LEXICAL PROCESSING WITH DEAF AND HEARING: PHONOLOGY AND ORTHOGRAPHIC MASKED PRIMING

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This preliminary study investigates lexical retrieval of written English with native English speakers (i.e., hearing) and American Sign Language (ASL) signers (i.e., deaf) by using masked priming techniques. Repetition and pseudohomophone priming were tested. These types of priming were employed in order to investigate phonological and/or orthographic effects. A significant facilitative phonological effect for hearing participants and a significant inhibitory orthographic effect for deaf participants were found, showing clearly that the modality differences of participants who use sign or spoken languages are a factor in the lexical processing of written English.

INTRODUCTION

Exposure to language for most people is first through the spoken word, and only later in life do people learn to read. Thus, early in life, words are accessed exclusively through phonology. Throughout one's lifetime, lexical access continues to be accomplished phonologically when spoken language is being processed. But when written words are being processed, does the mature reader achieve lexical access directly from the visual cues, or is it necessary to recode the visual representation into a phonological representation in order to access the word in the lexicon? Everyone is familiar with "hearing words in one's head" when reading. Is this part of the process of lexical access? Or is this instead a post-access phenomenon, a checking mechanism perhaps? Or might it be that words are searched through two parallel processes, one using the visual cue and one using a recoded phonological representation?

This paper describes an experiment that was designed to examine phonological and orthographic issues in lexical processing. It is important to keep in mind that hearing people read in their first language (L1), which is based on their spoken language. This does not apply to deaf people because they use sign languages. There is lack of a standard written version of American Sign Language (ASL) (Baker-Shenk & Cokely, 1980; Supalla & Bahan, 1992); a deaf person always reads in his or her second language (L2). Thus, for the deaf participants, any priming with written words occurs within the L2 (e.g., written English).

Modality differences (i.e., sign versus spoken) here play an important role which do not apply to previous bilingual priming studies with hearing people. Given these modality differences, this experiment explores what potential differences there are in a hearing population's and a deaf population's responses to written English words; written English is used instead of ASL graphemes (see Supalla, Wix, & McKee, 2001). It is important to note that the system of ASL graphemes is new and in the developing stages. It has been used with deaf children for a decade but has not been used with deaf adults. Therefore there is no official writing system in ASL, and in order to study how the deaf process written language, written English must be used.

PHONOLOGICAL AND ORTHOGRAPHIC MASKED PRIMING STUDIES

There are a number of studies that suggest that people use both phonological and visual cues in visual word recognition (e.g., Ferrand & Grainger 1993; Lukatela, Frost, & Turvey, 1998; Grainger & Ferrand, 1994; Lukatela & Turvey, 1994; Van Orden, Pennington, & Stone, 1990). These studies showed facilitation in processing a target word when the word that came before it, the prime, overlapped phonologically with the target. However, because these studies used languages with alphabetic writing systems, in which the written versions of words are based on the phonological characteristics of the words, it is very hard to tease apart the influence of visual and phonological cues in reading. That is, the homophonic words *sail* and *sale* are identical in phonology, but they also overlap in orthography, so if faster responses are found to *sale* when it is primed by *sail*, it is difficult to decide which factor is responsible. Conventionally, investigators use a control prime that is matched for orthographic overlap with the phonological prime (e.g., *saul*), but in the absence of any theory of orthographic similarity, one cannot be certain that the matching is accurate. One way to find out is to carry out the experiment with a sample of deaf participants. Because deaf participants could not be employing phonological cues from the spoken language in visual word recognition, any tendency to obtain more priming in the homophonic condition (sail-SALE) than in the control condition (saul-SALE) would indicate that this result is due to inadequate orthographic matching. Thus, deaf participants provide a way of calibrating for orthographic similarity without contamination from phonological properties.

One of the earliest experiments to investigate the question of what role phonology plays in visual word recognition was a lexical decision task experiment by Rubenstein, Lewis, and Rubenstein (1971). In a lexical decision task, subjects indicate, as quickly and accurately as possible, whether each string of letters that they see, shown one by one on a screen, is a word or not. Rubenstein, et al. (1971) found a delay effect with pseudohomophones; subjects were slower to classify as nonwords items that were homophonic with real words (for instance LEEF). It was postulated that items are recoded phonologically and that this recoding is used in attempting lexical access through the phonological input system. In the case of a pseudohomophone, a word with a matching phonological representation is located, but then a post-access check detects a mismatch between this word's orthography and that of the input, and it is at this stage that the time cost occurs.

However, post-access processes are not the primary object of investigation. The question of whether phonological recoding is a necessary part of lexical access must be investigated at the pre-lexical stage. It is the pre-access phenomena that can properly be said to lead to lexical access, while post-access processes can involve other mechanisms, including episodic memory, decision making, strategy use and guessing. The difference between pre-access and post-access phenomena is a matter of milliseconds. One way to get at these questions, and the method employed in the present study, is with the masked priming paradigm (Forster & Davis, 1984). In the *forward* masked priming paradigm, before subjects see the letter string upon which the decision is made (the *target*), another word, called the *prime,* is flashed for a time so brief (usually 30 to 60 ms) that the subject is not consciously aware of seeing it. Nonetheless, masked primes have been shown to have an effect on reaction times to target words. When the masked prime and the target are the same, reaction times are reliably quicker (Bodner & Masson, 2004). Other relationships between masked primes and targets have resulted in quicker reaction times. Semantic priming has been demonstrated (Perea & Gotor, 1997). Orthographic overlap (Andrews, 1997) and phonological overlap (Perfetti, Bell, & Delaney, 1988) have also been shown to result in priming. It is assumed that the way in which these unconsciously perceived primes affect the subject's response time is due only to the unconscious and automatic processes of lexical access and not to other processes.

Depending on which experimental task the masked priming paradigm is used with, it may still be unable to isolate issues enough to answer the question of whether or not phonological recoding plays an essential role in visual word reading. For example, with Chinese, in which there is no systematic connection between phonology and the written system, phonology has been shown to affect reaction times in the naming task but not the lexical decision task (Shen & Forster, 1999). Subjects in a naming task read words out loud, which means that phonological recoding is required for this task. This requirement makes the naming task fundamentally different from silent visual word recognition precisely in terms of phonology's role in the performance of the tasks.

The lexical decision task is a better method for the present inquiry. Lexical access is required in order to perform this task, but phonological recoding is not necessarily required. Lukatela, Frost, and Turvey (1998) reported evidence for phonological recoding in a lexical decision task that used the masked priming paradigm. The subjects in this experiment responded more quickly to items when there was phonological overlap between the prime and the target. However, the effect was significant only when the experiment was done with the additional condition of dim lighting. As they say in a footnote, "It was only by reducing the room illumination that provided by a single desk lamp at floor level that we could obtain reliable priming differences" (p. 671).

The studies discussed thus far used forward masked priming. In contrast, Perfetti, Bell, and Delaney (1988) argued for using *backward* masked priming. That is when the target word is presented for a very brief amount of time (usually 15-30 ms) and then is followed by a nonword, which appears for 15-60 ms. Then this masked word is replaced with a simple pattern mask (such as #######). Usually, participants perceive only the target word and are not consciously aware of the masked nonword. Using this method, Perfetti, et al. (1988) found that phonological similarity had a strong facilitatory effect.

Similarly, Frost (2003) conducted a masked priming study with Hebrew using both forward masked priming and backward masked priming. From his findings, he then claimed that there is a significant phonological effect. However, word and nonword targets exhibited very similar effects. If the phenomenon of study were a purely lexical access issue, words and nonwords should display different effects.

Other studies' results instead provide support for the theory that an orthographic route is the primary route to visual word recognition (Davis, Castles, & Iakovidis, 1998; Forster & Davis, 1984; Forster & Taft, 1994). The search model (Forster, 1976) proposes that visual word recognition relies on orthography. Only after lexical access has been achieved through the orthographic cues does information about the word's phonology and semantics become available. Davis, et al. (1998) conducted a masked priming study with children and adults to determine whether phonological similarity affected priming. They found little evidence for a phonological priming effect with either children or adults. They did find that the younger the children were, the more there was a tendency in the data to show a phonological priming effect, but it did not reach significance. Davis, et al. (1998) noted that the slow readers perhaps use phonological information more often than the more skilled readers do. Still, they found that the repetition priming effect (e.g., wash-WASH) was faster than the sound-same prime (e.g., wosh-WASH). Thus, they claimed that these children's primary process for lexical access was the orthographic one.

Another group of researchers has proposed the use of a connectionist framework of lexical processing which employs both phonological and orthographic routes (Plaut, 1997; Seidenberg & McCelland, 1989; Van Orden et al., 1990). This framework represents phonological, orthographic, and semantic units, which are all active during lexical processing, and all influence each other. In between these three kinds of representational units are hidden units. The hidden units' function is to meditate the representational units (Seidenberg & McCelland, 1989). Lexical decision is based on the interaction of all routes, and none of these routes is the primary route in this framework.

Simultaneous use of phonological and orthographic information need not necessarily require a connectionist framework, however. Coltheart, Davelaar, Jonasson, and Besner (1977), finding pseudohomophones to act as primes (for example when leef primes LEAF), proposed the dual route model. By this model, the pronunciation of visually presented words is calculated by grapheme-phoneme correspondence (GPC) rules, while at the same time the word is accessed directly by means of the orthographic form. The word corresponding to the computed pronunciation and that which was directly accessed by means of the orthographic form are both activated; one or the other may reach threshold first, depending on the nature of the items and the task.

In short, there are three major possibilities for the role of phonology in visual word recognition. It might be that phonology is the primary route for all word recognition. It might instead be that orthography is the primary route, with phonology as a post-access check or an alternative route. Alternatively, phonology and orthography may both be utilized even in the earliest stages of lexical access.

In all of the studies mentioned above, the question of whether phonology or orthography is the primary route to lexical access remains clouded by the fact that in the languages tested, orthography reflects phonology. When a homophone or pseudohomophone primes a word, it may be due to the overlap in orthography. Shen and Forster (1999) addressed this issue when they tested for priming effects in homophones in Chinese. Because no priming effects were found in the lexical decision task, it appears that native Chinese speakers do not employ a phonological route in lexical access in visual word recognition. Still, this does not mean that the same is necessarily true for visual word processing for people whose first language is English or another language that uses a phonologically based writing system.

Hearing people are able to use both phonological and orthographic information to control lexical processing while reading a word, while deaf people cannot. How deaf people's lexical processing differs from hearing people's lexical access has yet to be fully examined. To test whether access to spoken-language phonology alters the process of visual word recognition, a study comparing hearing and deaf people's lexical decision task is needed. This present study looked at hearing versus deaf people's reaction times to words when they were preceded by phonologically similar primes (bloo-BLUE) and when they were not. The assumption was that if the effects that have been ascribed to phonological processing are in fact simply a product of orthographic overlap, then the hearing and deaf participants' results would be quite similar in this part of the experiment. If on the other hand the results showed to find significant differences in the two populations' reaction times, this would lend support to the claim that phonology plays an essential role in visual word reading for hearing people.

THE EXPERIMENT

Materials and Design

The experiment was designed to investigate the issue of phonological priming. Phonologically similar prime-target pairs were taken from Perfetti, et al.'s (1988) experiment in which evidence for phonological priming was said to be found. The original experiment in 1988 employed backward masked priming. In the current experiment, the same materials were used but with forward masked priming (see Appendix A for the list of word pairs). Within this section of the experiment, repetition priming was also tested. Repetition priming, when the prime and target are equivalent, should produce very strong priming (e.g., Forster & Davis, 1984). Words for this section were chosen from the MRC Psycholinguistic Database web site, http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm. This web site allowed the present study restricts word choice to more frequent words (see Appendix B for word list). All nonwords for the experiment were taken from the ARC Nonword Database (http://www.maccs.mq.edu.au/~nwdb/). The choice of nonwords was restricted to letter combinations that are phonologically possible in English.

Two counterbalanced lists were constructed such that if a target was preceded by its pseudohomophone/identity prime on List A, it was preceded by its control prime on List B, and vice versa (see Table 1 for examples). No word appeared twice within the materials. For both conditions, there were 12 targets per list with related primes, or exemplars, and 12 targets per list with unrelated primes. This gives a total of 48 pairs of words per list. Additionally, there was an equal number of nonword pairs, and there was also a block of practice items at the beginning of the experiment. After the practice items, pairs were presented at random to the subjects, using DMDX software developed at the University of Arizona by J.C. Forster (Forster & Forster, 2003). The primes were displayed for 67 ms after a 606 ms hash mark display. Response times (RTs) were recorded to the nearest millisecond.

Also, a questionnaire was administered to the participants. The purpose of the questionnaire was to gather information on gender, age, education level, and language backgrounds. This questionnaire was given to the deaf participants because it is quite common that deaf people have a variety of language backgrounds and it is important to know when they acquired or learned ASL. This gives a general picture of the deaf participants' language background.

Table 1. Breakdown of Item Types and Numbers, with Examples

Condition	Examples	
	List A	List B
Identity	12 exemplars sample-SAMPLE	12 control items caught-SAMPLE
	12 control items victory-HIGHWAY	12 exemplars highway-HIGHWAY
Pseudohomophone	12 exemplars bloo-BLUE	12 control items scron-BRAKE
	12 control items caft-BLUE	12 exemplars braik-BRAKE

Subjects were debriefed after completing the lexical decision task. Most hearing participants showed surprise to learn about the presence of the masked primes, but three of them claimed to have been aware that there was something between the display span and the words on which they were told to make a lexical decision. One participant claimed to have known that it was letters. Most of the deaf participants had noted that there was something unusual in the display span, but none of them said it was a string of letters. Once they were told about how the masked priming procedure works, most of them said that, when they saw it again, they could detect the presence of flashing letters before the target word display.

Participants

There were two groups of participants: hearing people and deaf people. The hearing participants were twenty native English speakers, eight of whom were female. Their ages ranged from 18 to 62. Twelve of them were advanced speakers of at least one other language (Spanish, French, Portuguese, Japanese, Korean, and Mandarin Chinese). One participant had also a very basic knowledge of ASL.

The deaf participants were 14 ASL users from the deaf community from the southwestern United States. Half of these participants were female. The age of these participants ranged from 23 to 53 years old. All of them except for one were born deaf. The one exception became deaf before the age of 18 months. Six of them were exposed to ASL prior to three years of age. All of these deaf participants have used ASL more than ten years. All of them also were either graduates of or currently enrolled in college or university (AA to Ph.D.) and had mastered written English as their L2.

RESULTS

Only the participants' responses to words were analyzed in the present study. Data from trials **in** which the subject responded incorrectly were discarded. When the subject's response time was far from his or her mean response time, those times were replaced with the value equal to the cutoffs 2 SD units above or below the mean for that participant. Table 2 shows the result of the repetition and phonological priming conditions for hearing and deaf participants. The facilitatory effect of repetition priming is significant for both groups and of a similar magnitude, 44 ms for hearing subjects and 42 ms for deaf subjects. This effect was highly significant in the hearing population in both the subject analysis, $F1(1,18)=55.72$, $p<.001$, and in the item analysis, $F2(1,22)=46.94$, $p<.001$. The effect was also significant for the deaf participants, by subject, $F1(1,12)=16.58$, $p<.01$, and by item, $F2(1,22)=12.25$, $p<.01$.

Table 2. Mean Reaction Times to Words for Hearing and Deaf Participants on Lexical Decision with Masked Phonological and Repetition Primes (in milliseconds)

Participants	Conditions	Related	Unrelated	Priming Effect
Hearing				
	Phonological Priming	543	565	22*
	Repetition Priming	485	529	44*
Deaf				
	Phonological Priming	594	560	-34*
	Repetition Priming	527	569	42*

* = Significant Priming Effect

Phonological priming effects were significant in both groups as well, but the effect was facilitatory for the hearing population (22 ms), whereas it had an inhibitory effect in the deaf population (-34 ms). For the hearing population, the effect was significant both by subject, $F1(1, 18)=9.46$, $p<.01$, and by item, $F2(1, 22)=6.40$, $p<.05$. For the deaf participants the effect was also significant by subject, $F1(1,12)=8.68$, $p<.05$, and by item, $F2(1,22)=12.42$, $p<.01$.

DISCUSSION

Repetition priming

Repetition priming was strong and facilitatory for both deaf and hearing populations. There was nothing surprising in finding these results (although this is the first time they have been shown for deaf subjects). Indeed, if seeing a word before does not aid its processing upon its second presentation, then there would be no reason to expect any other kind of priming within the masked priming paradigm. The fact that the effect appeared much stronger in the hearing population is certainly due in part to having data from more participants, and it may also be related to the difference in processing one’s L1, as in the case of the of the hearing participants, as opposed to an L2, which was the case with the deaf participants.

Phonological priming

The results are much more intriguing with the phonological primes. The results turned out decidedly different in the two populations. The deaf participants show the opposite effect as the hearing participants; they show inhibition instead of facilitation. Because the deaf participants do not have access to the words' phonology, the priming effects are due to the words' orthography. What this suggests is that if the hearing participants had responded to these items purely in terms of their orthography, they would have shown a similar inhibitory effect. Such inhibitory effects have been found before. Feldman (1992) reported orthographic inhibition in a study with varying prime durations. In her study, orthographic similarity between primes and targets resulted in facilitation with shorter (66 ms) SOAs (stimulus onset asynchronies, that is, the duration of the presentation of the prime plus any additional time—here, 50 ms—between that and the presentation of the target) but produced inhibition with SOAs of 116 ms, and even greater inhibition with an SOA of 300 ms. This might suggest that a similar effect occurred with the deaf subjects of the present study, who were presented the prime for a full 67 ms.

Segui and Grainger (1990) found inhibition in the processing of targets that were primed with words that were neighbors (that is, words whose spelling differs by only one letter) of the target but of lower frequency than the targets, when the prime was not masked and was shown for a full 350 ms. On the other hand, unmasked primes that were higher frequency orthographic neighbors to the primes had a facilitative effect. A facilitative effect was also found with masked primes, whether of higher or lower frequency. The Segui and Grainger (1990) paper agrees with Feldman (1992) in suggesting that whether a prime has a facilitative or inhibitory effect on the processing of the target will be affected by the length of presentation of the prime. It furthermore brings in the issue of the relative frequency of the prime and target. Unlike the Segui and Grainger (1990) experiment, however, is the fact that in our study, the phonologically similar primes were nonwords. Furthermore, it is not clear that frequencies and neighborhood densities function the same way with deaf subjects reading in their L2 as they function with hearing subjects reading in their L1. The long prime duration in the present study, however, should certainly be considered as an important factor.

Hearing participants' processing of targets was facilitated when the targets were preceded by phonologically similar primes. If the inhibition caused in the deaf participants resulted from the conflict between the prime and target stimuli, the facilitation shown in the hearing participants could be the result of the phonological similarity between primes and targets, and it would furthermore appear that the phonological similarity was able to override the orthographic dissimilarities.

These results of phonology facilitating the processing of visual words for hearing subjects is predicted by the connectionist framework in which each level of representation—orthography, phonology and semantics—is thought to be interconnected to every other. Proponents of this framework place special importance on the idea of the development of lexical processes throughout an individual's development (Seidenberg & McClelland, 1989). By this model, the fact that people (generally) know what words sound like before they are able to read continues to shape the way words are processed throughout a person's lifetime. Strong connections between orthography and phonology exist, and therefore any connections between orthography from the input and corresponding phonology should facilitate the lexical decision task. This same model could be used to partially explain the inhibitory effect found with the deaf subjects. In this case, phonology is not facilitating lexical access. Instead a similar but nonequivalent prime is present and may cause competition among candidates at the stage of lexical access for the target. The primes in this experiment were nonwords and should have been as likely to activate the targets as any other neighbors they had.

An interactive-activation model (McClelland & Rumelhart, 1981) would also predict the results that were found with respect to phonological priming. Spreading activation causes the phonological properties of the prime to be activated, and this would in turn cause the target, which shares the activated phonological properties, to have a raised activation level. Because the target has a raised activation level, lexical access is facilitated—for the hearing population. This model has little to say about the case of the deaf population, because unlike the model, phonology does not interact with orthography among the deaf.

In a search model (Forster, 1976), it is assumed that the written word is processed primarily through an orthographic access file. However, within this model, it would be possible to have a simultaneous search in the phonological access file, based on an assembled phonology arrived at through grapheme-phoneme correspondence rules, like the dual route model proposed by Coltheart, et al. (1977). If the results of the orthographic-route search and the phonological-route search match, then response to the stimulus is faster, and if there is a mismatch, the response is delayed. Alternatively, phonology might only come into play in a post-access check, with the phonological properties of the accessed lexical entry being checked against the assembled phonology. Because the prime duration in the present experiment was unusually long—67 ms—the evidence for phonological priming with the hearing subjects could easily be attributed to a post-access stage. Ferrand and Grainger (1993) found phonological priming effects, but only with a prime duration greater than 50 ms. That finding throws the strong phonological model, which says that direct orthographic access is impossible, into serious doubt.

Further research using much shorter prime durations should be done in written English, comparing once again the results of deaf and hearing participants. The search model would predict that the results of deaf and hearing participants would be more similar with shorter prime durations because in this model, phonology only plays a role later, after initial lexical access has been achieved. In contrast, phonology is said to have a role from the very beginning of the process of lexical access in both interactive-activation models and connectionist models, and therefore both of these models would predict that the sharp differences in RTs between deaf and hearing participants would still show up, even with shorter prime durations.

What is clear from the findings is that phonological recoding is an automatic process at some stage of visual word recognition in hearing people but not for deaf people, and hence the way in which a person learns to read impacts in a fundamental way how reading is subsequently performed due to the modality constraints. This means that there exist differences in the way basic lexical processing happens among even healthy, brain-damage-free adults. This could have implications for models of learning and cognition based on written English which underlies spoken language.

It would be interesting to investigate whether a deaf person who reads ASL graphemes processes them in a manner similar to how a hearing person whose L1 is English processes written English. Phonology plays a role in visual word recognition at some stage in a hearing person's process (that is, when the written language is based on the phonology of the spoken language). Because the ASL grapheme system was based on the actual physical way in which ASL signs are produced, it might be predicted that this ASL version of phonology would influence ASL grapheme reading in a manner not unlike how spoken language phonology influences reading in the hearing population's reading. This is yet another avenue of research that has yet to be explored.

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APPENDIX A

words used for repetition priming and, in center column, their controls

1. youth worry youth
2. noted urban noted
3. interior thousand interior
4. sensitive financial sensitive
5. breakfast otherwise breakfast
6. touched suggest touched
7. sample caught sample
8. highway victory highway
9. smooth formal smooth
10. share loose share
11. phase novel phase
12. author oxygen author
13. capital explain capital
14. dozen crowd dozen
15. gross bread gross
16. manager promise manager
17. weight salary weight
18. complex sitting complex
19. smoke model smoke
20. plain inner plain
21. index beach index
22. closer vision closer
23. empty throw empty
24. engine sight engine

APPENDIX B

pseudohomophonic prime – control – target word

1. bloo caft blue
2. braik scron break
3. flore grent floor
4. floo nade flu
5. gote stel goat
6. grait merse great
7. groze flase grows
8. heer fode hear
9. hoal plis hole
10. mayd stor made
11. mone drok moan
12. wun bec one
13. fayze compt phase
14. peese droat piece
15. porze fedir pores
16. kwoat melst quote
17. soal jeck sole
18. staik narth steak
19. stial grost style
20. sute mage suit
21. tode lert toad
22. waid drill wade
23. wate hond wait
24. woar boke war