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Activation of Multiple Phoneme Associates of Graphemes in Visual Word Recognition

Marielle Lange

Université Libre de Bruxelles, Bruxelles, Belgium, and University of New South Wales, Sydney, New South Wales, Australia

One general issue in the domain of visual word recognition is to delineate the nature of readers' knowledge of the print-sound mapping. A more specific question is to determine whether multiple grapheme–phoneme associations are available and activated during the phonological transcoding of a letter string. Evidence for the activation of irregular associations during print-to-sound transcoding, independently from lexical influences, was assessed in a letter detection task by examining performance on target-absent pseudowords. We contrasted two types of pseudowords that could be considered homophone with a real word by application of either grapheme–phoneme correspondence rules or of multiple phonemic activation. Performance on both types of homophones was compared to nonhomophone control pseudowords, strictly equivalent in terms of orthographic similarity to the base words. The finding of a homophony disadvantage for the homophones by multiple activation was interpreted as evidence for multiple phonemic activation in the print-to-sound conversion system.

Key Words: visual word recognition; letter detection; print-to-sound conversion.

INTRODUCTION

In alphabetic systems like English and French, the mapping between spelling and sound is quasisystematic: letters or groups of letters that form graphemes (e.g., C, AI, OU) have in general one highly probable pronunciation (AI is highly frequently sounded /eɪ/ as in PLAIN) and several irregular pronunciations (AI is also sounded /ɪ/ in BARGAIN, /ɛ/ in AGAIN, /æ/ in PLAID, and /ə/ in CHIEFTAIN). One general issue in the domain of visual word recognition is to specify the nature of readers' knowledge of this mapping.

Whereas most recent models of written word recognition assume a knowledge that closely reflects the distribution of the print-to-sound relations in the language, a distinctive characteristic of the Dual-Route Cascaded model (DRC-G, Coltheart et al., 1993; and then DRC-L, Rastle & Coltheart, 1998) is that its print-to-sound conversion system is based on exclusively one-to-one, all-or-none, grapheme–phoneme correspondence rules. Each grapheme in the rule system is converted into its most frequent phonemic associate, without any influence of the strength of the association

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Address correspondence and reprint requests to Marielle Lange, School of Psychology, University of New South Wales, Sydney NSW 2052, Australia. E-mail: mlange@unsw.edu.au.

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between the grapheme and the phoneme in the language (i.e., a rule has only two states, active or not) or of the ambiguity of the pronunciation when multiple pronunciations exist for a given grapheme. In a recent article, the authors argued that these choices were predominantly based on parsimony because there is, in their view, no unequivocal empirical evidence establishing that the knowledge used by readers for print-to-sound conversion is more elaborate than such a rule system. As stated by Rastle and Coltheart (1999, p. 484): ''Although simple to implement, we have not explored the notion of rule strength in the DRC model because we are not aware of any work which demonstrates that any kind of rule-strength variable has effects on naming latencies when other variables known to affect such latencies such as neighborhood size (e.g., Andrews, 1992) and string length (e.g., Weekes, 1997) are controlled.'' In this article, we present a study aimed at assessing whether readers evoke multiple pronunciations of a grapheme in the course of word recognition, and we review previous evidence that appears relevant to the issue.

Since the first formulations of the dual route theory of visual word recognition, much research, based on the seminal study by Glushko (1979), has concerned the issue of the sufficiency of an all-or-none grapheme–phoneme conversion system to account for nonlexical reading performance. The initial findings reported by Glushko (1979) indeed seemed to provide incontrovertible evidence against the notion of a GP rule based conversion mechanism.

Against the proposition that print-to-sound conversion bears exclusively on correspondences between graphemes and phonemes, Glushko (1979) found that words and nonwords regular in terms of GP correspondences but labeled as inconsistent because their body (the group of letters made of the vowel cluster and final consonants of a monosyllabic words, as AVE in HAVE) were pronounced irregularly in some words (e.g., the body AVE in the word GAVE or the nonword TAVE which share their body with HAVE) were named more slowly and caused more pronunciation errors than regular and consistent words or nonwords. He even noted that sometimes readers produced a pronunciation that disobeyed the GP rules, with for example HEAF read [hɛf] rather than [hiːf].

Against the proposition that print-to-sound associations are captured by all-or-none rules, with no modulation of the activation of a phoneme by the relative strength of the association in the language, the same study also revealed that skilled readers are not only influenced by the regularity of the pronunciation on larger units but also by the degree of consistency of the body–rime association (Glushko, 1979; Kay, 1982). A similar influence of the strength of the grapheme–phoneme correspondences on naming times was reported by Rosson (1985), who found that words and nonwords including only frequent grapheme phoneme correspondences were named more rapidly than items with one or more low frequency correspondences.

Finally, against the hypothesis that correspondences are strictly one-to-one, with only the most frequent correspondence activated during conversion, Kay and Marcel (1981) demonstrated that a nonword pronunciation could be biased toward the regular or the irregular pronunciation by the prior presentation of a word sharing its body, with more frequent irregular pronunciations when the nonword was preceded by an irregular word likely to have activated the irregular pronunciation (more irregular pronunciations of YEAD after the irregular HEAD than after the regular BEAD or the control SHED).

Based on these data, some authors completely rejected the idea of a grapheme–phoneme rule system in favor a unique set of associations which captures the statistical properties of the language; for instance, in the form of a distributed connectionist network (e.g., Seidenberg & McClelland, 1989). This standpoint was far from being uniformly shared; many authors rejected the possibility that a model without an independent print-to-sound conversion system could adequately account for nonword reading performances. But, at least, in the mid-1980s all of them agreed on the fact that these data implied at minimum a correspondence system with multiple and graded activation of multiple levels of associations (e.g., Patterson & Morton, 1985; Norris, 1994). Print-to-sound correspondences were thought to involve graphemes but also body rimes, typical cluster, and so on (G sounded /ɡ/ but G followed by E, I, or Y sounded /ʒ/; IGHT sounded /aɪt/), possibly with activation of multiple phonemic associates for a given spelling unit, their activation being modulated by the encoded strength of the print-to-sound association.

Surprisingly, this was contested in 1993 by Coltheart and colleagues who made the provocative claim that none of the findings outlined above constituted unequivocal evidence for a print-to-sound conversion system more elaborate than a rule system. In support for their position, Coltheart and colleagues (2000) argued that a computational model based on these principles would be capable of accounting for the findings enumerated above even though neither multiple associations, graded activation, nor multiple levels of units were introduced. Although it is not totally clear at present whether the DRC model would effectively be capable of simulating the various findings presented above, the impact, in DRC-L, of grapheme composition on the speed of the nonlexical treatment as well as the possibility to have multiple phonemes activated in a common phonological buffer combining the output of the two pathways might lead to discard empirical evidence in which grapheme complexity or lexical contribution has not been adequately controlled for.

Yet, in our view, some evidence less equivocally suggests that there is activation of multiple phonemic code in the conversion system, independently of multiple activation in the phonological buffer. First, when comparing pronunciation errors from normal and impaired young readers, Bryson and Werker (1989) found that normal young readers produced variable pronunciations corresponding alternatively to the regular and to the irregular pronunciation despite the absence of lexical neighbors likely to activate the irregular pronunciation of the grapheme. Importantly, Bryson and Werker also noticed that the errors on the vowels corresponded a lot more often to one of their alternative pronunciations than to a speech sound that was not a possible phonemic associate of the grapheme. In other words, when the activation of the irregular phonemic associates by the sole lexical treatment predicted as much confusion errors than association errors, a strong tendency to irregular mispronunciations was reported by these authors. With French skilled readers, Peereman (1991; see also Content & Peereman, 1992) revealed analoguous mispronunciations in a nonword naming task. He exploited the characteristics of the letter G, which has two possible pronunciations /ɡ/ or /ʒ/, systematically determined by the following orthographic context (G followed by E, I, or Y is pronounced /ʒ/ and /ɡ/ in any other context excepted N). French nonwords including the G letter such as GIRLER and MONGOUR were sometimes pronounced irregularly despite their low similarity to lexical instances.

Second, Peereman (1991, Experiment 2) examined whether the incorrect phonemic assignment of G would influence performance in a lexical decision task. He compared lexical decision times to nonwords which deviated by a single letter from base words wich contained G and which either conserved the letter G (GANTIL from GENTIL by a single letter substitution; PIGON from PIGEON by a single letter suppression) or did not (e.g., PURDON from PARDON; VAPUR from VAPEUR). Both sets of base words were matched on frequency, CV structure, and bigram frequency, and the derived pseudwords in both sets were by design direct neighbors of lexical instances. In the G pseudowords, some items were designed to be ‘‘homophonic-if-erroneous’’ such that a homophone of the base word would result if the incorrect phonemic assignment occurred (e.g., G_o translated with /ʒ/); this was never the case for the control pseudowords. It was found that ‘‘homophonic-if-erroneous’’ pseudowords were associated to slower decision times and higher errors rates than control nonwords. This effect clearly suggests that errors on the grapheme G are induced by a competition between the phonemic codes /ʒ/ and /g/ activated during the print-to-sound conversion and not exclusively by the partial activation of the phoneme /ʒ/ via the activation of the orthographic and then phonological form of the lexical neighbor.

Finally, previous experiments that exploit a statistical analysis of the grapheme–phoneme associations of French and English (Lange, 2000; Lange, 2001) to derive different measures of grapheme frequency or grapheme’s pronunciation ambiguity showed a sensitivity of the reader to the strength of the grapheme–phoneme correspondence. A regression study which analyzed and compared the contribution of different estimates of the degree of regularity on the naming latencies for monosyllabic and disyllabic English words revealed an effect of the consistency of the grapheme–phoneme associations over and above the regularity category of these words. A follow-up study (Lange & Content, 1999) showed an effect of the strength of the GP correspondence on the naming performance of French nonwords using a new variable, the mean graphemes’ pronunciation entropy. This entropy variable corresponds to a measure of the uncertainty of the pronunciation of each grapheme in the string in a way that reflects both the probability of the regular association and the probability of the alternative pronunciations of the grapheme. French nonwords with graphemes of high entropy values (low uncertainty of the pronunciation) were read significantly faster than nonwords with graphemes of low entropy values.

Obviously, more direct evidence would favorably complement the grapheme entropy effect on nonword naming reported by Lange and Content (1999), allowing to go one step further to unambiguously establish that far from what is maintained by Coltheart and colleagues, an associative system that reflect not only a modulation of the activation by the strength of the correspondence but also an indecision when the grapheme can have multiple pronunciations, is the minimal system that can be proposed to account for human performance. Hence, even if we find difficult to imagine how a system that maintains a representation of the sole most frequent correspondence can encode that relative strength during a learning phase, evidence for a modulation by the strength of the correspondence during the conversion process alone does not require more than the representation of the frequency or probability of the correspondence, in a framework where eventually only the regular phonemic associates of a grapheme are activated during visual word recognition. Evidence for the activation of irregular phonemic associates of a grapheme (not only the most frequent one) on the other unambiguously implies the representation of the multiple associations of a grapheme in the conversion system.

In the present study, we aimed at extending the findings of Peereman (1991) by examing the effect of homophony in a letter detection task in which participants were asked to decide if a prespecified letter was present (or not) in a briefly presented and backward-masked pseudoword. This task was preferred to the lexical decision one because the masking of the string is reputed to have for effect to blur the orthographic information and to reduce the lexical influences on the pronunciation of the string, whereas the phonological activation is relatively unaffected. Hence priming studies typically found that stronger phonological effects were associated to the brief and masked presentation or the degrading of the visual information (e.g., Hino, Lupker, & Sears, 1997, in lexical decision; Hawkins, Reicher, Rogers, & Peterson, 1976; Spoehr, 1978; Van Orden, 1987). Also, with this paradigm, Ziegler and colleagues (e.g., Ziegler & Jacobs, 1995; Ziegler, Van Orden, & Jacobs, 1997) found a homophony disadvantage of the kind we are looking for: When the letter was absent from the pseudoword, participants produced more false detections when the pseudoword was a homophone of a word that contained the target letter (I in GANE, homophone of GAIN in English) as compared to an orthographic control (I in GARN). They attributed this effect to the activation of the lexical unit via a phonological code rapidly generated.

The complete design is as follows. Participants were asked to detect a letter J or S in a nonword neighbor of a word containing J or S. Homophonic nonwords were derived from the base word by replacing the letter to detect by a letter G or C which has the same pronunciation as one of the legal associate of this letter (e.g., G sometimes sounded /ʒ/; C sometimes sounded /s/; GEUDI, BONGOUR, PENCER, PINCON). Control nonwords were derived from the same base word by replacing the letter to detect by any consonant other than G, C, S, or J (BEUDI, PENTER, BONDOUR, PINVON). Based on Ziegler and Jacobs' (1995) findings, homophonic nonwords are more likely than controls to cause false detection of the letter (that is, decide that J, the letter present in the orthographic neighbor, is present in the target nonword). If only the most frequent phonemic associate of a grapheme is stored in the conversion system, only nonwords such as GEUDI, which we call ''homophonic-by-rule'' because they are homophonic of the lexical neighbor (i.e., the French word JEUDI) when relying on the contextually regular grapheme–phoneme correspondences, are likely to produce more false detections and/or longer detection times than orthographic controls (as found by Ziegler & Jacobs, 1995). ''Homophonic-by-rule'' nonwords are introduced as a baseline condition to insure that Ziegler and Jacobs's results are effectively replicated with our polysyllabic material, and it is only the use of ''homophonic-by-multiple activation'' nonwords that is critical to establish whether there is multiple activation in the course of conversion. If the multiple associates of the grapheme G are activated during print-to-sound conversion, then a homophony disadvantage will also show up for ''homophonic-by-multiple activation'' nonwords that are homophones of the lexical neighbor when the contextually irregular associate is used because for both GEUDI and BONGOUR, the /ʒ/ phoneme is partially activated, as a regular association in GEUDI and as an irregular association in BONGOUR.

METHOD

Participants

Forty-eight French speaking first-year students from the Université Libre de Bruxelles participated for course credit. All of them were French speaking and none of them reported any problems learning to read in their younger years. All had normal or corrected-to-normal vision.

Material

Three hundred forty-four nonwords, 4 to 8 letters long, were constructed for this experiment, with 80 GC nonwords, 80 orthographic controls, and 184 fillers. All of them deviated by a single letter from a French word. The GC and control items were derived from 80 words which contained a J (40 items) or a S (40 items) in which the J or S was replaced by another consonant. The GC items were constructed by replacing the J with a G and the S with a C (e.g., GEUDI derived from JEUDI and PINCON derived from PINSON; 20 J and 20 S); the control items were derived from the same base words by replacing J or S by a consonant other than G or C (e.g., BEUDI derived from JEUDI and PINVON derived from PINSON). Half of the GC nonwords had the G or C letter followed by E, I, or Y and half of them had this letter followed by another vowel. Consequently, for half of the GC items the J to G and S to C substitutions produced nonwords ''homophonic-by-rule'' (GEUDI is the homophone of JEUDI and PENCER is the homophone of PENSER) and for the other half, it produced nonwords that were ''homophonic-by-multiple activation'' (the regular pronunciation of the substituted letter is different from the one of the base word but PINCON would be a homophone of PINSON or BONGOUR a homophone of BONJOUR if C is pronounced with the irregular phonemic association in this context). The position of the J or S in the base word varied from position 1 to 4 and was not manipulated experimentally. For homophonic and control nonwords, the letter to detect was the substituted letter, that is the letter J or S that is present in the base word but absent in the nonword (e.g., J in GEUDI and BEUDI). In order to diversify the material and to provide an equal number of positive and negative responses, 184 filler nonwords were added to the 80 items. These nonwords were constructed by the substitution of a consonant by another in a French word (e.g., SPANDALE derived from SCANDALE). For trials corresponding to positive responses (132 nonwords), the letter to detect was the replacement letter (e.g., P in SPANDALE); for negative response (52 nonwords), the letter to detect was the substituted letter (e.g., T in MOBEUR, derived from MOTEUR).

Two stimulus lists (A and B) were prepared to be presented to different subjects. Each list contained the 184 filler nonwords mixed with 40 GC nonwords and 40 control nonwords derived from distinct base words. In both lists, there were 20 nonwords that were ‘‘homophonic-by-rule’’ (GEUDI), 20 nonwords that were ‘‘homophonic-by-multiple activation’’ (BONGOUR), 40 control nonwords (BEUDI, BONDOUR), as well as the 184 filler nonwords. Half of the participants (24) were presented List A, the other half (24) List B.

Apparatus and Procedure

The experiment was run on a PC piloted by the MEL experimental software. Participants were seated in front on a computer screen. On each trial, the computer screen successively displayed a letter (700 ms), a transition screen with a ‘‘:’’ symbol (700 ms), a briefly presented nonword (57 ms), and a visual mask made of ‘‘O’’ superimposed onto an ‘‘X’’ for the same length as the nonword (for a maximum response of 2000 ms). Participants were asked to decide if the prespecified letter was present in the nonword and the response was given by pressing one of two buttons on a response box (the left key for ‘‘letter was present’’ and the right key for ‘‘letter was absent’’). The response box conveyed the nature of the responses (‘‘letter present/absent’’) as well as their latency measured from the end of the presentation of the mask. During the practice session, but not during the experimental session, each participant received feedback on his or her response (a sound signal when the response was wrong). Nonwords were presented in a different random order for each subject.

RESULTS

Analysis of Errors

Variance analyses by subjects (F_1) used homophony (GC item vs orthographic control), type of homophony (‘‘homophonic-by-rule’’ vs ‘‘homophonic-by-multiple activation’’), and the identity of the letter (J vs S base word) as within-subjects factors. Variance analyses by items (F_2) used a repeated factors design based on the base word with the kind of item as within items factor and type of homophony as well as the identity of the letter as between items factor. Data for the fillers were not analyzed in detail but participants with a percentage of correct responses lower than 55% for the ‘‘target-present’’ or ‘‘target-absent’’ fillers or lower than 65% for an average of the two values were replaced. For the fillers, we found a mean number of false detections of 19% for the ‘‘target-absent’’ fillers and a mean number of omissions of 28% for the ‘‘target-present’’ fillers.

Results are summarized in Table 1. The letters J or S were more frequently erroneously detected in words in G and C (GEUDI and PINCON) than in their orthographic controls (BEUDI and PINVON). We found 29.5% of false detections for the GC nonwords against 25.2% for their orthographic controls. That difference was significant both by subjects and by items; $F1(1, 47) = 7.9$, $p < .01$, $F2(1, 77) = 5.2$, $p < .05$. When nonwords in G and C were analyzed separately, a disadvantage for homophony was found for both kinds of nonwords (difference of 3.5% vs 4.7%). This effect was significant in a contrast analysis based on the analysis by subjects, $F1(1, 47) = 4.3$, $p < .05$, for nonwords in G; $F1(1, 47) = 7.5$, $p < .01$, for nonwords

TABLE 1
Percentage of False Detections for Homophones and Control Items and Subject Means (Standard Deviations in Parentheses)

	All homophones		Homophonic-by-rule		Homophonic-by-multiple activation	
Target absent	*M*	*SD*	*M*	*SD*	*M*	*SD*
G & C together						
GC nonwords	29.5	(16.0)	33.5	(16.0)	25.7	(15.2)
Controls	25.2	(15.4)	(27.8)	(13.1)	23.3	(12.2)
GC nonwords-controls	4.3		5.8		2.4	
G						
GC nonwords: GEUDI, BONGOUR	31.7	(16.6)	34.4	(18.3)	29.1	(17.7)
Controls: BEUDI, BONDOUR	28.2	(13.7)	29.9	(16.3)	26.5	(15.9)
GC nonword-controls	3.5		4.4		2.6	
C						
GC nonwords: PENCER, PINCON	27.5	(19.5)	32.7	(23.4)	22.3	(20.3)
Controls: PENTER, PINVON	22.8	(15.9)	25.6	(19.5)	20.0	(15.8)
GC nonword-controls	4.7		7.1		2.3	

in C. There was no significant interaction with the type of homophony, $F1(1, 47) = 1.5$, $F2(1, 77) = 1.7$, or with the identity of the letter (J vs S to detect), $F1(1, 47) < 1$, $F2(1, 77) < 1$. Nonetheless, in contrast analyses the difference between GC nonwords and controls was found to be significant for ‘‘homophonic-by-rule’’ nonwords but not for ‘‘homophonic-by-multiple activation’’ nonwords (differences of 5.8% vs 2.4%). This was the case in a contrast analysis from the analysis by subjects as well as in a variance analysis on either group of items; $F1(1, 47) = 11.3$, $p < .005$, $F2(1, 39) = 5.4$, $p < .05$, for the former; and $F1(1, 47) = 2.0$, $F2(1, 39) < 1$, for the latter.

Analysis of Reaction Times

In analyzing reaction times, values corresponding to errors were discarded from the analyses. Data that diverged from the means by subject and condition by more than 2 standard deviations were replaced by the mean value for this subject and condition (less than 1.2% of the data). There was no difference in the proportion of null responses (less than 0.4% of the trials) as a function of the experimental manipulations. Data associated to fillers were not analyzed. The mean reaction times associated to them were 770 ms for the ‘‘target-absent’’ fillers and 688 ms for the ‘‘target-present’’ fillers.

An ANOVA by subjects (*F*1) used homophony (GC nonwords vs their orthographic controls) and type of homophony (‘‘homophonic-by-rule’’ vs ‘‘homophonic-by-multiple activation’’) as within-item factors. An ANOVA by items (*F*2) started from the base word with homophony as a within-item factor and type of homophony as a between-items factor.

Results are presented in Table 2. Participants required more time to decide that J or S was absent in the homophonic nonwords than in their orthographic controls (809 vs 785 ms). That difference was significant by subjects and by items, $F1(1, 47) = 4, 7$, $p < .05$; $F2(1, 78) = 6.5$, $p < .05$. That factor did not interact with homophony, $F1(1, 47) < 1$, $F2(1, 78) < 1$. In short, for latencies of correct no responses, a disadvantage for homophony was observed for both ‘‘homophonic-by-rule’’ and ‘‘homophonic-by-multiple activation’’ nonwords.

TABLE 2
Mean Detection Latencies (Standard Deviations in Parentheses) for Correct ‘‘Target Absent’’ Responses and Subjects Means

	All homophones		Homophonic-by-rule		Homophonic-by-multiple activation	
Target absent	*M*	*SD*	*M*	*SD*	*M*	*SD*
G & C together						
GC nonwords: GEUDI, BONGOUR	809	(176)	792	(158)	826	(193)
Controls: BEUDI, BONDOUR	785	(162)	766	(153)	803	(170)
GC nonword-controls	24		26		23	

DISCUSSION

In this letter detection task experiment, where participants had to rapidly decide if a briefly presented and then masked letter was present in a word, we observed more erroneous detections of the letters J and S in nonwords homophonic of a word containing J or S as compared to their orthographic controls. This disadvantage for homophony for GEUDI compared to BEUDI replicates the Ziegler and colleagues’ (Ziegler & Jacobs, 1995; Ziegler et al., 1997) results and, as assessed by Ziegler and colleagues, establishes the early activation of sublexical phonological codes which influences the decision process; were it not the case, the competition would have been equal for BEUDI and GEUDI, neighbors of JEUDI, which both activate /ʒ/ in the course of the lexical treatment.

In our study, however, the focus was more on the nature of these codes than on the time course of phonological activation. Specifically, ‘‘homophonic-by-multiple activation’’ items (BONGOUR) were added to the ‘‘homophonic-by-rule’’ items (GEUDI) found in Ziegler and colleagues’ study to evaluate whether the activation of the irregular pronunciation of a sublexical unit might also impair the ‘‘ letter absent’’ decision. The logic was that BONGOUR and BONDOUR are strictly equivalent in their orthographic similarity to the French baseword BONJOUR, that in both cases the letter is absent, and that one letter is no more similar to the ‘‘J’’ letter to detect than the other; therefore, any difference in performance between the two types of nonwords has to be attributed to the fact that the former but not the latter nonword partially activates the contextually irregular /ʒ/ pronunciation in the course of sublexical print-to-sound conversion.

This is exactly what was suggested by the data. On errors, although there was no interaction, in contrast analyses the homophony effect was not significant for the nonwords that were ‘‘homophonic-by-multiple activation’’. But for the detection latencies, the homophony effect was present for both kinds of homophones; decision latencies were longer for nonwords whose pronunciation induced a false detection of the letter, for the nonwords that were ‘‘homophonic-by-rule’’ (J in GEUDI vs J in BEUDI), as well as for the nonwords that were ‘‘homophonic-by-multiple activation’’ (J in BONGOUR and J in BONDOUR).

Importantly, the finding that participants found it more difficult to decide that J was absent in BONGOUR than in BONDOUR, as shown by the latency effect, invalidated the DRC hypothesis of a print-to-sound conversion system, which stores only the regular phonemic associate of each grapheme. In this conversion system, the G in BONGOUR should never activate its irregular /ʒ/ phonemic associate and there is nothing in this model that can explain why BONGOUR items were associated to different reaction times than BONDOUR items. Specifically, the equivalence in terms of orthographic similarity to the base words for the homophone and controls nonwords of our study guaranteed that BONGOUR items did not produce a higher activation of the phoneme /ʒ/ in the phonological buffer.

Undoubtedly, this homophony disadvantage found for naming latencies confirmed our previous results establishing that a representation of the strength of the association has to be coded in the system; if multiple pronunciations are activated (as /ʒ/ and /ɡ/ with the letter G), the strongest and most frequent pronunciation must be favored. Even more, they established that the notion of grapheme–phoneme correspondence rules itself—with each grapheme occurring in the language mapped onto a single phoneme (the speech sound most frequently associated to it)—was too limited to account for the readers' performance. The results of a recent study from Perry and colleagues (2000) further adds to this by suggesting that a dual-route model must also introduce multiple levels of representation (i.e., at least grapheme–phoneme and body–rime). Hence, despite initial claims that consistency effects were simulated in the computational dual-route model due to confounds with grapheme complexity, human subjects showed a consistency effect in the absence of such confounds, whereas the computational model did not.

In contrast, our results can easily be interpreted in a dual-route reading model with a conversion system configured as a network of multiple levels of association (e.g., Shallice & McCarthy, 1985; Norris, 1994) wherein the multiple phonemic associates of a grapheme (regular, contextually dependent, as well as irregular) are partially activated during the print-to-sound conversion process, with a modulation of their activation by the strength of the association in the language. In this framework, the disadvantage for homophony found with ''homophonic-by-multiple activation'' nonwords would mark a reinforcement of the activation of the phoneme /ʒ/ in the phonological buffer, already caused by the activation of the lexical neighbor BONJOUR by the partial activation of the irregular association between G_o and /ʒ/ (in parallel with the regular association between G_o and /ɡ/). The absence, for the same items, of an analogous disadvantage for homophony on errors would then be explained by the fact that the irregular phonemic associate /ʒ/ of $G_{o,}$ necessarily less active than the regular associate /ɡ/, would not be active enough to determine an erroneous response.

Interestingly, such a framework offers some support to the view defended by Share (1995), following which a knowledge of the multiple phonemic associates of a grapheme might play an important role in the initial reading's learning stages, allowing the beginning reader to identify the association between a letter string unknown to him or her and a word that is already part of his or her oral vocabulary. By trying the different pronunciations of a grapheme, a child can identify a letter string still unknown to him or her; he or she can discover, for example, that the irregular word *hook* corresponds to the word so often heard in the story of Captain Hook. Without such knowledge, access to the meaning of irregular words would depend on the presence of an adult who would have to explain, ''see, *hook* is a word you already know; it is a hook—it is not pronounced *hok* but *hook.*''

Equally important, our results confirm to some extent the intervention of low-level units (grapheme–phoneme and eventually letter–phoneme associations) in print-to-sound conversion found in regularity studies (e.g., Jared, 1997; Lange and colleagues studies already cited). As pointed out by Andrews and Scarratt (1998), the finding of a regularity effect on small-size units supports an explanation calling to a knowledge source specifically nonlexical and challenges unitary connectionist or analogy models that are sensitive principally to the regularity on large-size units (rime–body but not grapheme–phoneme correspondences).

Nevertheless, if the obtained results cast some doubts on the validity of a rule-based conversion system or an unitarian connectionist network, the exact nature of the conversion system is left undetermined. It could be a multiple-level network calling to intermediary symbolic units of different sizes, as in Shallice and McCarthy (1985) or Norris (1994); a network in which any intermediary unit presenting some kind of similarity with the clusters present in the string are activated, as proposed by Ans, Carbonnel, and Valdois (1998); in a dual-route framework, a connectionist network with a hidden unit analogous to the one introduced by Plaut, McClelland, Seidenberg, and Patterson (1996) but reflecting a knowledge of the low-level regularities; or a connectionist network with direct associations between letters and sounds, as defended by Zorzi, Houghton, and Butterworth (1998). We are confronted here with the same difficulty as that faced by Treiman et al. (1995), whose data revealing an effect of the degree of regularity on syllabic size segments could not distinguish between architectures with intermediary units from architectures where the structural effects emerged from the learning and storing of individual linguistic items in a connectionist or analogical network. Undoubtedly, further research would have to find a way to establish the realism or inadequacy of the intermediary unit hypothesis to constrain in a more precise way the nature of the system that governs print-to-sound conversion. Hence, if it is truly the case that the actual state of knowledge about the representations and mechanisms involved in print-to-sound conversion is quite poor, it is certainly more important to isolate clear constraints on the nature of this system than to substantiate the most parsimonious theoretical hypotheses made in some models of written word recognition by the absence of nonequivocal empirical evidence, even if a computational model based on these principles can be shown to produce a pattern of performance similar to the one of human readers.

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