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Brief article

A phoneme effect in visual word recognition

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Abstract

In alphabetic writing systems like English or French, many words are composed of more letters than phonemes (e.g. BEACH is composed of five letters and three phonemes, i.e. /biJ/). This is due to the presence of higher order graphemes, that is, groups of letters that map into a single phoneme (e.g. EA and CH in BEACH map into the single phonemes /i/ and /J/, respectively). The present study investigated the potential role of these subsyllabic components for the visual recognition of words in a perceptual identification task. In Experiment 1, we manipulated the number of phonemes in monosyllabic, low frequency, five-letter, English words, and found that identification times were longer for words with a small number of phonemes than for words with a large number of phonemes. In Experiment 2, this 'phoneme effect' was replicated in French for low frequency, but not for high frequency, monosyllabic words. These results suggest that subsyllabic components, also referred to as functional orthographic units, play a crucial role as elementary building blocks of visual word recognition. © 1998 Elsevier Science B.V. All rights reserved

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1. Introduction

A critical characteristic of alphabetic writing systems like English or French is the

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non-isomorphic relation between orthography and phonology. That is, considering the letter as the basic element of the word's orthographic representation and the phoneme as the basic distinctive element of the word's phonological representation (Jakobson et al., 1952), one can often find a mismatch between the number of letters and the number of phonemes. For example, the English word BEACH (/biJ/) has five letters but only three phonemes while the English word CRISP (/krIsp/) has five letters and five phonemes. CRISP and BEACH have thus the same number of letters but a different number of phonemes.

In an attempt to reduce the mismatch between the number of letters and the number of phonemes, linguistic and psycholinguistic theories introduced the notion of grapheme (e.g. Venezky, 1970; Coltheart, 1978). A grapheme is defined as the written representation of a phoneme (see Henderson, 1985; Berndt et al., 1987; Berndt et al., 1994). One of the properties of graphemes is that they can be composed of either a single letter or a group of letters. This property allows one to distinguish between different orders of graphemes. For example, the letter A in GLASS can be defined as a first-order grapheme, and the letter pair EA in BEACH as a second-order grapheme. Another property of graphemes is that higher-order graphemes are composed of lower-order graphemes. In our example, the second-order grapheme EA is composed of two first-order graphemes, i.e. E and A. These properties of graphemes imply that during the orthography-to-phonology computation, the reading system has to group some letters into chunks (i.e. higher-order graphemes) in order to activate the correct sequence of phonemes, and accordingly, to avoid letter-by-letter processing. The necessity to group letters into higher-order-graphemes and the potential conflict between a letter-level and a higher-order-grapheme-level of processing is a crucial aspect of reading and learning-to-read that has been almost entirely ignored by psycholinguistic research and computational modeling.

The purpose of the present study was to investigate whether the presence of higher-order graphemes affected word processing times. More precisely, three questions were addressed. (1) Does it take more time to recognize words that have more letters than phonemes? In Experiment 1, we manipulated the number of phonemes for three classes of low-frequency, five-letter English monosyllabic words. We found that word identification latencies were longer for words having a smaller number of phonemes. (2) Can this 'phoneme effect' be extended to a different alphabetic system? In Experiment 2, we manipulated the number of phonemes for two classes of low-frequency, five-letter French monosyllabic words. The phoneme effect was replicated in French. (3) Can the phoneme effect be obtained for high-frequency words? The frequency manipulation in Experiment 2 showed that the phoneme effect was only robust for low-frequency words.

Both of these experiments were run using a perceptual identification task because perceptual identification does not necessarily imply an orthography-to-phonology computation and thus provides a more conservative test of the existence of phonological effects in visual word recognition. The present research used a variant of the ascending method of limits (e.g. Feustel et al., 1983; Voker et al., 1986; Grainger and Segui, 1990; Snodgrass and Poster, 1992; Ziegler et al., 1998) in which visual information is progressively displayed by steadily increasing the luminance of a target word located in the middle of the screen, so that the word slowly emerges from the background (Rey et al., submitted). In this task, participants are asked to interrupt the luminance increasing process as soon as they have identified the target word. Then, they enter their response on the keyboard. Dependent variables are response time and participant's report.

2. Experiment 1: phoneme manipulation in english

2.1. Method

2.1.1. Participants

Twenty-seven Arizona State University introductory psychology students participated in the experiment. All were native English speakers and had normal or corrected to normal vision.

2.1.2. Stimuli and apparatus

Three groups of 25 monosyllabic five-letter words were selected. The three groups contained words that were composed of either three, four, or five phonemes (e.g. TEETH $\rightarrow$ /tiT/ in the 3-phoneme condition; BLEAT $\rightarrow$ /blit/ in the 4-phoneme condition; BLAST $\rightarrow$ /bl#st/ in the 5-phoneme condition). Frequency was estimated using the CELEX frequency count (Baayen et al., 1993). The mean frequency of the three, four, and five phoneme groups was 11.4, 11.3, and 11.3 occurrences per million, respectively. The three lists were matched as closely as possible for the number of orthographic neighbors (2.5, 2.5 and 2.6 for the three-, four-, and five-phoneme groups, respectively), the number of higher frequency neighbors (1.7, 1.6, and 1.7), and the summed bigram frequency (6807, 5941, and 6640 respectively).

The experiment was controlled by an IBM PC 486 DX2 computer. The stimulus words were typed in lowercase. The experiment was run in a dark room that was lit with a lamp placed behind the participants. The contrast of the screen was set at its maximum, i.e. the background was as dark as possible. Stimulus luminance, on the other hand, was set to be as high as possible.

2.1.3. Procedure

Each trial began with a 1-s presentation of a fixation mark (« + ») in the center of the screen. The fixation mark was replaced by the target word that was written in black (i.e. completely invisible, the background also being black). The luminance of the target word was then progressively increased by modifying the color of the target word. This was done by incrementing every 100 ms the values of the RGB (red, green, blue) counters of one unit. Thus, every counter was set at 0 at the beginning. After 100 ms, the red counter was set at 1 (the green and blue counters still being at 0). After 200 ms, the RGB counters were at 1-1-0, respectively, after 300 ms

→ RGB = 1-1-1; after 400 ms → RGB = 2-1-1; etc. As soon as the participants could identify the target word, they interrupted the luminance increasing process by pressing the space bar. Then, the item was replaced by a pattern mask and participants had to enter what they had seen using the keyboard. After this, they pressed the ‘return’ key and the screen remained black for 500 ms until the next trial. For each trial, response time was recorded (that is, the time interval between the onset of the luminance increasing procedure and the space bar pressing). Participants were instructed to stress accuracy rather than speed.

2.2. Results

Mean correct response times and error rates for the three experimental conditions are reported in Table 1. The trimming procedure excluded scores greater than three SDs above and below the participant’s overall response time. Analyses of variance (ANOVAs) were conducted using both participants (F_1) and items (F_2) as random factors, treating the number of phonemes as a within-participant factor.

As shown in Table 1, response times gradually increase as the number of phonemes composing the word decreases, $F_1(2,26) = 5.45$, $P < 0.01$; $F_2(2,72) = 3.66$, $P < 0.05$. A significant 28 ms difference was observed between the 3- and 5-phoneme conditions, $F_1(1,26) = 10.81$, $P < 0.01$; $F_2(1,48) = 7.23$, $P < 0.01$. The difference between the 3- and 4-phoneme conditions was not significant, $F_1(1,26) = 3.62$, $0.05 < P < 0.1$; $F_2(1,48) = 2.62$, $P > 0.1$, nor was the difference the 4- and 5-phoneme conditions, $F_1(1,26) = 1.92$, $P > 0.1$; $F_2(1,48) = 1.14$, $P > 0.1$. The error data did not show a clear phoneme effect, $F_1(2,26) = 4.29$, $P < 0.05$; $F_2(2,72) = 1.95$, $P > 0.1$.

Table 1
Mean correct response times (RT in ms), percentage of errors (Err%), and corresponding SEs for the three lists of words in Experiment 1

	Number of phonemes		
	$n = 3$	$n = 4$	$n = 5$
RT (ms)	2235	2219	2207
SE	58	58	57
Err (%)	3.7	1.1	2.2
SE	0.9	0.5	0.5

3. Experiment 2: phoneme and frequency manipulation in french

3.1. Method

3.1.1. Participants

Twenty-two participants from the Center for Research in Cognitive Neuroscience participated in the experiment. All were native French speakers and had normal or corrected to normal vision.

3.1.2. Stimuli, apparatus, and procedure

Four lists of 20 monosyllabic 5-letter words were created, of which two contained low-frequency words (LF words, $F < 10$ occurrences per million), and two were composed of high frequency words (HF words, $F > 50$ occurrences per million). One list in each frequency condition contained words that were composed of two or three phonemes (2/3P words); the other list contained words composed of four phonemes (4P words). For example, CRAIE $\rightarrow$ /kR$/ belonged to the low frequency 2–3 phoneme condition (LF-2/3P); TRIPE $\rightarrow$ /tRip/ to the low frequency 4-phoneme condition (LF-4P); VINGT $\rightarrow$ /vê/ to the high frequency 2–3 phoneme conditions (HF-2/3P); GLACE $\rightarrow$ /glas/ to the high frequency 4-phoneme condition (HF-4P). Frequency was estimated using the BRULEX frequency count (Content et al., 1990). The mean frequency of the LF-2/3P, LF-4P, HF-2/3P and HF-4P conditions was respectively 5.1, 5.2, 150.8, and 149.3. The mean number of phonemes for these four lists was respectively 2.9, 4, 2.9 and 4. The four lists were also matched as closely as possible for the number of orthographic neighbors (2.3, 2.1, 2.2, and 2.2, respectively), the number of higher frequency neighbors (1.7, 1.5, 0.3, and 0.3, respectively), and the summed bigram frequency (8300, 9645, 9396, and 9700, respectively). The experiment was controlled by a Compaq Pentium Prolinea 575e microcomputer. The experimental set up and procedure were identical to the one used in Experiment 1.

3.2. Results

Mean correct response times and error rates for the four experimental conditions are reported in Table 2. Because of an error in stimulus selection, one low frequency word composed of three phonemes (RHUME) was repeated during the experiment and this item was thus removed from the analysis. The trimming procedure excluded scores greater than three SDs above and below the participant's overall response time. Analyses of variance (ANOVAs) were conducted using both participants (F_1) and items (F_2) as random factors, treating the number of phonemes as a within-participant factor.

Table 2
Mean correct response times (RT in ms), percentage of errors (Err%), and corresponding SEs for the four lists of words in Experiment 2

	RT (ms)		Err (%)	
	2–3 Phonemes	4 Phonemes	2–3 Phonemes	4 Phonemes
Low F	2259	2220	2.29	1.38
SE	55	51	0.87	0.59
High F	2192	2180	0.70	0.69
SE	48	46	0.38	0.38

As shown in Table 2, response times were affected by both frequency and number of phonemes. High frequency words were identified faster than low frequency words, $F1(1,21) = 28.53$, $P < 0.0001$; $F2(1,76) = 27.97$, $P < 0.0001$. Similarly, words with four phonemes were identified faster than words with two to three phonemes, $F1(1,21) = 14.87$, $P < 0.001$; $F2(1,76) = 7.58$, $P < 0.01$. Planned comparisons investigated the effect of the number of phonemes in the two frequency conditions. In the low frequency condition, 4-phonemes words were responded faster than 2–3 phonemes words, $F1(1,21) = 13.39$, $P < 0.005$; $F2(1,36) = 8.78$, $P < 0.005$. In the high frequency condition, no significant difference was observed between the 4- and 2–3-phoneme conditions, $F(1,21) = 1.1$, $P > 0.1$; $F2(1,38) = 0.82$, $P > 0.1$. The error data replicated the pattern of performance obtained with response times. However, most of the differences did not reach significance.

4. Discussion

The results of this study can be summarized as follows: in a perceptual identification task, we obtained longer identification times for words having a smaller number of phonemes. This phoneme effect was observed in English and French for low-frequency five-letter monosyllabic words, but was not obtained in French for high-frequency five-letter monosyllabic words.

The present research indicates that grouping letters into graphemes for an efficient orthography-to-phonology computation requires additional processing time. However, as suggested by current computational models of visual word recognition in which word identification results from two parallel and interdependent processes, whole word orthographic processing and sublexical orthography-to-phonology processing (Coltheart et al., 1993; Jacobs et al., 1998), there is a dissociation between the processing of high and low frequency words. Indeed, high frequency words seem less affected by the conflicts arising during the sublexical orthography-to-phonology computation (i.e. the conflict between a letter-level and a grapheme-level of processing), indicating that their identification is mainly and rapidly performed on the basis of whole word orthographic processing. Alternatively, low frequency words have a less stable orthographic representation and are thus more affected by the potential problems arising in the letter-to-phoneme translation. A similar result is observed when manipulating the consistency/regularity of the mapping between sublexical orthography and sublexical phonology (e.g. Waters and Seidenberg, 1985; Content, 1991; Treiman et al., 1995).

There may be, however, an alternative interpretation of the present phoneme effect. As a matter of fact, by manipulating the number of phonemes in a word, we also unavoidably changed their syllabic structure: 5-phoneme words had a CCVCC structure, 4-phonemes words had either a CVCC or a CCVC structure, and 3-phoneme words had mostly a CVC structure. Thus, one could argue that processing of 3-phoneme words was not inhibited due to competition between single- and multi-letter graphemes but rather that the processing of the 5-phoneme words was facilitated due to more constraining syllabic structures. Indeed, CCVCC words may be easier to recognize than CVC words because they are better specified in terms of their phonology and reside in a less dense phonological neighborhood. CCVCC words may then activate less competitors in the phonological lexicon compared to CVC words (which are more common structures in English and French). Therefore, the critical factor in the present experiment could be the number of phonological neighbors or, in other terms, the number of graphemes shared by the target word with other lexical entries.

Note, however, that there seems to be no independent empirical support for the existence of a phonological neighborhood effect in visual word recognition. The few studies that have investigated the effects of phonological neighbors on visual word recognition have reported null effects (Brown and Watson, 1994; Peereman and Content, 1997). In contrast, in a study on phonological dyslexia, Derouesne and Beauvois (1979) reported that some of their patients exhibited far greater problems when reading non-words with multi-letter graphemes than when reading non-words with single-letter graphemes. In addition, in a manipulation comparable to ours, Rastle and Coltheart (1998) recently reported a similar phoneme effect in non-word naming. This effect was present in both the human data and the simulations of their dual route cascaded model. An analysis of the locus of the effect within their simulation model showed that it was due to competition between multi-letter and single-letter graphemes for priority within the non-lexical route.

Thus, our data join those of Rastle and Coltheart and others to suggest that the reading process is influenced by the fine grained phonographic structure of words. It indicates that word identification processes are sensitive to the syllabic structure of words and to subsyllabic components such as graphemes. More precisely, the number and the position of graphemes in a word, together with the number of shared graphemes among different lexical entries, are factors that seem to critically influence the reading process. It thus supports the view according to which '…the proper unit of the reading system is neither the single letter nor the whole word but a higher-order invariant derived from grapheme-phoneme correspondences' (Gibson et al., 1962p. 570).

The idea according to which the reading system develops intermediate processing units during reading acquisition has been discussed at length in previous studies. However, there was considerable disagreement on the size of these units, that is, if these units should be syllables, morphemes, consonant and vowel clusters, onset and rimes, etc. (for a review of these different suggestions, see Rapp, 1992). We will not argue here for the predominance of a single reading unit. Instead, we favor a 'hierarchical' point of view in which different sizes of reading units co-exist. These different units would emerge during reading acquisition, with some units having a primary and more fundamental role, and other units, generally of a larger size, being established later (the functional role of these latter units being to increase the automaticity and rapidity of skilled reading).

In such a framework, graphemes could be considered as the minimal and primary reading units. Larger and secondary units may be developed during the maturation of reading, allowing the reader to detect and recognize written words more rapidly.

For example, onset and rimes may be possible larger units of the reading system, in English in particular (see Treiman and Chafetz, 1987; Treiman and Zukowski, 1988; Treiman, 1989; Treiman et al., 1990, 1995; Wise et al., 1990; Bowey, 1990, 1993). Syllables may also be considered as higher order units, and may even be more adequate units in French (see Spoehr and Smith, 1973; Taft, 1979; Prinzmetal et al., 1986; Rapp, 1992; Ferrand et al., 1996a,b). Together, these different levels of reading units would co-exist in the reading system as stable patterns of letter representations. The stability of these patterns may depend on their frequency of occurrence, that is, on the number of times that they have been experienced and associated with their phonological counterpart. Following Laberge and Samuel (1974), we conclude that the development of higher-order reading units during reading acquisition is a critical feature of skilled visual word recognition.

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