$, $p > .70$).

Discussion

Experiment 2 confirms that, when RP = .5, the relation between strength of association, semantic priming and stimulus quality reported by Stolz and Neely (1995) and here in Experiment 1 are likely not driven by the particular targets used: even when targets are counterbalanced across conditions, the pattern of results found in Experiment 1 hold.

That is, once again the interaction between stimulus quality and context (observed for strong associates) is eliminated when the prime-target pairs are only weakly associated. Finally, there are now three experiments (Experiments 1 & 2 here, and Stolz & Neely, 1995) that fail to produce the interaction between strength of association and context for bright trials that is predicted by Stolz and Neely's (1995) time-course account.

General Discussion

Stolz and Neely (1995) evaluated the ability of a number of accounts to explain both the typical over-additive effects of stimulus quality and context, and the additive joint effects of these same factors when relatedness proportion is low or strength of association is weak. Automatic spreading activation, semantic matching/compound cueing, and expectancy-based accounts were all found to be lacking. Instead, Stolz and Neely (1995) proposed two accounts (one for relatedness proportion, and one for strength of association) that are based on Besner and Smith's (1992) interactive activation framework (see Figure 1). For relatedness proportion, Stolz and Neely (1995) proposed a control mechanism that is able to track the proportion of related trials within an experimental block. This control mechanism is proposed to toggle feedback from the semantic system to the orthographic system (on or off) in an effort to conserve spreading activation: If only a few trials are related then feedback from semantics is not helpful. On the majority of trials this feedback increases competition within the orthographic system by activating lexical entries that are unlikely to be the eventual target. This account relies on the notion of a monitor that tracks the global context of the experiment and determines whether or not the feedback is useful enough to justify the increased activation throughout the orthographic system. A consequence of turning off the feedback from semantics is that the interaction between stimulus quality and context is eliminated since semantic information (where context is thought to have its influence) no longer finds its way into the lexical system.[6]

For strength of association, Stolz and Neely (1995) proposed that the elimination of the interaction resulted from different time-courses of processing. This time-course account argues that activation spreads more slowly from prime to target when the pair is weakly associated. In the experiment with a short prime target SOA, the argument goes, activation is too slow to produce detectable effects in the lexical system. I earlier highlighted two problems with this account. The first is with the assumption that activation would not spread fast enough for weak associates to produce a context effect in the lexical system. It seems unlikely that 800 msecs (the time between prime and the average time to produce a response to the target) is not enough time to produce at least some interaction between stimulus quality and context, no matter how weakly associated the cue-target pairs. Furthermore, this account predicts that there should be a larger context effect for strongly associated prime-target pairs than for weakly associated prime-target pairs, even in the bright condition. This pattern is not found in Stolz and Neely's data (1995) nor in either of the two experiments reported here.

Here I propose a new account and suggest that Stolz and Neely's (1995) account of relatedness proportion can be extended to strength of association, with some modification. Stolz and Neely's control mechanism monitors global contextual information to determine whether, across several trials, feedback served a useful function. Such a control mechanism can successfully account for the effect of manipulating relatedness proportion or strength of association across blocks, since the participant can predict the utility of feedback on the next trial. However, a control mechanism relying only on global contextual information cannot account for the finding in Experiments 1 and 2 here that strength of association mediates the joint effects of stimulus quality and semantic context even when trials of differing association strengths are *intermixed*. If only global information were being used, inter-mixing trial types should either dilute the global strength-of-association enough for the control monitor to turn off feedback, or it should not, but the same context should apply to all trials within the experiment. Thus the significant three way interaction reported in Experiments 1 and 2 here (stimulus quality x context x strength of association such that stimulus quality and context are over-additive for strong associates but additive for weak associates when the two types are inter-mixed) cannot be reconciled with a purely global account. The participant is unable to predict the potential trial-type; therefore, the information required by the monitor must be available within the trial, but before the target arrives. Any control mechanism operating here must operate at a very local level. The only event within a trial that precedes target processing is the onset of the prime. Thus, whatever local information the monitor is using must be available during prime processing.

Strength of Association as a Proxy for Number of Associates

In the Nelson, McEvoy, and Schreiber (1998) corpus used to produce the stimulus lists in Stolz and Neely (1995) and here, there is a very close link between the number of associates each cue produces and the strength of association between the cue and its most strongly associated word. Indeed, for the 5,018 cue words in the data set the correlation between the maximal association strength and the number of associates is -0.75[7]. That is, the more associates a cue has, the weaker the association strength tends to be for the strongest associate. This is unsurprising since the association strength between a prime and target represents the proportion of participants who, when given the prime, respond with the target in a free association task (e.g., 94% of participants given the cue SHOVE, respond with

PUSH so that the pair SHOVE-PUSH has a strength of association of 0.94). Consequently when a word has a very strong associate (as in SHOVE-PUSH), there is room for only a few other associates while a prime who's strongest associate is relatively weakly associated (as in CARPET-RUG, with a strength of association of only 0.25) there is ample room for a large number of alternative associates.

Given the strong relationship between strength of association and number of associates it can be suggested that the local control monitor uses a rule based on the number of concepts in the semantic system that are activated by the prime to determine whether or not feedback from the semantic system to the orthographic input lexicon will be useful or not. If a prime results in activation for 20 potential targets at the semantic level, feedback from the semantic system will only increase the amount of noise in the orthographic input lexicon. To reduce the noise, feedback is turned off for the duration of the trial, reducing competition from irrelevant associates at the orthographic level, which in turn helps in subsequent target processing. A consequence of using this local control mechanism is that the interaction between stimulus quality and relatedness proportion is eliminated.

Plaut and Booth (2000, 2006)

To date, few implemented models of visual word recognition have attempted to address the pattern of data reported in Stolz and Neely (1995). One notable exception is the PDP model proposed by Plaut and Booth (2000). In it, Plaut and Booth successfully produce the interaction between stimulus quality and context that is found for strong associates and for blocks with a high relatedness proportion. Though they do not attempt to simulate the additive effects observed between semantic relatedness and stimulus quality when strength of association is weaker, or when the proportion of related trials is reduced[8], they do claim to successfully produce additive effects of two other factors in their model: stimulus quality and word frequency. It seems reasonable to suppose that if the model is capable of producing additivity between these two factors it might also be capable of producing the additive effects discussed here with some work. However, it is important to note that the model's success in this respect has been questioned (see also Besner & Borowsky, 2006; Borowsky & Besner, 2006 versus Plaut & Booth, 2006). More recently, Besner, Wartak & Robidoux (2007) reported a number of new simulations suggesting that the simulations reported in Plaut and Booth (2000) do not provide an accurate representation of intact and skilled human readers performance in lexical decision. Testing the model more extensively, they found that additivity is the exception rather than the rule and occurs only under very narrow circumstances (a small range of stimulus quality). This point is not insignificant given that stimulus quality and word frequency are additive in humans across a wide range of experimental manipulations.

Control in PDP models.

It may be possible for specific instantiations of PDP models, such as the one proposed by Plaut and Booth (2000), to produce additivity in some circumstances (though this remains to be demonstrated). Another challenge for such modelers is to account for how control might be exerted. In models where the weights are trained it will be difficult to determine what combination of weights should be modified to produce key findings such as those in Stolz and Neely (1995), and here. Processing in such a model will have to be much more dynamic than is currently the case in any PDP models I have seen.

Conclusion

Stolz and Neely (1995) reported data that suggested the need for a control mechanism in order to explain the elimination of the (typically reported) interaction between stimulus quality and semantic context when the proportion of related trials is low, or when the strength of association between related pairs is weak. The data they reported could be parsimoniously accounted for by assuming this monitor relied on conditions across a number of trials (or, in the terms described here, the global experimental context) because relatedness proportion and strength of association were blocked factors in their experiments. The present experiments produced identical results (a three way interaction between strength of association, stimulus quality, and context such that the interaction between stimulus quality and context is present for strongly associated prime-target pairs but absent for weakly associated prime-target pairs) even when trials with different strengths of association are intermixed. These results cannot be accommodated by a global monitor alone. Instead they imply that the monitor must be relying in part on information within each trial and making the adjustment before the target appears. In order to exert control soon enough (before processing of the target begins) the control mechanism must be relying on information available during prime processing. I propose that a strength of association manipulation is confounded with the number of associates for a prime, and that it is this information that the mechanism relies on to make adjustments to the feedback from semantics to the orthographic input lexicon during prime processing (and before target processing).

The results of the two experiments reported here are consistent with the assumptions of two forms of control over feedback from semantics to the lexical level in the context of semantic priming in lexical decision. The state of one is global and is set by an estimate of the relatedness proportion across a block of trials. If the proportion is high then feedback is operative whereas if the proportion is low then feedback is blocked. A second form of control is local, and operates within a trial. The estimate of strength of association is set by the prime. If the strength of association is strong (and thus only a few potential associates are activated) then feedback is operative but if the strength of association is weak (and a large number of potential associates are activated) than feedback is blocked for both prime and target processing.

Ferguson, Robidoux, and Besner (2007) have shown that the three-way interaction between context, stimulus quality, and relatedness proportion extends to reading aloud and discussed the implications for models of visual word recognition that include phonology (e.g., Coltheart et al.'s (2001) Dual Route Cascaded model). Future work should seek to establish whether the three-way interaction observed here (between context, stimulus quality and strength of association) when trials of all types are intermixed is also seen in the context of reading aloud. Whether the framework proposed here to account for the data proves useful or not for guiding future work remains to be seen. Whatever explanatory framework is adopted, it will have to be able to accommodate the three-way interaction between stimulus quality, semantic priming and strength of association that is now reasonably well established.

Endnotes

[1] Note this second result regarding the strength of association only obtains at a relatively short stimulus onset asynchrony of 200 ms. Stolz and Neely (1995) report that the interaction between stimulus quality and semantic context is unaffected by strength of association when the SOA is increased to 800 ms.

[2] One of Wilding's experiments, with a long ITI, produced an interaction, as did the long ITI condition in Norris (1984). Wilding attributed the interaction to the joint effects of the long fore-period and attention, arguing that it had nothing to do with reading related processes.

[3] Note that there is some debate in the literature about whether or not this result extends to reading aloud. Yap and Balota (2007) have demonstrated that stimulus quality and word frequency interact in reading aloud. O'Malley and Besner (2007) however, have found that this result is mediated by the presence of nonwords in the experiment (typically absent in reading aloud tasks).

[4] One of Wilding's experiments, with a long ITI, produced an interaction, as did the long ITI condition in Norris (1984). Wilding attributed the interaction to the joint effects of the long fore-period and attention, arguing that it had nothing to do with reading related processes.

[5] Although the third-order interaction is only marginally significant in experiment 2, I feel confident in proceeding with the a priori tests since the trend is clearly in the same direction as the significant interaction in Experiment 1, and represents the third report of this

pattern (including Experiments 1 & 2 here, and Stolz & Neely, 1995). Suspicions that the marginal significance can be attributed to a lack of power are confirmed given that when the two experiments are combined in a 2 x 2 x 2 x 2 ANOVA (Stimulus Quality x Context x Strength of Association x Experiment) the four-way interaction is not significant, but the increased power now yields a significant three-way interaction (Stimulus Quality x Context x Strength of Association; $F(1,102) = 7.5$, $MSE = 2467.8$, $p < .01$).

[6] It should be noted that some models carry out the lexical decision task, not by monitoring individual representations until one meets a response threshold, but by monitoring the global activation of the lexical level (see for instance Coltheart et al.'s Dual Route Cascaded model, 2001; or Grainger & Jacobs, 1996). In such models, the lexical decision is made when there is enough activation in the lexical level that the likelihood of a word being present is high.

[7] In the set of cue-target pairs used in the present experiments the correlation between strength of association and number of associates is -0.93 for Experiment 1 and -0.91 for Experiment 2. The stronger relationships arise because I have sampled items only from the extremities of the overall distribution in the full Nelson, McEvoy, and Schreiber corpus.

[8] Indeed, Plaut and Booth (2006) appear sceptical of this result.

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Appendix A – Experiment 1 Stimuli

High Strength of Association Pairs				Low Strength of Association Pairs			
Cue	**Target**	**SoA**	**Set Size**	**Cue**	**Target**	**SoA**	**Set Size**
shove	push	0.94	2	butter	bread	0.36	15
weep	cry	0.92	3	deep	shallow	0.31	13
east	west	0.89	4	blue	sky	0.28	14
keg	beer	0.88	4	death	life	0.27	15
husband	wife	0.88	4	beg	plead	0.25	18
text	book	0.88	5	carpet	rug	0.25	17
bride	groom	0.87	4	surprise	party	0.25	14
trousers	pants	0.85	5	yard	grass	0.24	15
assist	help	0.84	3	beauty	beast	0.23	17
day	night	0.82	6	away	far	0.23	17
thunder	lightning	0.82	6	grape	vine	0.22	17
icing	cake	0.81	9	theory	idea	0.22	25
frame	picture	0.81	7	basket	weave	0.21	19
hive	bee	0.81	5	bug	insect	0.20	16
broth	soup	0.81	4	demand	want	0.19	16
brawl	fight	0.80	4	door	open	0.18	23
hammer	nail	0.80	7	land	sea	0.18	25
despise	hate	0.80	5	honest	truth	0.18	18
exam	test	0.78	7	air	breathe	0.18	17
pistol	gun	0.77	10	hole	ground	0.17	24
north	south	0.77	9	justice	law	0.17	15
king	queen	0.77	8	water	drink	0.17	18
question	answer	0.77	6	catch	throw	0.16	19
sketch	draw	0.76	8	chance	luck	0.16	19
win	lose	0.76	7	average	normal	0.16	19
table	chair	0.76	10	sharp	dull	0.16	18
pony	horse	0.75	5	report	card	0.15	23
attempt	try	0.75	8	stay	leave	0.15	19
petals	flowers	0.75	3	safe	secure	0.15	21
aunt	uncle	0.75	3	master	slave	0.14	24
brother	sister	0.75	10	decide	choose	0.14	14
hog	pig	0.74	9	health	sick	0.14	21
spool	thread	0.74	5	view	look	0.14	18
girl	boy	0.74	8	show	tell	0.13	24
father	mother	0.71	4	school	work	0.13	22
stumble	fall	0.71	4	ability	capable*	0.12	22
false	true	0.70	4	turn	off	0.12	21
top	bottom	0.70	11	hold	grasp	0.11	17
canary	bird	0.69	4	dishes	plates	0.10	19
banner	flag	0.69	6	coast	beach	0.10	22

High Strength of Association Pairs				Low Strength of Association Pairs			
Cue	**Target**	**SoA**	**Set Size**	**Cue**	**Target**	**SoA**	**Set Size**
globe	world	0.68	10	lace	shoe*	0.10	24
look	see	0.68	11	retreat	run	0.10	27
hot	cold	0.68	8	busy	bored	0.10	24
dog	cat	0.67	5	space	stars	0.09	25
rich	poor	0.66	7	snake	rattle	0.08	21
paste	glue	0.63	4	plan	organize	0.08	28
dagger	knife	0.61	10	clothes	wear	0.08	26
gift	present	0.61	16	riot	mob	0.08	20

* Where the prime was contained within the target of a prime-target pair (e.g., LACE-SHOELACE), Stolz and Neely (1995) modified the target to eliminate the overlap (e.g., LACE-SHOE).

Appendix B – Subject Data from Experiment 1

	REACTION TIMES (ms)								PERCENTAGE ERRORS (%)							
	Bright				Dim				Bright				Dim			
	Related		Unrelated		Related		Unrelated		Related		Unrelated		Related		Unrelated	
	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong
1	606	636	701	651	707	651	814	830	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
2	519	471	575	577	549	514	658	613	0.0	8.3	0.0	0.0	0.0	0.0	8.3	0.0
3	581	554	589	599	586	538	693	668	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0
4	457	461	508	459	484	459	538	513	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0
5	636	616	644	608	702	558	671	722	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	522	561	633	553	634	640	678	686	0.0	0.0	8.3	0.0	0.0	8.3	8.3	8.3
7	452	489	480	488	532	487	593	608	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	556	557	572	551	785	509	605	665	0.0	0.0	16.7	0.0	8.3	0.0	8.3	0.0
9	583	517	558	665	689	643	669	680	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	728	674	829	833	725	753	959	950	0.0	8.3	0.0	0.0	0.0	0.0	0.0	8.3
11	546	477	632	553	554	514	527	567	0.0	0.0	0.0	8.3	0.0	0.0	8.3	0.0
12	637	586	564	589	569	531	773	575	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
13	481	503	485	560	519	541	613	544	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
14	510	553	680	637	618	602	746	811	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
15	497	503	586	547	703	732	892	883	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
16	590	504	570	572	754	630	741	717	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
17	480	459	508	575	586	574	615	594	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	670	643	1,004	676	730	746	889	882	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	489	559	525	548	543	533	623	582	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7
20	504	529	698	550	774	675	699	719	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	548	520	513	517	611	540	619	575	0.0	0.0	0.0	0.0	16.7	0.0	8.3	0.0
22	569	651	715	636	848	804	996	943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	731	644	715	613	706	583	796	644	0.0	0.0	0.0	16.7	0.0	0.0	8.3	0.0
24	492	525	566	679	593	713	595	587	8.3	8.3	8.3	0.0	0.0	0.0	0.0	8.3

	REACTION TIMES (ms)								PERCENTAGE ERRORS (%)							
	Bright				Dim				Bright				Dim			
	Related		Unrelated		Related		Unrelated		Related		Unrelated		Related		Unrelated	
	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong
25	453	466	465	494	580	591	624	675	0.0	0.0	8.3	0.0	0.0	0.0	0.0	25.0
26	623	539	489	533	608	503	601	537	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
27	744	611	771	746	704	650	843	827	0.0	0.0	0.0	8.3	0.0	0.0	0.0	8.3
28	544	527	564	518	673	528	679	638	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
29	644	566	647	774	839	711	814	1,002	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
30	617	669	618	629	740	691	662	733	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
31	499	468	537	555	689	489	597	613	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0
32	500	474	543	553	531	540	588	603	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
33	540	472	670	549	613	587	678	729	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0
34	471	492	541	482	572	580	737	582	0.0	8.3	16.7	0.0	0.0	0.0	16.7	8.3
35	849	782	719	707	991	888	963	883	0.0	8.3	0.0	0.0	0.0	8.3	25.0	0.0
36	630	593	732	695	618	555	820	696	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	488	490	612	497	562	600	563	560	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
38	612	567	734	707	652	618	718	758	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
39	553	511	529	521	582	552	580	663	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	641	727	742	690	675	728	725	840	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3

Appendix C – Experiment 2 Stimuli

Target	Strong Cue	SoA	Set Size	Weak Cue	SoA	Set Size
jeans	denim	0.81	6	pocket	0.12	18
square	rectangle	0.72	7	box	0.19	15
end	beginning	0.75	4	result	0.20	17
pen	ink	0.70	10	marker	0.26	20
deer	doe	0.72	8	hunting	0.15	15
girl	boy	0.70	10	gal	0.33	12
salt	pepper	0.70	6	seasoning	0.30	10
high	low	0.78	6	stoned	0.23	13
cake	icing	0.81	9	dessert	0.15	13
talk	discuss	0.69	6	comment	0.13	20
king	queen	0.73	7	empire	0.10	25
boat	row	0.74	9	starboard	0.14	14
can	opener	0.77	4	aluminum	0.32	8
belt	buckle	0.67	7	sash	0.14	19
see	look	0.68	11	notice	0.13	14
angel	halo	0.65	9	saint	0.09	24
bear	grizzly	0.72	8	fuzzy	0.19	19
gas	fuel	0.66	5	pump	0.20	21
help	assist	0.84	3	benefit	0.17	21
back	front	0.72	5	retreat	0.12	27
fall	stumble	0.71	4	faint	0.21	18
corn	cob	0.88	2	stalk	0.13	25
bone	marrow	0.78	4	hip	0.19	18
beer	keg	0.88	4	bottle	0.13	20
tired	exhausted	0.89	3	lazy	0.14	19
wrong	incorrect	0.67	6	invalid	0.16	19
nut	cashew	0.75	6	squirrel	0.30	11
close	open	0.72	5	intimate	0.26	20
clam	chowder	0.76	4	mussel	0.30	11
sick	ill	0.82	6	health	0.14	21
bread	rye	0.79	2	roll	0.16	20
cow	moo	0.96	2	leather	0.10	20
run	jog	0.78	4	hit	0.16	18
lie	fib	0.82	4	betray	0.09	17
sleep	nap	0.73	11	relax	0.15	20
puzzle	jigsaw	0.84	6	pieces	0.34	14
teeth	gums	0.71	9	grind	0.11	23
two	one	0.70	6	double	0.20	16
mistake	error	0.68	5	folly	0.08	13
laugh	giggle	0.78	7	ridicule	0.15	18
airplane	flight	0.67	9	controls	0.14	23

Target	Strong Cue	SoA	Set Size	Weak Cue	SoA	Set Size
old	new	0.72	10	musty	0.11	17
fish	salmon	0.75	6	catch	0.16	19
spaghetti	meatballs	0.68	11	noodles	0.24	17
cry	sob	0.76	4	onion	0.21	15
book	library	0.79	4	fiction	0.20	16
work	labor	0.69	10	school	0.13	22
rabbit	bunny	0.73	7	carrots	0.20	12
poor	rich	0.66	7	ghetto	0.13	20
church	cathedral	0.72	9	holy	0.14	15
cute	adorable	0.69	8	handsome	0.20	13
pig	hog	0.74	9	ham	0.19	18
cat	meow	0.84	3	claw	0.18	15
blood	plasma	0.82	4	cut	0.17	21
picture	frame	0.81	7	hang	0.09	29
rock	boulder	0.66	8	music	0.15	25
leg	arm	0.67	6	crutch	0.16	21
light	bulb	0.79	7	aura	0.13	18
fruit	kiwi	0.71	6	forbidden	0.12	20
kill	slay	0.69	6	destroy	0.20	24
card	credit	0.65	9	report	0.15	23
tear	rip	0.71	9	fray	0.11	26
baby	crib	0.84	4	powder	0.15	17
shoes	socks	0.66	4	platform	0.26	12
shy	bashful	0.73	4	modest	0.31	14
window	pane	0.83	3	glass	0.14	21
gun	pistol	0.77	10	bang	0.28	17
add	subtract	0.69	6	sum	0.28	11
fire	blaze	0.81	6	camp	0.14	19
push	shove	0.94	2	force	0.18	17
cold	chill	0.73	9	symptom	0.16	16
loud	noisy	0.67	8	noise	0.34	14
soup	broth	0.81	4	chicken	0.09	29
land	acre	0.67	9	frontier	0.14	24
funny	hilarious	0.81	5	silly	0.18	16
north	south	0.69	7	direction	0.16	24
bad	good	0.76	8	crime	0.10	24
stop	halt	0.91	2	blockade	0.15	17
hat	cap	0.71	6	straw	0.25	16
test	quiz	0.79	5	score	0.16	18
lost	found	0.81	5	confusion	0.07	29
street	avenue	0.68	4	corner	0.14	22
forward	backward	0.71	7	advance	0.23	21
clothes	attire	0.65	6	fit	0.08	21

Target	Strong Cue	SoA	Set Size	Weak Cue	SoA	Set Size
train	caboose	0.72	8	rail	0.25	14
butter	margarine	0.86	4	melt	0.19	17
sister	brother	0.75	10	sibling	0.30	12
dog	hound	0.79	5	shed	0.09	26
fly	swatter	0.75	8	superman	0.16	18
pool	chlorine	0.66	7	gene	0.17	18
try	attempt	0.75	8	strive	0.17	18
time	clock	0.65	7	date	0.14	20
happy	joyous	0.67	8	cheer	0.14	21
headache	migraine	0.80	6	advil	0.18	13
smell	odor	0.70	6	essence	0.10	20
steak	sirloin	0.81	5	meat	0.18	17

Appendix D – Subject Data from Experiment 2

	REACTION TIMES (msecs)								PERCENTAGE ERRORS (%)							
	Bright				Dim				Bright				Dim			
	Related		Unrelated		Related		Unrelated		Related		Unrelated		Related		Unrelated	
	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong
1	419	427	419	423	536	516	485	595	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	454	465	514	441	481	529	542	513	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
3	571	533	620	644	878	618	571	795	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	649	599	614	563	642	534	655	698	0.0	0.0	0.0	0.0	8.3	0.0	0.0	8.3
5	461	472	480	467	529	578	545	597	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
6	500	447	543	488	557	556	572	709	0.0	0.0	0.0	0.0	0.0	8.3	8.3	0.0
7	624	622	627	650	690	599	733	870	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
8	432	419	484	457	497	519	607	564	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
9	571	638	567	597	700	707	706	780	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	512	692	563	589	546	641	608	774	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	512	527	569	619	666	643	687	677	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
12	491	474	491	502	623	535	544	585	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
13	516	478	491	498	587	594	684	631	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	414	426	434	478	559	482	538	490	0.0	8.3	0.0	0.0	16.7	0.0	0.0	8.3
15	517	590	531	520	577	589	644	589	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0
16	476	453	495	502	504	552	533	574	0.0	0.0	8.3	8.3	8.3	8.3	0.0	16.7
17	477	515	555	533	572	585	566	599	0.0	0.0	0.0	0.0	0.0	8.3	8.3	0.0
18	636	650	772	680	733	689	749	705	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
19	398	381	388	457	445	444	480	473	0.0	0.0	0.0	8.3	16.7	8.3	0.0	0.0
20	486	490	572	519	561	543	577	568	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
21	473	454	501	646	540	522	603	604	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	548	570	490	522	652	602	692	611	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
23	426	456	473	521	559	653	521	604	0.0	0.0	8.3	0.0	0.0	0.0	0.0	8.3
24	493	542	515	540	699	587	678	685	0.0	0.0	0.0	0.0	0.0	8.3	0.0	8.3
25	489	470	531	566	574	635	683	628	8.3	0.0	0.0	0.0	8.3	0.0	8.3	0.0

	REACTION TIMES (msecs)								PERCENTAGE ERRORS (%)							
	Bright				Dim				Bright				Dim			
	Related		Unrelated		Related		Unrelated		Related		Unrelated		Related		Unrelated	
	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong
26	417	397	423	469	494	499	520	532	0.0	0.0	0.0	8.3	16.7	8.3	0.0	0.0
27	505	684	765	674	700	623	700	703	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
28	530	476	556	585	483	483	580	532	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	617	643	722	610	748	571	640	671	0.0	0.0	0.0	8.3	8.3	0.0	0.0	0.0
30	574	568	561	580	619	721	811	685	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	428	464	422	429	492	532	615	613	0.0	0.0	8.3	0.0	0.0	0.0	8.3	16.7
32	454	454	478	432	494	500	481	507	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	478	506	480	541	522	512	539	549	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	530	461	447	492	582	557	559	583	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
35	519	527	513	569	567	581	567	609	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7
36	460	494	474	549	571	515	608	548	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	713	773	715	898	752	662	907	767	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
38	440	449	450	456	514	490	475	546	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	481	526	660	559	591	577	578	821	0.0	0.0	0.0	0.0	0.0	0.0	8.3	16.7
40	518	509	521	500	725	638	670	653	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	489	507	531	566	598	568	599	612	0.0	0.0	8.3	0.0	0.0	0.0	16.7	0.0
42	680	606	682	699	628	617	648	671	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
43	528	552	623	525	611	580	610	631	0.0	0.0	0.0	0.0	8.3	8.3	16.7	0.0
44	453	444	562	473	511	510	575	555	0.0	0.0	0.0	0.0	0.0	0.0	8.3	8.3
45	639	556	583	687	584	587	695	695	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
46	523	497	539	512	516	546	531	587	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
47	473	463	535	466	589	525	572	611	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	559	462	486	511	527	504	562	567	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0
49	493	486	490	541	604	606	561	682	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	563	526	594	488	545	532	605	582	0.0	8.3	0.0	0.0	0.0	0.0	8.3	0.0
51	425	428	456	426	589	521	562	593	16.7	0.0	0.0	0.0	8.3	16.7	0.0	0.0

	REACTION TIMES (msecs)								PERCENTAGE ERRORS (%)							
	Bright				Dim				Bright				Dim			
	Related		Unrelated		Related		Unrelated		Related		Unrelated		Related		Unrelated	
	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong
52	623	546	648	609	663	757	721	755	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	560	557	516	546	614	582	641	614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	543	600	600	641	644	599	587	630	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
55	617	555	581	575	604	572	618	686	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	554	440	542	547	605	503	570	593	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	631	782	749	642	798	795	989	749	0.0	0.0	8.3	0.0	0.0	0.0	8.3	0.0
58	562	627	543	553	787	539	660	602	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
59	547	541	550	535	574	600	585	600	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
60	518	572	576	594	596	625	592	688	8.3	0.0	0.0	0.0	8.3	0.0	0.0	0.0
61	436	444	418	445	536	498	506	503	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	640	582	574	651	733	692	573	700	0.0	0.0	0.0	8.3	0.0	0.0	0.0	8.3
63	730	718	616	675	628	771	828	727	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
64	812	733	697	716	674	774	721	733	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0