Silent letters and the interaction of lexical and sublexical processes in spelling

A case study in an English-speaking dysgraphic patient

Zachariah Calluori
Columbia University

ABSTRACT. Various studies have suggested that lexical and sublexical processes may interact (Folk et al. 2002, Folk & Jones 2004, Laiacona et. al 2009). The present study examines whether the summated semantic and sublexical activation from semantic information and orthography-to-phonology conversion mechanisms help activate corresponding entries in the Phonological Output Lexicon. It was hypothesized that in words with silent letters, pronounced letters would receive activation from both the lexical and sublexical routes whereas silent letters would only be supported by the lexical route as a result of prior lexical-semantic knowledge. A patient, SoDa, was selected according to performance on Johns Hopkins Dysgraphia Battery. Six word lists were created totaling 167 words; there were two conditions, "opaque" and transparent," that were varied according to position of the silent letter, whether initial, middle, or final. The words were verbally administered to SoDa, who was instructed to provide written spellings. Only the responses in which the error affected one of the letters in the silent consonant cluster in the opaque words or their transparent correlates were considered. In the middle condition, the consonant cluster containing the silent letter was more likely to contain an error both compared to the other letters in the word and compared to the fully pronounced correlate in the transparent word-match. The results are consistent with a graphemic buffer deficit, which disproportionately affects spelling in the middle position of words. The results lend support to the notion that lexical and sublexical processes interact and, together, activate letters in a word to varying degrees.

1. Introduction

The dual-route model posits the existence of two cognitive mechanisms – the lexical route and the sublexical route. The lexical route accesses and employs previously stored lexical-semantic information to solve reading or spelling tasks. Therefore, lexical mechanisms are specialized for the reading and spelling of familiar and irregular words. On the other hand, the sublexical route accesses and employs phonological principles and the phoneme-to-grapheme conversion route. Therefore, sublexical mechanisms are specialized for the reading and spelling of unfamiliar, nonwords, and regular words. How does the brain approach a given spelling or reading task? One way to understand the relationship between the lexical and sublexical routes is what Laiacona et. al (2009) called "independent cooperation". In this conception of the dual-route model, a word is processed in parallel by lexical and sublexical mechanisms. Simultaneous and independent function ensures that the brain can efficiently arrive at a pronunciation or spelling, which is important for language fluency. Ultimately, the demands of a given task will dictate whether the response produced is the result of lexical or sublexical processes. The lexical and sublexical routes can operate and be lesioned independently (Folk & Jones, 2010). Joubert et. al (2004) showed that lexical and sublexical processes in reading activate different regions within a network of brain structures. Greater activation in the left inferior prefrontal gyrus was observed in sublexical tasks, whereas an area at the border of the left angular and supramarginal gyri was more engaged in lexical tasks. The fact that they can operate independently necessitates the conclusion that they exhibit "independent cooperation" in all cases. Other researchers have posited that the lexical and sublexical routes interact. An increasing body of work has investigated the possibility of interactivity between the lexical and sublexical routes. Studies have repeatedly shown that the sublexical process assists the selection of a target word over competing form neighbors by strengthening its graphemes (Folk et al. 2002, Folk & Jones 2004). Laiacona et. al (2009) also reported lexical and sublexical interaction supported regular word spelling in three of twelve Italian cases of mixed dysgraphia.

If the lexical and sublexical routes interact, one would expect that a given spelling is the product of contributions from the lexical and sublexical routes. Lexical priming experiments carried out by Folk, Rapp, and Goldrick (2002) and Folk and Rapp (2004) have obtained results that indicate contributions from both the lexical and sublexical routes. For example, Folk, Rapp, and Goldrick reported errors made by a dysgraphic patient, LAT, that contained a combination of very low probability phoneme-grapheme correspondences, indicating contributions from both lexical and sublexical routes.

An interactive model of summative activation from both lexical and sublexical routes on the graphemic level is hypothesized. Hillis and Caramazza (1991) have previously proposed a summative model, but their model deals with semantics and whole word selection. They suggest that the summated semantic and sublexical activation from semantic information and orthography-to-phonology conversion mechanisms, together, help activate corresponding entries in the Phonological Output Lexicon to threshold levels, and thereby activate the correct response.

The experiment aims to gather support for an interactive model of summative graphemic activation using a task that involves spelling words with silent letters. In an interactive model, silent letters should receive the least amount of activation. Pronounced letters will receive activation from both the lexical and sublexical routes whereas as silent letters will only be supported by the lexical route as a result of prior lexical-semantic knowledge. Therefore, errors are most likely to occur at the positional location of the letter cluster containing the silent letter.

Figure 1. An illustration of the contributions of the lexical and sublexical routes in spelling "ledge".

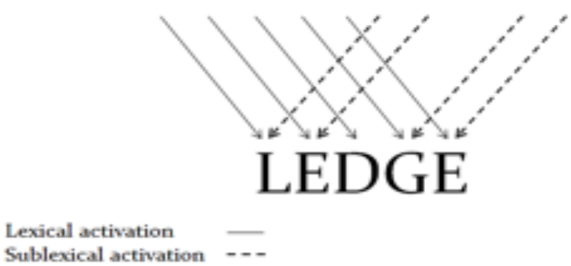
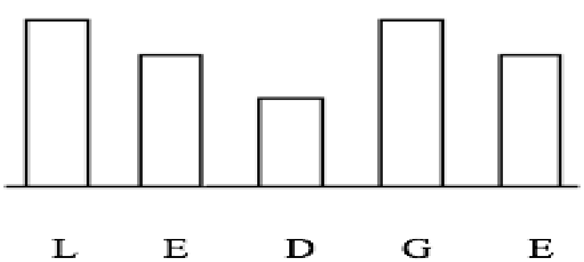
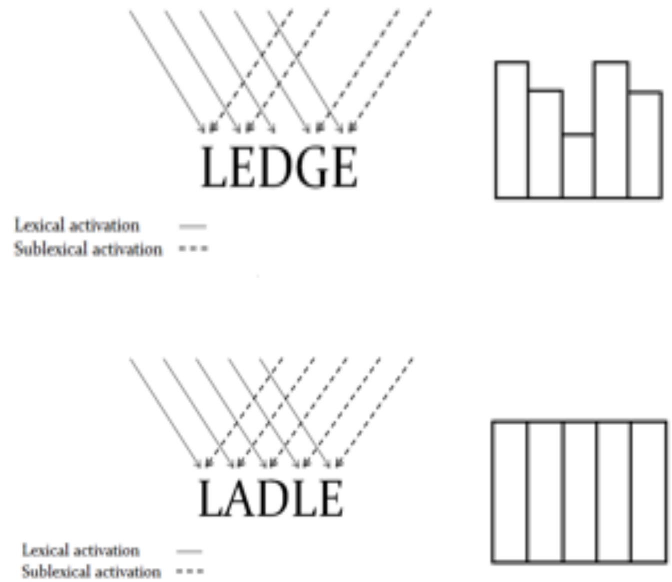


Figure 2. A graphic representation of the expected summative activation levels from lexical and sublexical routes for the word "ledge".



Words with silent letters will be matched with words in which every letter is pronounced. In the latter condition, the formerly silent letter will be in the same position as a point of comparison. The performance of an English-speaking dysgraphic subject, SoDa, on this spelling-to-dictation task was recorded and analyzed.

Figure 3.



2. Case Report

SoDa suffered from a cerebrovascular accident (CVA) that involved the frontal and temporal areas of the left hemisphere, including Broca's area. She is a university graduate. She obtained a Master's degree in education and worked as a teacher. Immediately following her CVA, a severe impairment of speaking abilities was observed. In time, she showed a partial recovery of speaking abilities. However, articulatory and spelling difficulties remain. SoDa was administered parts of the Johns Hopkins Dysgraphia Battery to investigate her spelling deficit. The data were collected between October 2013 and December 2013. Several word lists were presented to SoDa. The tasks evaluated phoneme-grapheme conversion, word length, concreteness, part of speech, nonwords, and picture naming. Spelling accuracy was significantly influenced by word length, word frequency, word status, and response modality. The words presented were between 4 and 8 letters long, and spelling accuracy was generally lower for longer words, indicating a graphemic buffer deficit. Low frequency words were spelled correctly at a significantly lower rate than high-frequency words, indicating an impaired lexical route (86% for high-frequency words and 55% for low-frequency words). Nonwords were spelled with significantly less accuracy than either regular or irregular words (3% for nonwords, 93% for regular words, and 87% for irregular words). In addition, dissociation was observed between written and spoken response modalities, with accuracy improving in the spoken condition. Overall, SoDa's speaking is moderately fluent and her sentence processing and semantic capabilities are mostly intact.

3. Methods

Stimuli

A list of two-consonant clusters containing a single, silent, consonant letter was created. In total, 22 different consonant clusters were tested.

Table 1. Table of consonant clusters that contain silent letters that were used.

Consonant Clusters Tested			
Initial Position	Middle Position		Final Position
ho (eg. honor)	dg (eg. ledge)	pt (eg. receipt)	ow (eg. arrow)
kn (eg. knife)	lf (eg. half)	gn (eg. foreign)	mn (eg. column)
gn (eg. gnat)	sw (eg. answer)	tg (eg. mortgage)	mb (eg. climb)
wr (eg. wrist)	ld (eg. could)	sc (eg. descend)	ch (eg. monarch)
wh (eg. whose)	st (eg. listen)	lm (eg. salmon)	
ps (eg. psycho)	ct (eg. indict)	ch (eg. orchid)	

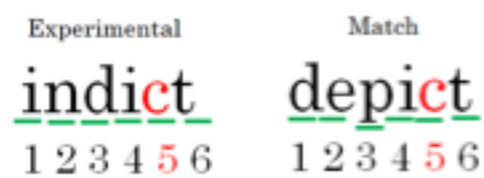
Six word lists were created totaling 167 words; there were two conditions, "opaque" and transparent," that were varied according to position of the silent letter, whether initial, middle, or final. Words for which the phonological form is inconsistent with the graphemic form, for example, "indict," were considered "opaque". Each word in the "opaque" condition was matched with a "transparent" word – one for which the phonological form is consistent with the graphemic form – for example, "depict". All word lists were compiled using the Dictionary Utility Interface of the MRC Linguistic Database provided online by The University of Western Australia and selected so that they share the following characteristics:

1. All words are morphologically simple.
2. All words are heteronyms.
3. All words are between 4 letters and 11 letters long.

Words in the opaque condition were selected from the output generated by the MRC Linguistic Database for the following additional characteristics:

1. The word must contain a silent letter.
2. There may only be one silent letter in the word.
3. The silent letter must be a consonant.
4. The silent letter must be the first letter to occur (in first position) in a word in the initial condition. Likewise, the silent letter must occur between the first and last position in the middle condition and in the last position in the final condition.

Figure 4. "C" is is the single, silent consonant letter in indict. The "c" in "depict" occurs in the same position and consonant cluster, but it is pronounced.



Words in the transparent condition were selected from the output generated by the MRC Linguistic Database for the following additional characteristics:

1. The word contains the sounded version of the consonant that is silent (unsounded) in the match word.
2. The consonant in question is in the same position in both the opaque word and transparent match.
3. The transparent match is approximately the same length as its opaque word.
4. The transparent match has approximately the same mean logarithmic HAL (Hyperspace Analogue to Language) frequency as its opaque counterpart.

The mean logarithmic HAL frequency, or Log_Freq_HAL, was the chosen measure of frequency used to compare words in the lists. The mean Log_Freq_HAL was obtained from the English Lexicon Project provided online by Washington University in St. Louis.

In summary, the criteria for word selection ensured that the "opaque" word would contain a single silent (unsounded) letter that was matched with a "transparent" word that contained the same letter in the same position, but sounded rather than unsounded. Words with multiple silent letters or silent vowels were excluded to allow for the most specific and accurate analysis.

Testing was completed within a three week span which encompassed two testing sessions. A fully randomized list including the entirety of the stimuli was produced prior to testing. Due to a significant number of "Don't Know" responses in the first testing session, the list was revised. A second fully-randomized list was created prior to the second testing date to test newly added words. This list also included both opaque and transparent words from initial, middle, and final conditions. The lists were presented in a writing-to-dictation task. Lab members read the stimuli aloud to SoDa. SoDa was instructed to repeat the word aloud to ensure comprehension. If necessary, the lab member would repeat the stimulus again and/or use it in a sentence. Then SoDa handwrote the spelling. SoDa's handwritten responses were manually input into a spreadsheet for analysis.

4. Results

All responses were first analyzed in terms of accuracy. The incorrect responses were isolated for further analysis. Only the responses in which the error affects one of the letters in the silent consonant cluster (wh-, -st-, -ow, etc.) in the opaque words or their fully-voiced correlates in the transparent words were considered. The frequency of this specific type of error was found in each condition. A percentage was calculated by dividing the number of this type of error over the number of words in that condition. The intial and final conditions showed similar error percentages and were combined for comparison with the middle condition. There was no significant difference between the error percentage in the initial+final condition for opaque words, the initial+final condition for transparent words, or the middle condition for transparent words. The error percentage was significantly greater in the middle condition for opaque words. It was more than double the error percentage in the combined initial and final conditions for opaque words.

Table 2.

Opaque Condition		Transparent Condition	
Given	Response	Given	Response
knit	net	kelp	heln
gnaw	nob	straw	su
gnat	nat	curfew	curvise
wrangle	ringale	withdraw	withdrawel
shadow	shawon	common	commer
damn	dam	victim	vimur
autumn	autem, auturm	bulb	buld
comb	comp	crib	crip
womb	wown	suburb	suburna

Table 3.

Opaque Condition		Transparent Condition	
Given	Response	Given	Response
pledge	plegish, prieve	hurdle	heaful
hedge	head	ladle	laido
fridge	rigid	paddle	pallow
bridge	bring, brigt	fester	fenner
hustle	huckily	startle	strangh
bristle	brisson		
receipt	receiver		
mortgage	morgo		
ascent	accee		
orchid	orciade		

Table 4.

	Opaque		Transparent	
Initial + Final	17.1%	(9/53)	16.7%	(9/54)
Middle	35%	(12/34)	19.1%	(5/26)

5. Discussion

The results lend support to the notion that lexical and sublexical processes interact and, together, activate letters in a word to varying degrees, but not in every condition. Only the middle condition exhibits the expected result – the consonant cluster containing the silent letter is more prone to error compared to the other letters in the word and compared to the fully-pronounced correlate in the transparent word-match. The fact that the greatest percentage of error occurs in the middle condition lends further evidence a graphemic buffer deficit in SoDa. The middle of a word is often to the most prone to error for a patient with a graphemic buffer deficit. The result of an elevated error percentage for the middle condition is only observed in the opaque condition. The transparent condition is not significantly higher than the error percentages observed in the initial and final conditions for opaque or transparent words. Why does this result occur selectively for words with median-position silent letters? Looking at the chart of consonant clusters tested, one notices that the middle position has the greatest number of consonant clusters and variety of silent letter identities within those clusters. Ehri and Wilce (1982) suggested that readers store spelling by studying how letters represent sounds. Therefore, silent letters – unsounded letters – should be more difficult to remember. Ehri and Wilce also suggested that due to their unique status, silent letters may become more salient in memory representation. Ehri (1987) confirmed the latter hypothesis by testing the reaction times of children to decide whether a known word with a silent letter, such as "listen," contained its silent letter, in this case a "t". Next, only the letter was presented, and the child had to identify words containing that letter in its silent form. Pronounced letters were identified more accurately, evidencing that silent letters are harder to remember. Silent letters were identified faster than pronounced letters and prompted the retrieval of more words than pronounced letters. Similarly, although the initial or final consonant clusters may be less frequent, they may also be less productive, meaning that there are fewer words to memorize. For the middle condition, despite the relative productivity of some of the consonant clusters, there are a greater number of consonant clusters and words to memorize, contributing to the elevated difficulty evidenced by the higher error percentage. Therefore, the disorder with a sensitivity to silent letters may actually occur before the graphemic buffer translates the letter string with which it is provided. Further research must be done to examine the relative frequencies of the consonant clusters in words. Some clusters, such as "sc" occur both at the beginning of words and in the middle of words. Ensuing tests might develop word lists that will isolate the effect of position.

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