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The influence of phonological neighborhood on visual word perception

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In the research reported here, we investigated the influence of phonological neighborhood density on the processing of words in the visual lexical decision task. The results of the first experiment revealed that words with large phonological neighborhoods were verified more rapidly than words with small phonological neighborhoods. In the second experiment, we replicated this effect with a more tightly controlled set of stimuli. These results demonstrate the importance of phonological codes when processing visually presented letter strings. We relate this research to previous results on semantic and orthographic neighborhoods and discuss the results within the context of a model in which lexical decisions are based on stimulus familiarity.

Models of visual word perception must attempt to account for the effects of words' orthographic, phonological, and semantic characteristics. For example, consider a distributed model that contains fully interconnected orthographic, phonological, and semantic systems. When a letter string is presented, a pattern of activation occurs across the orthographic units, which in turn activates the phonological and semantic systems. As a consequence of the activation being passed among these three systems, a word comes into the viewer's perception (Van Orden & Goldinger, 1994).

Plaut (1997) proposed that lexical decisions are based on differences in semantic patterns generated by words versus nonwords. That is, decisions are made in terms of semantic *familiarity*. In keeping with a model that has orthographic, phonological, and semantic systems, it is plausible that decisions can be based on the activation in any of these systems. Thus, the more activation that occurs within one or more levels, the more familiar the letter string will appear, leading to faster responses.

Here we investigate the role of activation within the phonological system. Specifically, we investigate the influence of words' *phonological* neighbors. Our manipulation is analogous to orthographic neighborhood (i.e., the number of words that can be formed by changing one letter of the target word; Coltheart, Davelaar, Jonasson, & Besner, 1977). Andrews (1997) reviewed the literature regarding orthographic neighborhoods and noted that most studies have shown facilitative effects for orthographic neighborhood density (e.g., Andrews, 1992; Sears, Hino, & Lupker, 1995), with the exception of studies in which words were blocked by orthographic neighborhood. Thus, the effect of orthographic neighborhood, at least when the words are mixed, appears to be facilitative.

A similar facilitative effect of neighborhood density is obtained with semantic neighborhood, defined as the number of words associated to the target word (Nelson, Schreiber, & McEvoy, 1992). Words with large semantic neighborhoods are responded to more rapidly than words with sparse semantic neighborhoods (Buchanan, Westbury, & Burgess, 2001; Locker, Simpson, & Yates, 2003; Yates, Locker, & Simpson, 2003). Thus, the effects of semantic and orthographic neighborhood are similar, with larger neighborhoods leading to faster lexical decisions.

Such effects can be understood in terms of a model of the type discussed above. A word with a large orthographic neighborhood leads to greater activation in the orthographic system due to its shared neighbors. The system interprets this increased orthographic activation as indicating that the letter string is a word, and the "yes" response can be produced more rapidly than for a word with a small orthographic neighborhood.

There is some evidence that phonology also plays a role in visual word perception. For example, consistent words (i.e., words whose bodies have only one pronunciation) are named more rapidly than inconsistent words (i.e., words whose bodies have multiple pronunciations; Jared, McRae, & Seidenberg, 1990). Although Jared et al. failed to find an effect of consistency on lexical decisions, Ziegler, Montant, and Jacobs (1997) did report a significant effect of consistency. In addition, Pexman, Lupker, and Jared (2001) showed that homophony slows

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lexical decisions, and Van Orden (1987) demonstrated that homophony increases false positives in a semantic categorization task.

To further test the role of phonology in visual word processing, the present research evaluated the role of phonological neighborhood in the lexical decision task. Given the facilitative effect of orthographic and semantic neighbors, we expected phonological neighborhood to exert a similar facilitative effect. Specifically, a word with a large phonological neighborhood should lead to a stronger pattern of activation at the phonological level than should a word with a small neighborhood. This stronger pattern of activation can be taken by the system as an indication that the letter string is a word, allowing more rapid "yes" responses for words with larger phonological neighborhoods.

EXPERIMENT 1

Experiment 1 investigated whether words with small phonological neighborhoods would lead to longer lexical decision latencies than would words with large phonological neighborhoods.

Method

Participants. The participants were 24 undergraduate students at the University of Kansas with normal or corrected-to-normal vision. Four were excluded from the data analyses because of error rates greater than 15%. Thus, the analyses are based on 20 participants.

Materials. The stimuli consisted of 60 English words. Half had small phonological neighborhoods (M = 3.9), and half had large phonological neighborhoods (M = 19.1). Phonological neighborhood density was determined by using the Wordmine database (Buchanan & Westbury, 2000), which contains CELEX frequencies (Baayen, Piepenbrock, & Gulikers, 1995) of four- to six-letter words. The database provides orthographic and phonological neighborhood size, as well as neighborhood frequencies based on the CELEX norms. Using the Wordmine database, we defined phonological neighbors as words that could be formed by changing only one phoneme of the target word. For example, the word *gate* has the words *hate* and *get* as phonological neighbors, making this measure the phonological analogue of Coltheart's *N*.

Large- and small-neighborhood words did not differ in printed frequency (according to either Kučera & Francis, 1967, or the CELEX norms), orthographic neighborhood density, orthographic neighborhood frequency, summed bigram frequency (Balota et al., 2002), number of syllables, or number of letters. Finally, the average of the mean phonological neighborhood frequencies did not differ between the small and large phonological neighborhoods. There were no significant differences between the two groups on any of the control variables (all ps > .10) (see Appendix A for a complete list of experimental stimuli and Table 1 for the means and standard deviations for the control variables).

Table 1
Means and Standard Deviations for the Control Variables from Experiment 1

	Large Neighborhood		Small Neighborhood	
Control Variables	*M*	*SD*	*M*	*SD*
KF printed frequency	12	14	10	15
CELEX printed frequency	8	7	7	10
ON density	3	3	2	2
Average ON frequency	18	37	12	28
Average PN frequency	15	17	13	18
Summed bigram	6,245	3,369	6,098	2,845
Syllables	1.3	0.5	1.3	0.5
Number of letters	5.1	0.7	5.2	0.7

Note—KF, Kučera–Francis; ON, orthographic neighborhood; PN, phonological neighborhood.

Sixty pronounceable pseudowords were chosen from the English Lexicon Project database (Balota et al., 2002) as lexical decision foils. The pseudowords did not differ significantly from the words in terms of either summed bigram frequency (M = 5,866) or length (M = 5.1).

Procedure. The stimuli were shown on a computer running Micro Experimental Laboratory (Schneider, 1988). The participants were instructed to respond as quickly as possible, but to avoid errors. They first performed lexical decisions on 30 practice stimuli, containing an equal number of words and pseudowords not used in the experimental trials. There were 120 trials in the experimental session, and each trial consisted of a blank screen for 250 msec, followed by a fixation stimulus (+) centered on the screen for 750 msec. Immediately following the fixation stimulus, a word or pseudoword was shown in lowercase and remained until the participant responded by pressing one of two keys on the keyboard. "Yes" responses were made using the dominant hand, and "no" responses with the nondominant hand.

Results and Discussion

Defining outliers as responses of less than 250 msec or greater than 2,000 msec resulted in removal of less than 1% of the cases. Words having large phonological neighborhoods were responded to more rapidly (M = 620 msec, SD = 84) than words with small neighborhoods (M = 681 msec, SD = 89) [$t_p(19) = 6.23, p < .01$; $t_i(58) = 3.44, p < .01$]. In addition, participants made more errors with words with small phonological neighborhoods (19%) than with words with large phonological neighborhoods (3%) [$t_p(19) = 7.64, p < .01$; $t_i(58) = 4.45, p < .01$].

The results are quite clear: Words with larger phonological neighborhoods are responded to more rapidly and accurately than are those with smaller neighborhoods. However, after the experiment was conducted, it was discovered that the two groups differed in subjective familiarity (Nusbaum, Pisoni, & Davis, 1984) and number of phonemes, in such a way that the faster condition was more familiar (M = 6.8) than the slower condition (M = 6.4) and had fewer phonemes (M = 3.6) than the slower condition (M = 4.5). Therefore, we used subjective familiarity and number of phonemes as covariates in an items analysis (the word *poorly* was not included because its familiarity value was not available). The analyses of covariance (ANCOVAs) indicate that phonological neighborhood facilitates both latencies [$F(1,55) = 4.47, p < .05$] and accuracy [$F(1,55) = 13.25, p < .01$], after removal of variability attributable to subjective familiarity and number of phonemes.

EXPERIMENT 2

Because these results have important implications for current models of visual word recognition, Experiment 2 was designed to replicate the effects from Experiment 1 while exercising more control over additional variables. Also, we chose to use only monosyllabic words in Experiment 2 because current computational models of visual word recognition are most often evaluated using monosyllabic words.

Method

Participants. The participants were 34 undergraduate students at the University of Kansas with normal or corrected-to-normal vision. Seven participants were excluded because of error rates greater than 15%, leaving 27 participants.

Materials. The stimuli consisted of 10 monosyllabic English words with large phonological neighborhoods ($M = 17.1$) and 10 with small neighborhoods ($M = 5.2$). The two sets of words did not differ in printed frequency according to Kučera and Francis (1967) or the CELEX norms, orthographic neighborhood density, orthographic neighborhood frequency, phonological neighborhood frequency, summed bigram frequency (Balota et al., 2002), or number of letters. The two groups were also matched on number of phonemes, subjective familiarity (Nusbaum et al., 1984), and phonological frequency (according to the CELEX norms). There were no significant differences between the two groups on any of these control variables (all ps $> .10$) (see Appendix B for a complete list of the stimuli and Table 2 for a summary of the control variables). Finally, in terms of feedforward consistency, the two groups had an equal number of consistent and inconsistent words. Although we were unable to match the two groups perfectly on feedback consistency, the large phonological neighborhood condition had more inconsistent words. Also, the consistency measures provided by De Cara and Goswami (2002) indicate that large neighborhood words were more feedback inconsistent ($M = 0.63$) than the small neighborhood words ($M = 0.79$), but this difference was not statistically reliable. Thus, any differences in feedback consistency should only work against the hypothesis given here.

Although the nonword foils from Experiment 1 did not differ from the words in terms of summed bigram frequency or length, it was subsequently discovered that they had a larger orthographic neighborhood ($M = 3.1$) than did the words.[1] This could lead participants to rely on phonology more than they otherwise would. In Experiment 2, therefore, nonwords were also matched to words on orthographic neighborhood. Nonword foils were pronounceable monosyllabic pseudowords chosen from the English Lexicon Project database (Balota et al., 2002). These nonwords did not differ from the experimental stimuli in number of letters ($M = 4.9$), summed bigram frequency ($M = 5{,}667$), or orthographic neighborhood ($M = 3.8$).

Table 2
Means and Standard Deviations for the Control Variables from Experiment 2

	Large Neighborhood		Small Neighborhood	
Control Variables	*M*	*SD*	*M*	*SD*
KF printed frequency	9	9	21	34
CELEX printed frequency	9	13	12	13
CELEX phonological frequency	9	20	11	17
Familiarity	6.8	0.2	6.8	0.2
ON density	5	3	4	3
Average ON frequency	26	29	14	14
Average PN frequency	15	21	4	7
Summed bigram	5,823	2,648	4,976	2,657
Number of letters	4.9	0.3	4.6	0.7
Number of phonemes	3.7	0.5	3.7	0.5

Note—KF, Kučera–Francis; ON, orthographic neighborhood; PN, phonological neighborhood.

Procedure. As in Experiment 1, the participants first performed lexical decisions on 30 practice stimuli. However, there were only 40 total trials in the experimental session. The rest of the procedure was identical to that of Experiment 1.

Results and Discussion

Outliers were defined as in Experiment 1, resulting in removal of less than 1% of the cases. Again words with large phonological neighborhoods were responded to more rapidly ($M = 601$, $SD = 81$) than were words with small neighborhoods ($M = 638$, $SD = 71$) [$t_p(26) = 3.69, p < .01$; $t_i(18) = 1.40, p > .10$]. Large-neighborhood words were also responded to more accurately (5% errors) than were words with small neighborhoods (11% errors) [$t_p(26) = 2.51$, $p < .05$; $t_i(18) = 1.34$, $p > .10$]. These results replicate those of Experiment 1 and demonstrate that phonological neighborhood facilitates lexical decisions. We note that the effects were nonsignificant by items in Experiment 2, but contend that this is due to the lack of power imposed by the control variables. In Experiment 2, we controlled for 13 variables, severely limiting the corpus of available words, which resulted in low power for the items analysis.[2] However, we do note that in Experiment 1 where we had more stimuli, and thus more power, the items analyses were significant, including the ANCOVA with familiarity and number of phonemes as covariates.

GENERAL DISCUSSION

The results of these experiments show that phonological neighborhood density affects *visual* lexical decisions. This finding has important implications for models of visual word recognition, which must include the influence of phonology on the perception of written letter strings. These results are consistent with a fully interconnected model comprising orthographic, phonological, and semantic components. Within such a model, lexical decisions can be based on the familiarity of the written letter string, which may be affected by activation in any of the three components. The increase in activation that results from a word having many neighbors (orthographic, phonological, or semantic) indicates that the stimulus is most likely a word and leads more rapidly to a “yes” response.

Although we have described these results in terms of a distributed approach, some localist models should also be able to account for the results. The two most notable are the dual-route cascaded model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and the multiple read-out model (Grainger & Jacobs, 1996). In both of these models, lexical decisions can be based on either the amount of activation within a single word unit or global activation. The latter account is often used to explain orthographic neighborhood effects. Words with many neighbors cause more global activation within the orthographic system, and this activation can be used for a “yes” response. These models could account for the results here by assuming that a high degree of phonological activation leads to a "yes" response. This is essentially the argument we make in relation to the distributed approach. It should be noted that this account of lexical decisions being based on global activation does not assume that full settling on a specific representation (or lexical selection, depending on the model) occurs before the lexical decision is made. To what degree lexical selection is affected by phonological neighborhood cannot be determined from the results reported here. As Andrews (1997) argues, it is important to obtain converging evidence across tasks to ascertain to what degree orthographic neighborhoods affect lexical selection. We believe this is the appropriate strategy for phonological neighborhood as well. To this end, we are investigating the influence of phonological neighborhood in the speeded naming task and in semantic categorization. This research will enable us to say with more confidence how phonological neighborhood influences lexical selection.

Another issue that must be addressed is the high correlation between phonological and orthographic neighborhood. In the present experiment, we were able to control for orthographic neighborhood, ensuring that the effects were due to phonological neighborhood. However, since phonological neighborhood has been neglected in the area of visual word perception, it is possible that previous research on orthographic neighborhood has been confounded with phonological neighborhood. We examined stimuli from three studies investigating the effect of orthographic neighborhood density (i.e., Andrews, 1989, 1992; Sears et al., 1995). For each experiment in these studies, we collapsed across all variables except orthographic neighborhood density. We then compared the high orthographic neighborhood density words with the low orthographic neighborhood density words with regard to *phonological* neighborhood density (see Table 3). In all instances, phonological neighborhood density significantly differed between the high and low orthographic neighborhood conditions. Thus, at least in these studies, it is difficult to determine whether the effects are due to orthographic or phonological neighborhood. Future research should examine what effect orthographic neighborhood may have when phonological neighborhood is tightly controlled.

Table 3
Mean Phonological Neighborhood (PN) Size From Previous Studies as a Function of Small Versus Large Orthographic Neighborhood (ON) Words

	Mean PN Size	
Study	Large ON	Small ON
Andrews (1989) Experiments 1–4*	21	11
Andrews (1992) Experiments 1 and 2*	20	15
Sears, Hino, and Lupker (1995)		
Experiments 1 and 2*	18	11
Experiment 3	22	12
Experiment 4	17	11
Experiment 5	17	12
Experiment 6	14	8

*Same stimuli used in each experiment.

The results reported here are opposite those seen in the auditory lexical decision task, in which the effect of phonological neighborhood is inhibitory (Luce & Pisoni, 1998; Ziegler, Muneaux, & Grainger, 2003). This inhibition is typically explained in terms of competition between the target word and its neighborhood. More neighbors lead to greater competition, resulting in a delayed lexical decision. Although the research presented here cannot fully address this discrepancy, it is worth considering two possible sources.

The first concerns the serial-versus-parallel nature of the input for the two modalities. In visual word recognition, the entire word can be input in a parallel fashion, provided it is short enough. However, for the spoken word, the input is serial. It is possible that this distinction could lead to inhibition for auditory input and to facilitation for visual input. For example, as the serial speech stream is input, a competitive process may be used to eliminate potential candidate words, resulting in an inhibitory neighborhood effect. However, when the input is parallel, as in the case of visually presented words, the entire neighborhood may be activated initially, and lexical decisions could be based on this initial activation, resulting in a facilitative neighborhood effect.

Another potential candidate could be the temporal differences of the stimuli within the two modalities. The spoken word is ephemeral, but the written word is not. Because the speech stream dissipates so rapidly, the system must settle on individual words as quickly as possible. One way of obtaining this rapid settling would be to allow competition between representations, such as the words in a neighborhood. However, when the input is permanent (i.e., visual), these competitive mechanisms may play a lesser role.

Finally, we assume that both written and spoken input ultimately tap a common lexical system. However, it is clear that specific characteristics of the input stimulus must play a role in the early stages of processing. A goal for future research should be to distinguish the point at which auditory and visual language processing converge. The fact that the phonological neighborhood effect reverses as a function of presentation modality may provide guidance in this endeavor.

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NOTES

1. We used the Wordmine database for computing orthographic neighborhood when controlling the words. Because the Wordmine database does not contain values for nonwords, we used the English Lexicon Project database values when comparing words and nonwords.

2. Also of concern is the fact that the item *drab* produced such a high error rate and slow latency. To ensure that this item was not responsible for the significant effects at the participants level, we removed it and reanalyzed the participants data. These analyses revealed that the effect was still significant for the latency data [$t(26) = 2.61$, $p < .05$], although the effect was no longer significant for errors ($p > .10$).

APPENDIX A

Large Neighborhood			Small Neighborhood		
Word	RT	Error	Word	RT	Error
waist	559	.00	width	631	.10
poorly	617	.00	picnic	571	.00
choke	598	.05	chant	696	.05
fade	585	.00	fruit	541	.00
soccer	549	.00	select	543	.00
sailor	580	.00	sullen	701	.25
booze	691	.05	broom	538	.00
jewel	562	.00	juror	754	.30
fern	700	.15	flair	765	.25
rudder	680	.10	russet	813	.60
hurt	620	.05	helm	662	.45
fever	598	.00	factor	539	.00
combat	622	.00	consul	957	.55
raise	587	.00	romp	714	.10
grease	580	.00	gruff	685	.35
shout	557	.00	shelf	601	.00
curve	609	.00	clutch	652	.00
breeze	598	.00	bronze	614	.00
birch	759	.10	brink	732	.05
fuzz	573	.00	flail	858	.55
cloak	680	.00	clump	697	.05
shack	685	.10	shrill	665	.05
crude	610	.00	cleft	819	.25
flute	595	.05	fifth	692	.10
beard	693	.00	brunt	852	.25
perch	685	.15	pluck	645	.35
patent	704	.15	parson	788	.40
soak	608	.00	shred	733	.10
roast	576	.00	rasp	649	.25
dial	585	.00	drab	743	.35

APPENDIX B

Large Neighborhood			Small Neighborhood		
Word	RT	Error	Word	RT	Error
cheap	548	.00	width	640	.11
vault	601	.04	drab	810	.44
crack	523	.00	turf	676	.07
breed	579	.00	shred	680	.04
cloak	688	.15	broom	561	.00
shack	655	.07	stag	696	.19
perch	660	.07	shrill	697	.04
harp	624	.04	fifth	707	.22
hound	556	.00	stay	536	.00
slack	620	.11	glow	518	.00

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