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Investigating the Role of Open Bigrams in Visual Word Perception

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INVESTIGATING THE ROLE OF OPEN BIGRAMS IN VISUAL WORD PERCEPTION

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To my parents…

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INVESTIGATING THE ROLE OF OPEN BIGRAMS IN WORD PERCEPTION

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ABSTRACT

Many models of word identification suppose a hierarchical system in which units at increasing levels respond to features, letters, letter combinations, and words. Some models suppose units responsive to bigrams—letter pairs—that may not be adjacent in a letter-string stimulus. In such a model, a stimulus such as BIRD would activate, at the bigram level, bigrams representing adjacent letters BI, IR, and RD, and also bigrams representing nonadjacent letters BR and ID. Grainger, Mathot, and Vitu (2014) reported an experiment in which strings to be classified as words or pseudowords were flanked by bigrams from the target string or not; for flanking bigrams consisting of target-string letters, the order of the bigrams was as in the target string or switched, and the order of letters within the bigrams was as in the target string or switched. For example, BIRD could appear with these flankers: BI BIRD RD; RD BIRD BI; IB BIRD DR; DR BIRD IB; CE BIRD NT. Grainger et al. (2014) found, for words, better performance when flanking bigrams contained target-string letters (e.g., BI BIRD RD; RD BIRD BI; IB BIRD DR; DR BIRD IB) than when they did not (e.g., CE BIRD NT); and better performance when flanking bigrams contained letters ordered as in the target (e.g., BI BIRD RD; RD BIRD BI) than switched (e.g., IB BIRD DR; DR BIRD IB); but whether flanking bigrams were ordered as in the target did not affect performance. We investigated whether flanking *open* bigrams facilitate lexical decisions. Experiment 1 investigated performance in the conditions from Grainger et al. (2014). The results of Experiment 1 essentially replicated those of Grainger et al. (2014). Experiment 2 included four additional conditions in which the flanking bigrams consist of letters

separated by one letter in the target (e.g., BR BIRD ID; ID BIRD BR; RB BIRD DI; DI BIRD RB). Importantly, results of Experiment 2 indicate that performance is better when flankers contain letters that are ordered as they are in the target, and this letter order effect does not depend on whether the flankers are adjacent-letter bigrams, or open bigrams.

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CHAPTER I

INTRODUCTION

Although there are numerous models of how we perceive words, many investigators of word identification assume information is processed through a hierarchical system: From the letters in a string of letters, features are processed; from these, units that represent letters are activated; and activated letter representations activate word representations in a mental lexicon. From among the representations in the mental lexicon, the most activated representation is assumed to be that of the presented word (e.g., McClelland & Rumelhart, 1981; Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & Zeigler, 2011). Various models of word recognition differ in how intermediate levels are specified, as well as in what representational subunits are assumed to contribute to word recognition. For example, McClelland and Rumelhart's (1981) computational model includes three layers of units: visual features, letters, and words. Dehaene et al.'s (2005) local combination detector model, motivated by neurophysiological research, consists of a hierarchy of seven types of detectors, which code local contrasts at the lower level, and small words and morphemes at the higher level. The levels in this model include case-specific letter detectors, abstract letter detectors (which respond to letters regardless of case), and bigram detectors, which are units that are responsive to pairs of letters.

The experiments described in this thesis were conducted to investigate the contribution of bigrams to visual word perception. To explain the motivation for these experiments, the following will be reviewed: 1) Models of word perception that involve units responsive to bigrams, including open bigrams, which are nonadjacent letter pairs (e.g., Grainger & van Heuven, 2003) and supporting evidence (e.g., Dare & Shillcock, 2013; Grainger, Mathot & Vitu, 2014); and 2) challenges to the idea of open bigrams (e.g., Kinoshita & Norris, 2013; Lupker, Zhang, Perry & Davis, 2014). Then, the rationale for the current experiments will be described.

Bigrams and Open Bigrams in Models of Word Perception

Whitney (2001) proposed that there is a level of processing at which words are encoded as letter pairs. For example, the word "BIRD" would be represented by the pairs BI, BR, BD, IR, ID and RD. Of these, BI, IR, and RD are adjacent–letter bigrams, and BR, ID, and BD are open bigrams. Open bigrams offer a representation for the relative position of letters in a string (Grainger & Whitney, 2004), and contribute to accounting for two types of priming: transposition priming and relative position priming (Grainger & van Heuven, 2003). Transposition priming is the finding that responses to *garden* are faster when preceded by *gadren* than when they are preceded by *gaften*. Relative position priming is the finding that responses to *garden* are faster when preceded by the masked prime *grdn* than the unrelated masked prime *pmts*.

According to Dehaene et al. (2005), relative position priming (e.g., *grdn* primes the word *garden*) activates neurons which form a subset of the code for the complete word. This explains how relative position primes like *grdn* can prime the target *garden*, and vice versa. Similarly, Dehaene et al. (2005) explained that the neural code used to prime a target using transposition priming is minimally changed, explaining how the prime *gadren* is used to prime the target *garden*. The supportive results in the case of open bigrams indicate that as long as letter order is preserved, a subset of letters are effective as a prime (Dehaene et al., 2005).

In proposing a role for open bigrams, Dehaene et al. (2005) extended the idea suggested by Whitney (2001), Grainger and van Heuven (2003) and Grainger and Whitney (2004). Dehaene et al. (2005) proposed that the neurons that are responsive to bigrams may be activated not only by adjacent letter pairs, but by letter pairs which are separated by one or two intermediate letters. As an example, the unit responsive to the ordered pair BR would be activated not only by the stimulus word BRAN, but also by the stimulus word BIRD, in which the B precedes R but these letters are separated by one letter, and possibly also by BOAR, in which B precedes R and these letters are separated by two intermediate letters.

Dehaene et al. (2005) also provided a provisional neuronal model which attempts to explain why a sensitivity to the detection of open bigrams is a crucial phase in visual word recognition. According to Dehaene et al. (2005), starting with the neurophysiology of vision is the appropriate first step. Within their model, a variety of local combination detectors (LCDs) make up a hierarchy, attempting to help explain invariant word recognition. This hierarchy begins at a low level, where LCDs work as local shape fragment detectors. The next level involves moving up to combining fragment detectors, forming local shape detectors, and ends at higher levels, where abstract letter identities are recognized (Dehaene et al., 2005).

According to their neuronal model, Dehaene et al. (2005) explained that bigram neurons are able to respond to stimuli with selectivity, and a moderate amount of tolerance to the location of letters. These local bigram detectors offer a compromise between letter-order coding and location invariance. Local bigram detectors are able to form partial location invariance by merging activation from several individual letter detectors. Because this leads to the tolerance of inexactness in location of letters, one or two intermediate letters may be skipped (Dehaene et al., 2005).

Dare and Shillcock (2013) provided evidence for the role of bigrams in word perception using the "flanking letters lexical decision" paradigm. Dare and Shillcock (2013) demonstrated that when displays presented for a lexical decision task contained a word flanked by adjacent-letter bigrams from that word, responses were faster than those to displays in which the flanking bigrams contained letters not in the target word. Specifically, Dare and Shillcock (2013) experimented with a lexical decision task involving three types of stimuli in which two bigrams flanked each target stimulus—one on the left and one on the right: (a) "adjacent" (e.g., BI BIRD RD); (b) "reversed" (e.g., RD BIRD BI); and (c) "unrelated" (e.g., LE BIRD SH). Dare and Shillcock (2013) found that lexical decision performance was facilitated when flanking bigrams were related, orthographically, to the target word. Specifically, for high-frequency words, reaction times were nearly identical for the adjacent and reversed conditions, while unrelated flanking bigrams were responded to much more slowly (Dare & Shillcock, 2013).

Grainger, Mathot and Vitu (2014) extended the paradigm of Dare and Shillcock (2013) by adding conditions in which the order of letters in the flanking bigrams were reversed from their order in the target items. Using five flanking-bigram conditions (e.g., BI BIRD RD; RD BIRD BI; IB BIRD DR; DR BIRD IB; CO BIRD AT), Grainger et al. (2014) replicated the findings of Dare and Shillcock (2013), finding that lexical decision performance in the BI BIRD RD and RD BIRD BI conditions was better than that in the CO BIRD AT condition. Additionally, Grainger et al. (2014) confirmed their prediction that although bigram order relative to the target does not matter, letter order within the flanking bigrams does. Specifically, Grainger et al. (2014) found that when flankers were comprised of letters from target words, but ordered differently than in the targets, lexical decision performance was facilitated relative to flankers containing letters not found in the target, but the degree of facilitation was less than when the letters in the flankers were ordered as in the targets. For example, “word” responses to displays such as IB BIRD DR and DR BIRD IB were faster than responses to displays such as CO BIRD AT, but were not as fast as responses to displays such as BI BIRD RD and RD BIRD IB.

The results of Dare and Shillcock (2013) and of Grainger et al. (2014) provided supporting evidence that flanking adjacent-letter bigrams facilitate word identification, regardless of their location relative to the target, and suggest that bigrams may play a role in word identification. However, neither of these experiments examined the possible role of open bigrams in visual word identification. If words are coded by open bigrams, for example, then flanking open bigrams should also facilitate lexical decision performance relative to situations in which flanking bigrams consist of letters different than those in the target word and relative to flanking bigrams in which letters are in the target word but switched in order.

While visually fixated on a particular target, our location-specific letter detectors process the information we are viewing foveally, as well as preprocessing upcoming words that fall into the parafovea, which is an area of vision just beyond where our fixation of gaze lies (Grainger, et al., 2014; White & Reichle, 2011). While text within the parafovea is visually degraded, reading is facilitated once some preprocessing has occurred. Many experiments investigating parafoveal processing use saccade-contingent display change techniques (White & Reiche, 2011). One of these techniques is called the moving-window paradigm. Results from moving-window experiments indicate that the boundaries of parafoveal vision are approximately four characters to the left of fixation and 15 characters to the right of fixation while reading English text (McConkie & Rayner, 1975, 1976; White & Reichle, 2011). Results of this research suggest that when presented with a target flanked by sets of bigrams, information in the bigrams may be preprocessed while viewing the target,foveally. In turn, lexical decision-making of the target may be facilitated (Schotter, Angele, & Rayner, 2012).

Challenges to the Notion that Open Bigrams Are Involved in Word Perception

Several researchers have provided evidence that challenges the idea that word perception is mediated by activation of representations of open bigrams. Kinoshita and Norris (2013) hypothesized that if open bigrams are involved in word identification, as proposed by Dehaene et al. (2005) and Grainger and Whitney (2004), priming should not occur by reversed open bigrams (e.g. *tc* in *cat*), nor should priming occur by bigrams composed of letters separated by more than two spaces in the target. One fundamental assumption of open bigram models is that ordered letter pairs represent the letter order in a word, so no priming effects should occur by reversed open bigrams (e.g., *cat* should not be primed by *tc*). Kinoshita and Norris (2013) demonstrated robust priming effects when reverse bigrams were used as primes.

Another assumption of open bigram models is that bigram primes should be limited to three intervening letters. As an example, Kinoshita and Norris (2013) explained that *je* should not prime the word *judge*. However, they found robust priming effects with bigram primes that spanned three intervening letters (Kinoshita & Norris, 2013).

On the basis of these findings, according to Kinoshita and Norris (2013), models which incorporate positional noise (Dehaene et al., 2005; Grainger et al., 2006) should be ruled out. Kinoshita and Norris (2013) suggested that their results are better explained by their noisy channel model (Kinoshita and Norris, 2012) or the Spatial Coding model (Davis, 2010).

Lupker, Zhang, Perry, and Davis (2014) investigated "superset" primes, which are primes that contain all the letters of the target and additional letters. Past research has indicated that superset primes, which are created by adding a letter into the middle of the target (e.g. *juwdge*), are effective primes (e.g., of the word *judge*) because the relative position of the letters within the target is maintained (Welvaert, Farioli, & Grainger, 2008; Van Assche & Grainger, 2006). Lupker et al. (2014) compared the effects of three types of superset primes to test a prediction common to all open bigram models. Lupker et al. (2014) hypothesized that first-letter superset primes (e.g., *wjudge* to prime the target *judge*) would be more effective than last-letter superset primes (e.g., *judgew* to prime the target *judge*) and standard superset primes (e.g., *juwdge* to prime the target *judge*).

Importantly, first-letter and last-letter superset primes would also preserve the relative positions of the letters within the target.

According to Lupker et al. (2014), utilizing first-letter and last-letter superset primes should capture the underpinnings of open bigrams better than standard superset primes, because these primes would not increase the span between letters in the bigrams, which may have the potential to lessen the probability of activation for some bigrams units (i.e., using a standard superset, such as *juwdge* to prime the word *judge* may not activate bigram units *jg* and *ue*, because they are too far removed). However, Lupker et al. (2014) found that first-letter superset primes were significantly worse primes than last-letter superset and standard substitution primes. Like Kinoshita and Norris (2013), Lupker et al. (2014) suggested that the orthographic coding process may be better explained by Davis's (2010) Spatial Coding model, or the Overlap model proposed by Gomez, Ratcliff, and Perea.(2008).

Current Study

The results of Dare and Shillcock (2013) and of Grainger et al. (2014) provided supporting evidence that flanking adjacent-letter bigrams facilitate word identification, and suggest that bigrams may play a role in word identification. If words are coded by open bigrams, for example, then flanking open bigrams should also facilitate lexical decision performance relative to situations in which flanking bigrams consist of letters different than those in the target word and relative to flanking bigrams in which letters are in the target word but switched in order.

The primary purpose of this research was to investigate whether lexical decision is facilitated by flanking open bigrams. From the model discussed by Grainger et al.

(2014) (who showed that flanking adjacent-letter bigrams facilitate lexical decision), if flanking bigrams facilitate lexical decision, open bigrams consisting of nonadjacent letters should do so as effectively as bigrams consisting of adjacent letters: That model does not distinguish between these two types of bigrams. Two lexical decision experiments were conducted. The first was a replication, with English stimuli, of the research by Grainger et al. (2014), which was conducted in French. The second experiment examined the effect on lexical decision performance of open bigrams (bigrams consisting of nonadjacent letters).

CHAPTER II

METHOD

Participants

Participants were recruited from the Cleveland State University Psychology Participant Pool. For Experiment 1, usable data was collected from 25 participants. For Experiment 2, usable data was collected from 45 participants. For Experiment 1, the session length did not exceed ½ hour; for Experiment 2, the session length did not exceed 1 hour. Consent forms were signed by all participants, and the current study was approved by the University's institutional review board (IRB).

Apparatus

The stimuli were displayed on Hewlett Packard 21.5 inch color monitors. The experiments were programmed using Superlab 4.5, and responses were collected using buttons on a Cedrus RB-530 response pad (Cedrus, 2011). For words, participants were instructed to press the right (green) button, and for pseudowords, participants were instructed to press the left (red) button.

Stimuli

Word Stimuli. From the SUBTLEX-US database (Brysbaert & New, 2009; http://expsy.ugent.be/research/Rdocuments/downloads/SUBTLEXus/index.htm), 180 four-letter words were selected that satisfied the following constraints, which parallel and extend the constraints used by Grainger et al. (2014): Values of zipf, a measure of word frequency, from 4-4.5; four unique letters; and for the word 1234 (in which the digits represent the positions of the four letters) to be selected, none of 3412, 2143, 4321, 1324, 2413, 3142, and 4231 is a word. For example, "ACTS" could not be used as a word because "CATS", the permutation 2143, is a word. (Grainger et al., 2014 used a different measure for word frequency, and did not exclude words, which had flanking open bigram permutations that were words.)

An additional 10 words that satisfied these criteria were selected to be used for practice.

Pseudoword stimuli. A set of 180 pseudowords was generated using Wuggy (Keuleers & Brysbaert, 2010), a pseudoword generator. For each of the 180 words, Wuggy was used to generate a set of orthographically regular four-letter strings that conform to specified constraints. For each word, one pseudoword was selected that conformed to the constraints specified that had not been selected for some other word.

Stimulus Lists

For Experiment 1, the target stimuli consisted of 200 trials, including 100 word targets and 100 pseudoword targets. Each target occurred in one of five flanker conditions. Experiment 2 consisted of 360 target stimuli trials, including 180 word targets and 180 pseudoword targets. Each target was presented in one of nine flanker conditions. The words and pseudowords for each experiment are shown in Appendix A.

Design

Each experiment was a repeated-measures experiment, in which each participant contributed data to every flanker condition.

Experiment 1

In Experiment 1, the five flanker conditions studied by Grainger et al. (2014) were used. In four of these, the flanking bigrams contained the same letters as the target word. These four flanking conditions were constructed by crossing two levels of flanker-order, which is defined by left-to-right order of the flankers with respect to their order in the target—same and switched—with two letter orders defined by their order in the target—same and switched. Table 1A shows these four flanker conditions for the target word BIRD.

Table 1A

Stimulus Conditions in Both Experiments (Flanking Bigrams Contain Letters that are Adjacent in Target)

		Letter Order	
		Same	Switched
Flanker Order	Nearer	BI BIRD RD	IB BIRD DR
	Farther	RD BIRD BI	DR BIRD IB

In the fifth condition, the flanking bigrams were comprised of letters not found in the target. For this condition, each word and each pseudoword was paired with another word or pseudoword, respectively, to supply the flanking bigrams for the different condition. The string which supplied the flankers for the different condition was chosen at random and without replacement from the target's category of strings (for both words and pseudowords) subject to the constraint that it share no letters with the target. (This differs from the approach of Grainger et al., who chose strings to supply flankers for the different condition by selecting from the target's category with replacement.) As an example, in the different condition, flankers for the target word BIRD might be CE and NT (from the word CENT) while the flankers for the pseudoword BIRK might be CE and ST (from the pseudoword CEST).

Each participant judged each of the 200 targets (100 words and 100 pseudowords), but each participant experienced each target in only one of the five conditions. Latin squares were used to assign targets with their flankers to participants so that over panels of five participants, each target occurred once in each of the five flanker conditions. Over 25 participants, each target occurred in each flanker condition five times.

Experiment 2

The design for this experiment was similar to that of Experiment 1, but included nine flanker conditions. In addition to the five flanker conditions of Experiment 1, there were four conditions in which flankers were comprised of pairs of letters separated by one letter in the target word. Just as with the adjacent-letter flanking bigrams, these four additional conditions were constructed by crossing two levels of flanker-order, defined by the left-to-right order of the flankers with respect to their order in the target—same and switched—with two letter-orders defined by their order in the target—same and switched. Table 1B illustrates these four additional flanker conditions with the target word BIRD.

Table 1B
Additional Stimulus Conditions in Experiment 2 (Flanking Bigrams Contain Letters that are Separated by One Letter in Target)

		Letter Order	
		Same	Switched
Flanker Order	Nearer	BR BIRD ID	RB BIRD DI
	Farther	ID BIRD BR	DI BIRD RB

Each participant judged 360 targets (180 words and 180 pseudowords), but each participant experienced each target in only one of the nine conditions. Latin squares were used to assign targets with their flankers to participants, so that over panels of nine participants, each target would occur once in the each of the nine flanker conditions. Over 45 participants, each target occurred in each flanker condition five times.

Procedure

For each of the two experiments, the procedures were similar to the procedures described by Grainger et al. (2014). For Experiment 1, a 20-trial practice block preceded the main data collection block; in Experiment 2, a 36-trial practice block preceded the main data collection block. Figure 1 demonstrates a schematic trial example of what participants experienced during Experiment 1 and Experiment 2. Participants were presented with a pair of vertical lines around the upcoming target location on a computer screen for 1000ms, and were then presented with a target, surrounded by flankers for 150ms, followed by a blank screen, which remained blank until participants responded. In order for their data to be used, a participant had to be at least 80% accurate on the practice. For Experiment 1, seven participants scored below the criterion for practice trials. For Experiment 2, twelve participants scored below the criterion for practice trials.

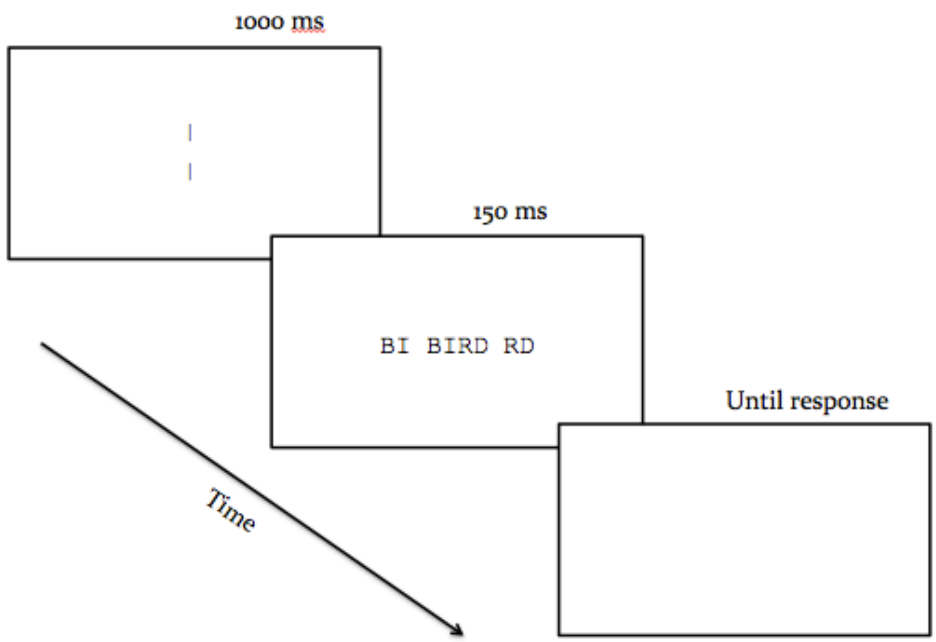

Figure 1. Schematic trial example

Data Analysis

Following Grainger et al. (2014), we analyzed inverse efficiency scores (IES), which is a measure that adjusts, for each condition, mean response time for accuracy by dividing reaction time by percentage of accurate responses (see Bruyer & Brysbaert, 2011). For our analyses, again following Grainger et al. (2014), mean response times were trimmed: For each participant, the overall mean and standard deviation of response times for correct responses were calculated; trials for which responses that differed from this mean by more than 2.5 standard deviations were eliminated.

Planned contrasts in a repeated measures analysis of variance were used as our general analytic approach. Separate analyses were conducted for responses to words and pseudowords. A comparison of responses to words and pseudowords is of little interest, but the effects of flanking bigrams on both words and pseudowords were equally relevant. Illustrated in Table 2 are the contrasts for Experiment 1, while those for Experiment 2 are shown in Table 3. For all tests, contrast-specific denominators were used, so, in Experiment 1, each test had 24 denominator degrees of freedom, and in Experiment 2, each test had 44 denominator degrees of freedom. The significance criterion of .05 was used for every contrast in each experiment.

Contrasts

For Experiments 1 and 2, the contrasts were labeled C1-C4 and C1-C8, respectively.

Contrasts in Experiment 1. Contrast C1 addressed whether response times were slower in the different flanker condition than the average of the four conditions in which flanking bigrams contained letters that are in the target. Contrasts C2, C3 and C4 addressed the effects among the four conditions where flanking bigrams contained letters that are in the target. C2 addressed whether, regardless of the arrangement of flankers around the target, performance was better when the order of letters in the flankers was the same as their order in the target BI BIRD RD, RD BIRD BI) than when the order of letters was switched (IB BIRD DR, DR BIRD IB). C3 addressed whether, regardless of the order of letters within the flankers, performance was better if the flanking bigrams contained letters that were near their locations in the target (BI BIRD RD, IB BIRD DR) than farther away (RD BIRD BI, DR, BIRD IB). C4 tests the interaction of these two effects. Contrasts C1, C2 and C3 were directional questions, so one-sided *P*-values were appropriate.

Table 2
Contrasts for Targets in Experiment 1

Contrast	Condition				
	FO Nearer/LO Same	FO Farther/LO Same	FO Nearer/LO Switched	FO Farther/LO Switched	Different
	BI BIRD RD	RD BIRD BI	IB BIRD DR	DR BIRD IB	CE BIRD NT
C1	-1	-1	-1	-1	4
C2	-1	-1	1	1	0
C3	-1	1	-1	1	0
C4	-1	1	1	-1	0

Contrasts in Experiment 2. The contrasts were similar to those used for Experiment 1, but a third factor was introduced—whether the flanking bigrams contained adjacent letters (as in Table 1A) or letters that were separated by one letter in the target (as in Table 1B). As shown in Table 3, contrast C1 addressed whether performance was worse in the different-letter flanker condition than in the average of the eight conditions in which flanking bigrams contained letters in the target. Contrasts C2-C8 collectively addressed effects among the eight conditions in which the flanking bigrams contained letters from the target. Contrast C2 specifically addressed whether overall performance was better with adjacent-letter flanking bigrams than with flanking open bigrams. Contrast C3 addressed whether, regardless of the arrangement of flankers around the target, performance was better when the order of letters in the flankers was the same as the order of letters within the target (BI BIRD RD, RD BIRD BI, BR BIRD ID, ID BIRD BR) than switched (IB BIRD DR, DR BIRD IB, RB BIRD DI, DI BIRD RB). Contrast

C4 addressed whether, regardless of the arrangement of flankers around the target, performance was better when the flankers contained letters that were, on average, nearer their locations in the target (BI BIRD RD, IB BIRD DR, BR BIRD ID, RB BIRD DI) than farther away (RD BIRD BI, DR BIRD IB, ID BIRD BR, DI BIRD RB). Contrast C5 addressed whether there was an interaction of the effects tested by contrasts C3 (order of letters in flanker relative to their order in the target) and C4 (relative proximity of flankers to their corresponding letters in the target). Contrasts C6, C7, and C8 investigated interactions of bigram type (adjacent-letter versus open) with Contrasts C3 (effect of flanker order), C4 (effect of letter order) and C5 (interaction of flanker order and letter order), respectively. Contrasts C1, C2, C3, and C4 were directional questions, where one-sided *P*-values were appropriate.

Table 3
Contrasts for Targets in Experiment 2

Contrast	Condition: Adjacent-Letter Flanking Bigrams				Condition: Open Flanking Bigrams				
	FO Nearer/LO Same BI BIRD RD	FO Farther/LO Same RD BIRD BI	FO Nearer/LO Switched IB BIRD DR	FO Farther/LO Switched DR BIRD IB	FO Nearer/LO Same BR BIRD ID	FO Farther/LO Same ID BIRD BR	FO Nearer/LO Switched RB BIRD DI	FO Farther/LO Switched DI BIRD RB	Different CI BIRD NT
C1	-1	-1	-1	-1	-1	-1	-1	-1	8
C2	-1	-1	-1	-1	1	1	1	1	0
C3	-1	-1	1	1	-1	-1	1	1	0
C4	-1	1	-1	1	-1	1	-1	1	0
C5	-1	1	1	-1	-1	1	1	-1	0
C6	-1	-1	1	1	1	1	-1	-1	0
C7	-1	1	-1	1	1	-1	1	-1	0
C8	-1	1	1	-1	1	-1	-1	1	0

CHAPTER III

RESULTS

Experiment 1

Table 4 shows mean IES values, reaction times and accuracy rates for each condition in Experiment 1. Analyses of IES are reported in this section; Table B1 shows test statistics for comparable analyses of reaction times and accuracy rates.

Table 4
Results of Experiment 1

Results of Experiment I:

Flanker Condition			Words			Pseudowords		
Bigram	Letter		IES	RT	Accuracy	IES	RT	Accuracy
Nearer	Same	BI BIRD RD	679 (115)	619 (80)	.92 (.08)	966 (360)	767 (158)	.84 (.14)
Farther	Same	RD BIRD BI	708 (108)	636 (101)	.91 (.08)	937 (256)	779 (162)	.84 (.08)
Nearer	Switch	IB BIRD DR	689 (129)	632 (93)	.92 (.07)	962 (220)	774 (165)	.82 (.12)
Farther	Switch	DR BIRD IB	734 (152)	661 (111)	.91 (.06)	962 (330)	770 (190)	.83 (.13)
Different Letter		CE BIRD NT	745 (104)	657 (96)	.88 (.07)	933 (232)	771 (166)	.84 (.12)

Words. Following Grainger et al. (2014), our analyses focused on IES being the variable of main interest. Our analyses also focused on several questions. First, were responses more efficient when the flankers were comprised of letters in the target, relative to when they were not, as Dare and Shillcock (2013) and Grainger et al. (2014) reported? Next, were responses more efficient when the letters in the flankers were ordered as they are in the target, relative to when they were switched? Additionally, were responses more efficient when the flankers were ordered so that letters were near their location within the target, relative to when they were not? Finally, was there a letter-order by flanker-order interaction?

Contrast C1 showed that performance was better for the conditions in which flankers were composed of letters from the target (BI BIRD RD, RD BIRD BI, IB BIRD DR, DR BIRD IB, mean = 702) than for the condition in which flankers were not comprised of letters within the target (CE BIRD NT, mean = 745), $t(24) = 3.22$, $p < .01$, $\eta_p^2 = .30$. Contrast C2 showed that responses were more efficient when the letters in the flankers were ordered as they were in the target (BI BIRD RD and RD BIRD BI, mean = 684) than when they were not (IB BIRD DR and DR BIRD IB, mean = 721), $t(24) = 2.87$, $p < .01$, $\eta_p^2 = .26$. Contrast C3 indicated that performance did not differ significantly when flankers were ordered so their letters were near their locations in the target (BI BIRD RD, IB BIRD DR, mean = 694) and when they were not (RD BIRD BI, DR BIRD IB, mean = 712), $t(24) = 0.54$, p = 0.3, $\eta_p^2 = .01$. Finally, the results of Contrast C4 indicate that there was not a statistically significant letter-order by flanker-order interaction ($F(1,24) = 1.86$, $p = .18$, $\eta_p^2 = .07$).

Pseudowords. Contrast 1 showed that performance did not differ significantly when flankers were comprised of letters from the target (mean = 957) than for the condition in which flankers were not comprised of the target (mean = 933), $t(24) = 1.00$, $p = .16$, $\eta_p^2 = .04$. Contrast 2 showed that performance did not differ significantly when letters in the flankers were ordered as they were in the target (mean = 964) than when they are not (mean = 949), $t(24) = .60$, $p = 27$, $\eta_p^2 = .01$. Contrast 3 showed that performance did not differ significantly when flankers were ordered so their letters are near their locations in the target (mean = 951) and when they were not (mean = 962), $t(24) = .58$, $p = 28$, $\eta_p^2 \approx .00$. Contrast 4 showed that there was not a statistically significant letter-order by flanker-order interaction, ($F(1,24) = .34$, $p = .90$, $\eta_p^2 = .01$).

Experiment 2

Table 5 shows mean IES values, reaction times and accuracy rates for each condition in Experiment 2. Analyses of IES are reported in this section; Table B2 shows test statistics for comparable analyses of reaction times and accuracy rates.

Table 5
Results of Experiment 2

Bigram Condition	Flanker Condition			Words			Pseudowords		
	Bigram	Letter		IES	RT	Accuracy	IES	RT	Accuracy
Adjacent-Letter	Nearer	Same	BI BIRD RD	658 (117)	613 (107)	.93 (.06)	863 (251)	732 (151)	.87 (.11)
	Farther	Same	RD BIRD BI	679 (114)	622 (100)	.92 (.08)	916 (339)	738 (148)	.84 (.13)
	Nearer	Switch	IB BIRD DR	693 (113)	628 (98)	.91 (.07)	895 (226)	747 (154)	.85 (.10)
	Farther	Switch	DR BIRD IB	706 (128)	638 (105)	.91 (.07)	923 (326)	754 (196)	.84 (.11)
Open									
	Nearer	Same	BR BIRD ID	684 (121)	622 (104)	.91 (.07)	901 (274)	747 (149)	.86 (.11)
	Farther	Same	ID BIRD BR	713 (131)	637 (106)	.90 (.07)	899 (302)	733 (175)	.84 (.13)
	Nearer	Switch	RB BIRD DI	694 (127)	629 (98)	.91 (.07)	859 (235)	750 (175)	.85 (.11)
	Farther	Switch	DI BIRD RB	715 (121)	637 (100)	.90 (.07)	889 (242)	728 (137)	.84 (.12)
	Different Letter		CE BIRD NT	752 (128)	655 (102)	.88 (.08)	902 (317)	746 (162)	.86 (.12)

Words. Experiment 2 extended the investigation of effects on performance by flanking bigrams to open bigrams; as for Experiment 1, the measure of primary interest was IES. Contrast 1 indicated that lexical decision performance was worse in the different-letter flanker condition (CE BIRD NT, mean = 752) than in the average of the eight conditions in which flanking bigrams contained letters in the target (BI BIRD RD, RD BIRD BI, IB

BIRD DR, DR BIRD IB, BR BIRD ID, ID BIRD BR, RB BIRD DI, DI BIRD RB, mean = 693), $t(44) = 4.37$, $p < .001$, $\eta_p^2 = .30$. Contrast 2 indicated that on average, for conditions in which flanking bigrams contained letters in the target, performance was better with adjacent-letter bigrams (BI BIRD RD, RD BIRD BI, IB BIRD DR, DR BIRD IB, mean = 684) than open bigrams (BR BIRD ID, ID BIRD BR, RB BIRD DI, DI BIRD RB, mean = 702), $t(44) = 2.54$, $p < .01$, $\eta_p^2 = .13$.

Contrasts C3, C4, and C5 in Experiment 2 investigated the same questions, averaged over adjacent-letter and open bigrams, as those investigated by contrasts C2, C3 and C4 in Experiment 1. Contrasts 6, 7, and 8 directly tested the interactions of contrasts 3, 4, and 5, respectively with bigram type (adjacent-letter versus open).

To address the most crucial question of Experiment 2, Contrast 3 compared IES between conditions in which the order of letters in flankers was the same as the order of letters in the target to conditions in which the order of letters in the flankers was switched from their order in the target, averaging over bigram type (adjacent-letter and open bigrams). Contrast 3 showed that lexical decision performance was better when letter order in the flankers was the same as in the target (BI BIRD RD, RD BIRD BI, BR BIRD IB, ID BIRD BR, mean = 682) than when letter order in the flankers was switched (IB BIRD DR, DR BIRD IB, RB BIRD DI, DI BIRD RB, mean = 703), $t(44) = 2.49$, $p < .01$, $\eta_p^2 = .12$. Notably, Contrast 6 showed that this effect did not interact significantly with bigram type, $F(1,44) = .50$, $p = .84$, $\eta_p^2 = .01$.[1]

[1]It should be noted that the reaction time results of Contrast 3 and Contrast 6 in Experiment 2 are consistent with the IES results, and these contrasts identified no significant effects for accuracy.

Contrast C4 compared IES between conditions in which the flankers contained letters that were, on average, nearer their locations in the target (BI BIRD RD, IB BIRD DR, BR BIRD ID, RB BIRD DI) than farther away (RD BIRD BI, DR BIRD IB, ID BIRD BR, DI BIRD RB), averaging over bigram type (adjacent letter and open bigrams). Contrast C4 showed that lexical decision performance was better when the flankers contained letters that were, on average, nearer their locations in the target (BI BIRD RD, IB BIRD DR, BR BIRD ID, RB BIRD DI, mean = 683) than farther away (RD BIRD BI, DR BIRD IB, ID BIRD BR, DI BIRD RB, mean = 702), $t(44) = 3.09$, $p < .01$, $\eta_p^2 = .18$. Contrast 7 showed that this effect interacted with bigram type, $F(1,44) = 4.68$, $p < .05$, $\eta_p^2 = .10$. For adjacent-letter bigrams, mean IES for nearer-letter and farther-letter flankers were 668 and 700 respectively; for open bigrams, these were 698 and 704, respectively.

Contrast C5 addressed whether there was an interaction of the effects tested by contrasts C3 (order of letters in flanker relative to their order in the target) and C4 (relative proximity of flankers to their corresponding letters in the target). This interaction was not statistically significant, $t(44) = .60$, $p = .28$, $\eta_p^2 = .01$. Contrast 8 tested the interactions of bigram type (adjacent-letter vs. open) with C5; this interaction was not statistically significant $F(1,44) = .01$, $\eta_p^2 \approx .00$.

Pseudowords. Contrast C1 showed the performance was no better when flanking bigrams (adjacent-letter or open) were comprised of letters from the target (mean = 897) compared with when they did not (mean = 902), $t(44) = .24$, $p = .37$, $\eta_p^2 \approx .00$. Contrast C2 showed that performance was not significantly better when flanking bigrams were adjacent-letter bigrams (mean = 899) than when they were open bigrams (mean = 896), $t(44) = .28$, 39, $\eta_p^2 \approx .00$.

Contrast C3 showed that performance did not differ significantly when letter order of the flankers were the same as the target (mean = 888) than when they were not (mean = 906), $t(44) = 1.21$, $p = .12$, $\eta_p^2 = .03$. Contrast C6 showed that there was no significant interaction with contrast 3 and bigram type, ($F(44) = 2.83$, $p = .44$, $\eta_p^2 = .06$).

Contrast C4 showed that performance did not differ significantly when the flanking bigram order was kept the same as the target (mean = 894) than when it was switched (mean = 900), $t(44) = .54$, $p = .30$, $\eta_p^2 \approx .00$. Contrast C7 showed there was not a statistically significant interaction with C4 and bigram type, ($F(1, 44) = 1.88$, $p = .53$, $\eta_p^2 = .04$). Contrast C5 showed that there was not a statistically significant flanker-order and letter-order interaction, $t(44) = .65$, $p = .26$, $\eta_p^2 = .01$. Contrast C8 showed there was not a statistically significant interaction between bigram type and C5, ($F(1,44) = .14$, $p = .99$, $\eta_p^2 \approx .00$.

CHAPTER IV

DISCUSSION

The primary purpose of the current study was to investigate whether lexical decision is facilitated by flanking open bigrams. Grainger et al. (2014) showed that flanking adjacent-letter bigrams facilitate lexical decision, and the rationale behind the current study was to explore whether open bigrams facilitated lexical decision performance, and if so, to what degree.

Experiment 1 was a straightforward replication of Grainger et al. (2014) and yielded results quite similar to theirs. The results of Experiment 1 indicated that: (a) responses were more efficient when the flanker letters were comprised of letters in the target relative to when they were not, (b) responses were more efficient when the letters of the flankers were ordered as they were in the target, relative to when they were switched, (c) responses were not significantly facilitated when flankers were ordered so their letters were nearer their locations in the target, relative to when they were farther. Because the results of the current study replicated those of Grainger et al. (2014), extending this research to open bigrams was the next logical step.

Experiment 2 was an extension of this replication of Grainger et al. (2014), where open bigrams were introduced. The results of Experiment 2 indicated that: (a) adjacent-letter bigrams and open bigrams facilitate lexical decision performance relative to the different-letter condition and (b) when flankers contain the letters that were in the target, adjacent letter bigrams facilitate lexical decision performance relative to open bigrams. Importantly, (c) over bigram types, lexical decision performance is facilitated when letter order was the same as the target, regardless of the proximity of the letters in the bigrams to their locations in the target, and, notably, (d) this effect did not interact with bigram type (adjacent-letter vs. open). In addition, (e) performance was better for conditions in which the flankers contained letters that were, on average, nearer their locations in the target, than when they were not, and (f) this effect interacted with bigram type, appearing to be present only for adjacent-letter bigrams. Finally, (g) there was no statistically significant interaction of the effects tested by contrasts C3 (order of letters in flanker relative to their order in the target) and C4 (relative proximity of flankers to their corresponding letters in the target), and (h) no interaction of this effect with bigram type. In short, the results of Experiment 2 demonstrate that for words, performance benefitted from flanking open bigrams with letters ordered as in the target, regardless of the positions of those flanking bigrams relative to the target, and, on average, there was more benefit from adjacent-letter bigrams than from open bigrams. Additionally, in neither experiment did performance for pseudowords depend systematically on flanker condition.

The multiple-word processing model proposed by Grainger et al. (2014) was created as a way to extend the single-word orthographic processing model of Grainger and van Heuven (2003). One of the main predictions of this model was that if the same word presented to the participant foveally was also presented parafoveally, lexical decision-making should be facilitated because of a parafoveal preprocessing benefit (Grainger et al., 2014). In 2013, Dare and Shillcock investigated parafoveal preprocessing. The results of their study, and the current study, indicated that orthographic information was processed in parallel between the fovea and parafovea, and when taken together, the recognition of the target within the fovea was influenced (Grainger et al., 2014).

Dehaene et al., (2005) investigated relative position priming, which activates neurons, and forms a code that will complete the target word (e.g. *grdn* would prime the target *garden*). The results of their research suggested that printed word perception should be insensitive to transposition priming, because there was sufficient correct relative-position information within the transposed stimuli (Grainger & Whitney, 2004). Similarly, Dehaene et al. (2005) used their model to explain that in transposition priming, the neural code used to prime a target was minimally changed, which explains how the prime *gadren* was used to prime the target *garden*. In the current study, lexical decision performance was better for conditions where flanking bigrams were ordered as the target, and when letters were ordered as the target. The facilitation of performance with flanker and letter ordering indicate that the results of the current study may be supportive of the model proposed by Dehaene et al. (2005).

In Experiment 1, 80% of the trials (word or pseudoword) had flanking bigrams that contained letters in the target. In Experiment 2, 88% of the trials (word or pseudoword) had flanking bigrams that contained letters in the target. The effect sizes found in the current study may have been influenced by these percentages. Because of these factors, further investigation may be necessary to determine whether the effect size of results depends on the frequency with which these trials contained flanking bigrams containing letters in the target.

Future research should further investigate the facilitation by flankers in this experimental paradigm. As an example, the inclusion of a non-flanked target (e.g. BIRD) might be able to tell researchers whether there was facilitation from the flankers in a different way than our condition of flankers being comprised of letters not found in the target. Another option may be to include flankers made of symbols, such as asterisks, rather than letters (e.g. ** BIRD **).

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APPENDIX

APPENDIX A

Appendix A1. *Experiment 1 Stimuli*

Experiment 1 Word Stimuli		Experiment 1 Pseudoword Stimuli	
ages	worn	bady	cont
bags	chef	bame	chup
bang	wipe	bert	cags
bath	clue	bilt	caze
belt	coma	bocs	grat
bend	cats	bope	dats
bets	corn	brue	dosh
bike	fond	cags	bert
bits	cage	caze	bilt
bone	dirt	ceal	gops
bout	cave	chup	bame
bowl	cure	coap	sive
bugs	coke	cont	bady
bump	cole	cort	dape
bush	dawn	cose	dunt
bust	deaf	crip	deas
cage	bits	cuid	wope
cats	bend	dape	cort
cave	bout	dats	bope
chef	bags	deas	crip
chip	wore	dest	flar
chop	wide	dile	grat
clue	bath	dits	fale
coke	bugs	dosh	brue
cole	bump	dums	ecax
coma	belt	dunt	cose
corn	bets	ecax	dums
cure	bowl	fale	dits
dawn	bush	flar	dest
deaf	bust	foxi	tage
debt	fail	frow	sile
deck	fans	funt	prew
dime	flat	gacs	hend
dirt	bone	geal	huck
dish	earl	goet	larn
dive	fort	gops	ceal

dump	flew	gots	hape
earl	dish	gour	hals
fail	debt	grat	bocs
fans	deck	grat	dile
flat	dime	hage	jows
flew	dump	hals	gour
fond	bike	hape	gots
fort	dive	hend	gacs
fund	gear	hent	lims
gear	fund	hine	loak
grew	halt	hink	leps
hail	jobs	hins	tode
halt	grew	hore	tigs
hire	lack	huck	geal
horn	lamb	hust	iban
jobs	hail	iban	hust
lack	hire	jear	wint
lamb	horn	jows	hage
laws	tire	junt	lage
leak	owns	lage	junt
lean	pigs	larn	goet
lend	mars	leds	tany
lips	navy	leps	hink
loan	pity	lims	hent
mars	lend	loak	hine
mile	path	loar	pite
navy	lips	maks	pire
nest	palm	malk	nost
ouch	wire	musy	roke
owns	leak	muts	parn
palm	nest	muts	redy
path	mile	nost	malk
pigs	lean	parn	muts
pile	ruby	pind	rawl
pity	loan	pire	maks
pole	rush	pite	loar
pour	sack	poil	shen
prom	wise	prew	funt
rate	sink	purs	tole
ruby	pile	pust	rike
rush	pole	rawl	pind

sack	pour	redy	muts
sail	tone	rike	pust
self	tank	roke	musy
shed	tail	rold	sike
shoe	taxi	serm	thun
sink	rate	shen	poil
site	warn	sike	rold
soda	thin	sile	frow
tail	shed	sile	toar
tank	self	sive	coap
taxi	shoe	soep	tand
thin	soda	stoe	wark
tire	laws	tage	foxi
toes	whip	tand	soep
tone	sail	tany	leds
warn	site	thun	serm
whip	toes	tigs	hore
wide	chop	toar	sile
wipe	bang	tode	hins
wire	ouch	tole	purs
wise	prom	wark	stoe
wore	chip	wint	jear
worn	ages	wope	cuid

Appendix A2. *Experiment 2 Stimuli*

Experiment 2 Word Stimuli		Experiment 2 Pseudoword Stimuli	
ages	worn	bady	cont
bags	chef	bame	chup
bail	tune	bant	shef
bath	clue	bave	lits
belt	coma	baze	cout
bend	cats	bert	cags
bets	corn	bilt	caze
bike	fond	blaw	hets
bits	cage	bocs	grat
blew	cuts	bope	dats
bond	weak	bost	dume
bone	dirt	brue	dosh
bout	cave	bune	dack
bowl	cure	bure	dilt
bump	cole	burk	chos

bury	dame	cags	bert
bush	dawn	caze	bilt
bust	deaf	ceal	gops
cage	bits	chos	burk
cats	bend	chup	bame
cave	bout	coad	lins
chef	bags	coap	sive
chip	wore	cont	bady
chop	wide	cort	dape
clue	bath	cose	dunt
cole	bump	cour	pake
coma	belt	cout	baze
corn	bets	crip	deas
cure	bowl	cuid	wope
cuts	blew	cust	deak
dame	bury	dack	bune
dawn	bush	dape	cort
deaf	bust	dats	bope
debt	fail	dave	fols
deck	fans	deak	cust
deny	fits	deas	crip
dies	flag	dest	flar
dime	flat	dewt	ourn
dirt	bone	dile	grat
dish	earl	dilt	bure
dive	fort	dipe	forn
dope	gain	dits	fale
drew	flip	dosh	brue
duck	earn	dume	bost
dump	flew	dums	ecax
dust	exam	dunt	cose
earl	dish	dute	frow
earn	duck	eaut	inds
ends	foul	ecax	dums
exam	dust	fage	udit
exit	frog	fale	dits
fail	debt	fiet	roul
fans	deck	flar	dest
fate	gods	flot	pacs
fits	deny	fols	dave
flag	dies	forn	dipe

flat	dime	foxi	tage
flew	dump	frow	dute
flip	drew	frow	sile
fond	bike	funt	prew
fort	dive	gacs	hend
foul	ends	gasy	moul
frog	exit	geal	huck
fuel	gray	geat	hord
fund	gear	goet	larn
gain	dope	gops	ceal
gear	fund	gots	hape
goal	heck	gour	hals
goat	hers	grat	bocs
gods	fate	grat	dile
gray	fuel	hage	jows
grew	halt	hals	gour
guts	zone	hape	gots
hail	jobs	havs	nily
halt	grew	hend	gacs
heal	junk	hent	lims
heck	goal	hets	blaw
hers	goat	hile	mact
hire	lack	hine	loak
hits	jean	hink	leps
horn	lamb	hins	tode
hung	lame	hord	geat
hunt	worm	hore	tigs
jean	hits	huck	geal
jobs	hail	hust	iban
junk	heal	iban	hust
lack	hire	inds	euat
lamb	horn	jear	wint
lame	hung	jink	lebs
lawn	rice	jows	hage
laws	tire	junt	lage
lazy	woke	lage	junt
leak	owns	lant	obes
lean	pigs	larn	goet
lend	mars	lebs	jink
lets	maid	leds	tany
lick	mate	leps	hink

ling	mask	lims	hent
link	math	lins	coad
lips	navy	lits	bave
load	pink	loak	hine
loan	pity	loar	pite
maid	lets	mact	hile
mars	lend	maks	pire
mask	ling	malk	nost
mate	lick	mang	oute
math	link	moul	gasy
meal	pork	musy	roke
mile	path	muts	parn
navy	lips	muts	redy
nest	palm	nily	havs
owns	leak	nost	malk
palm	nest	obes	lant
path	mile	ourn	dewt
pigs	lean	oute	mang
pile	ruby	pacs	flot
pink	load	pake	cour
pity	loan	parn	muts
plot	rage	pind	rawl
poem	ruin	pire	maks
pole	rush	pite	loar
pork	meal	pode	shar
port	sale	poil	shen
pour	sack	poys	rame
punk	rise	prew	funt
pure	sand	prog	wist
puts	rode	prou	tane
rage	plot	purs	tole
rate	sink	pury	seck
rice	lawn	pust	rike
rise	punk	rame	poys
rode	puts	rawl	pind
role	shaw	reak	vilt
rome	skip	redy	muts
ruby	pile	rike	pust
ruin	poem	roke	musy
rush	pole	rold	sike
sack	pour	rona	selp

sail	tone	roul	fiet
sale	port	rown	sape
sand	pure	rupe	woil
self	tank	sape	rown
shaw	role	seck	pury
shoe	taxi	selp	rona
sink	rate	serm	thun
sire	thou	shar	pode
site	warn	shef	bant
skip	rome	shen	poil
snow	tale	sike	rold
soap	term	sile	frow
soda	thin	sile	toar
sore	twin	sive	coap
soup	tear	slin	yeto
tale	snow	soep	tand
tank	self	stoe	wark
taxi	shoe	tage	foxi
tear	soup	tand	soep
term	soap	tane	prou
thin	soda	tany	leds
thou	sire	thun	serm
tire	laws	tigs	hore
toes	whip	toar	sile
tone	sail	tode	hins
torn	wave	tole	purs
toys	vice	tork	whis
tune	bail	tous	wike
twin	sore	tunk	wice
vice	toys	twan	zobs
warn	site	udit	fage
wave	torn	vilt	reak
weak	bond	wark	stoe
whip	toes	whis	tork
wide	chop	wice	tunk
wins	zero	wike	tous
woke	lazy	wint	jear
wore	chip	wist	prog
worm	hunt	woil	rupe
worn	ages	wope	cuid
zero	wins	yeto	slin

zone	guts	zobs	twan

APPENDIX B

Table B1. *Test Statistic Table for Experiment 1*

Test Statistics for Contrasts on RT and Error Rate for Experiment 1

		Test Statistics	RT	Accuracy
C1	(BI BIRD RD, RD BIRD BI, IB BIRD DR, DR BIRD IB vs. CE BIRD NT)	$t(24) =$	2.84, $p < .01$	2.20, $p < .01$
C2	(BI BIRD RD, RD BIRD BI vs. IB BIRD DR, DR BIRD IB)	$t(24) =$	2.91, $p < .01$	1.39, $p < .05$
C3	(BI BIRD RD, IB BIRD DR vs. RD BIRD BI, DR BIRD IB)	$t(24) =$	0.97, ns	0.00, $p \approx 1$
C4	(BI BIRD RD, DR BIRD IB vs. RD BIRD BI, IB BIRD DR)	$F(1, 24) =$	6.59, $p < .05$	0.01, ns

p-values for *t*-statistics are one-sided

Table B2. *Test Statistic Table for Experiment 2*

Test Statistics for Contrasts on RT and Error Rate for Experiment 2

		Test Statistics	RT	Accuracy
C1	(BI BIRD RD, RD BIRD BI, IB BIRD DR, DR BIRD IB, BR BIRD ID, ID BIRD BR, RB BIRD DI, DI BIRD RB vs. CE BIRD NT)	$t(44) =$	3.92, $p < .01$	3.33, $p < .01$
C2	(BI BIRD RD, RD BIRD BI, IB BIRD DR, DR BIRD IB vs. BR BIRD ID, ID BIRD BR, RB BIRD DI, DI BIRD RB)	$t(44) =$	1.86, $p < .05$	1.87, $p < .01$
C3	(BI BIRD RD, RD BIRD BI, BR BIRD ID, ID BIRD BR vs. IB BIRD DR, DR BIRD IB, RB BIRD DI, DI BIRD RB)	$t(44) =$	2.15, $p < .05$	1.45, ns
C4	(BI BIRD RD, IB BIRD DR, BR BIRD ID, RB BIRD DI vs. RD BIRD BI, DR BIRD IB, ID BIRD BR, DI BIRD RB)	$t(44) =$	2.64, $p < .01$	1.63, ns
C5	(BI BIRD RD, DR BIRD IB, BR BIRD ID, DI BIRD RB vs. RD BIRD BI, IB BIRD DR, ID BIRD BR, RB BIRD DI)	$t(44) =$	0.33, ns	0.50, ns
C6	(BI BIRD RD, RD BIRD BI, RB BIRD DI, DI BIRD RB vs. IB BIRD DR, DR BIRD IB, BR BIRD ID, ID BIRD BR)	$F(1, 44) =$	0.04, ns	0.44, ns
C7	(BI BIRD RD, IB BIRD DR, ID BIRD BR, DI BIRD RB vs. RD BIRD BI, DR BIRD IB, BR BIRD ID, RB BIRD DI)	$F(1, 44) =$	3.05, ns	1.48, ns
C8	(BI BIRD RD, DR BIRD IB, ID BIRD BR, RB BIRD DI vs. RD BIRD BI, IB BIRD DR, BR BIRD ID, DI BIRD RB)	$F(1, 44) =$	0.28, ns	0.23, ns

p-values for *t*-statistics are one-sided