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Learnability of graphotactic rules in visual word identification

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Abstract

Besides phonotactic principles, orthographies entail graphotactic rules for which the reader must convert a phonological representation on the basis of spelling adaptation rules. In the present study, the learnability of such rules will be investigated with reference to Dutch. Although Dutch orthography can be considered highly regular, there are graphotactic rules that change letter sequences in plural noun formation. In a lexical decision experiment, the acquisition and use of such rules were examined. Participants were groups of 31 children from Grade 3 and 34 children from Grade 6, and 25 adults. The results showed that both children and adults are significantly less accurate and slower in recognizing plural word forms which undergo vowel change as a consequence of pluralization. It is concluded that graphotactic rules in Dutch orthography complicate Dutch word identification from an early stage of development and continue to play a complicating role in the word identification process of adult readers. In the discussion it is shown that current models fail to fully explain the processing of graphotactic rules in visual word identification.

Keywords: Learnability; Lexical decision; Graphotactic rules; Dutch orthography; Dual-route model

The present study examines the extent to which orthographic representations are stored as such in the mental lexicon, and accessed directly, or indirectly via the computation of grapho-phonemic conversions and the application of graphotactic rules. Since graphotactic rules can be defined as orthographic rules which are not directly governed by phonological principles, an urgent question is, to what extent such rules can be learnt. This question is not only of importance for testing current models of visual word recognition but it can also be seen as relevant for educational practice. To further the quality of reading instruction, it is highly important to uncover the exact role of graphotactic rules in visual word identification at different stages of reading development. Moreover, the study of graphotactic rules may yield guidelines for spelling reform policies.

Research on visual word identification has greatly advanced during the past decade thanks to theoretical debates contrasting Parallel-Distributed Processing (cf. Plaut, McClelland, Seidenberg, & Patterson, 1996) vs Dual Route models (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Following a dynamic systems approach, Van Orden and Goldinger (1994) also showed how visual and phonological information interact in recurrent subsymbolic networks to produce word recognition. All of these models, however, have provided general frameworks which are highly concerned with word reading in English. Only recently, it has been acknowledged that alphabetic orthographies differ

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in the degree to which they adhere to a consistent representation of phonemes, or, alternatively, the degree to which they deviate in a principled way from representing the phonetic level in order to preserve deeper linguistic or lexical information. It has been claimed that the 'goodness-of-fit' between graphemes and phonemes affects both the process of reading and writing, and its acquisition. In comparative studies on reading and writing in different languages, cross-linguistic differences in orthographic regularity are usually expressed along the continuum *deep vs shallow* (see Berninger, 1994) which can be seen as a vague distinction from a theoretical point of view. In shallow orthographies like Italian, Finnish, or Serbo-Croatian, for example, the phonemes are said to be represented by the graphemes in a direct and unequivocal manner. In deep orthographies, such as English and French, on the other hand, the relationship between spelling and the basic ''subword sounds'' that make meaningful contrasts in the spoken language, is considered to be more opaque. In such orthographies, different letters may represent the same phoneme, and one and the same letter may represent different phonemes in different contexts. Seymour, Aro, and Erskine (2003) showed that in normal readers accuracy and speed of reading familiar words is affected by orthographic depth. Accuracy (and speed) was relatively low in French, Portuguese and Danish; the performance of the English-speaking first graders fell far below the levels of first-year groups in other countries. English is classified as the deepest orthography with many multi-letter graphemes, context dependent rules and irregularities. French, Portuguese and Danish are also at the deep end of the scale.

However, the orthographic depth hypothesis does not provide us with fundamental theoretical insights into the access to orthographic representations in the mental lexicon, because it is not fine-grained enough. In order to arrive at a better understanding of visual word identification processes, it is necessary to distinguish the principles that lead to deviation of simple grapheme-to-phoneme correspondences. Given the fact that in many cases spelling rules are not directly governed by phonotactic rules, the reader must convert sounds to an underlying orthographic representation to which spelling adaptation rules are applied, independent of the pronunciation (cf. Carney, 1994). The question is to what extent and how efficient such graphotactic rules are being used in the process of reading complex words. It may be the case that a given rule forms a heavy load for our cognitive system, and that the system may therefore prefer to avoid computation and to store the full orthographic representation in memory instead of doing grapheme-to-phoneme conversions and using graphotactic rules. Important factors that might influence the use of storage are the frequency with which a certain rule needs to be applied and word frequency. Word frequency is generally modeled in terms of the resting activation level of a word's access representation. There is general consensus that frequency-sensitive access representations are crucially involved in the recognition of words (Andrews, 1989; cf. McCann & Besner, 1987).

In the present study, the status of graphotactic rules in the mental lexicon of readers of Dutch is examined. Given that the Dutch language is located at neither the ''shallow'' nor the ''deep'' end of the dimension of transparency, the impact of various rules and analogy mechanisms on the reading of words can provide considerable insight (see Reitsma & Verhoeven, 1990). The conversion rules for Dutch orthography apply to phonemes and thus have morphemes as their main domain. Dutch phoneme-to-grapheme conversion rules apply to morphemes but are based on the phonological context. The conversion rules are fairly consistent with some exceptions that thus lead to non-isomorphemic written forms. However, Dutch polysyllabic words are partly based on autonomous graphotactic rules that change letter sequences when morphemes are combined to words. Such rules lead to non-isomorphemic written forms. In Dutch polysyllabic words, there is the complicated grapheme–phoneme conversion rule, pertaining to vowel and consonant letter doubling (cf. Kooij, 1994). Long vowels in Dutch can be written in two ways: as two identical vowel letters or as a single vowel letter. This striking aspect of Dutch orthography can at best be exemplified by means of plural formation. The productive and most frequently used plural morpheme for nouns is the suffix –*en* to be added after the singular noun stem. An example is given in (1).

(1) Singular: *boek* ('book')
Plural: *boeken* ('books')

Dutch short vowels are represented by a single vowel letter. If they are followed by a single consonant in longer words, as is the case in plural formation, this consonant is geminated. An example is given in (2).

(2) Single consonant: *bom* ('bomb')
Consonant geminate: *bommen* ('bombs')

If, on the other hand, the word stem contains a vowel geminate, it will change into a single vowel letter in the plural. An example is given in (3).

(3) Vowel geminate: *raam* ('window')
Single vowel letter: *ramen* ('windows')

The general rule is that the contrast between long and short vowels in open syllables is expressed by the alternation of single and double consonant letters, and in closed syllables by the alternation of single and double vowel letters.

In the present research, the role of orthographic constraints in Dutch visual word identification will be examined. We want to find out to what extent and how efficiently children learning to read use graphotactic rules. In a lexical decision experiment, the latency and error patterns of three types of noun plurals are analyzed: (1) Regular (*boek* − *boeken*), (2) Consonant doubling (*bom* − *bommen*), (3) Vowel change (*raam* − *ramen*). Each series was divided into subsets of plurals of high frequency and low frequency while keeping the frequency of the word stems and the family size constant. Our first expectation is to find evidence of a word frequency effect in that high frequency plural word forms will be identified faster and more accurately than low frequency plural word forms. In the high frequency domain, we expect to find no differences in latencies and/or correct scores for the three types of word forms. If so, this would be seen as an indication that a representation of the full plural word form could be accessed. However, in the low frequency domain we would expect that a full word form representation is not available so that the word needs to be segmented into the word stem and its plural ending. In that case, we expect graphotactic rules to constrain the process of visual word identification. For plural word forms which undergo vowel change, we expect word identification to take longer and to be less accurate as compared to regular plural word forms. For plural word forms which undergo consonant doubling, we expect a similar but smaller effect given the fact that the singular form can still be read from its plural.

1. Study 1: graphotactic rules in processes learning to read

In this study, we want to find out how difficult graphotactic rules are in the process of learning to read Dutch. The specific characteristics of Dutch orthography will furnish new insights into the structural regularities underlying the process of acquisition of reading and writing. Given the fact that in Dutch orthography there is a small set of graphotactic spelling rules, the study of the role of autonomy in acquisition can be seen as promising. It will be investigated to what extent data structures (storage) vs control structures (adaptation rules) are being processed in the reading process of 9- and 12-year-old Dutch children. For these children, phonological decoding can be seen as a self-teaching device (see Perfetti, 1998; Share, 1995). However, in the process of learning to read children not only have to learn the grapheme-to-phoneme correspondence rules. They also have to acquire autonomous graphotactic rules for reading polysyllabic words which are only partly governed by the phonological syllable structure.

1.1. Method

1.1.1. Participants

Groups of 31 children (16 boys, 15 girls) in Grade 3 (mean age = 8; 8 years) and 34 children (17 boys, 17 girls) in Grade 6 (mean age = 11; 9 years) from four primary schools in Nijmegen, a provincial town in the Eastern part of the Netherlands, were selected to participate. All children were native speakers of Dutch. They were previously instructed according to the same reading curriculum, that is, *Veilig Leren lezen* [*Learning to read safely*] (Mommers, Verhoeven, & van der Linden, 1991). It is the most widely used curriculum in the Netherlands, and it stresses the importance of phonics instruction.

1.1.2. Materials

Three sets of singular nouns and their corresponding plural forms were selected: regular words (e.g., *boek* − *boeken*), words with short vowels in the singular form and with consonant doubling in the plural (e.g., *bom-bommen*), and words with long vowels in the singular form and with vowel change in the plural (e.g., *raam-ramen*). Both singular and plural forms of all stimulus words occurred on two lists of words used in the context of primary education

Table 1
Numbers of items, frequency of plurals, frequency of singulars, and family size of regular, consonant doubling and vowel change word forms

	Regular	Consonant doubling	Vowel change
Number of items			
High	31	20	16
Low	31	20	16
Frequency plural			
High	1476	860	3133
Low	229	112	106
Frequency singular			
High	1657	786	1296
Low	1617	762	1300
Family size			
High	36	32	48
Low	24	20	23

(Schaerlaekens, Kohnstamm, & Lejaegere, 1999; Staphorsius, Krom, & de Geus, 1988). By using frequency counts from the CELEX-database (Baayen, Piepenbrock, & van Rijn, 1993), three sets of singular–plural pairs were constructed which were matched more or less with respect to stem frequency as well as the family size of the singular form. The frequency of singular and plural forms were computed as the sum of the frequencies as they occur in a corpus of 42 million word tokens of written Dutch. As far as the plurals is concerned, for each of the three sets a subset of high frequency and low frequency words were selected. For the first set (regular words), subsets of 31 words were selected. For the second set (consonant doubling), there were 20 words in the two subsets. The number of words in the subsets of the final set (vowel change) was 16. Table 1 shows the word frequency counts and family size for the singular and high vs low frequency plural forms in the three stimulus sets.

The total number of stimuli was 268: 134 singulars and the 134 corresponding plurals. Within each subset of items the mean frequency of singular forms was controlled for. Moreover, the three subsets were matched with respect to length and bigram frequency of the singular and plural forms. For all pairs of nouns the plural consisted of the orthographic form of the singular with the plural marker −*en* added. No other orthographic changes were involved. All noun stems being selected are unambiguously nouns. Nouns that can be derived from verbs without overt affixation were left out.

For each of the test items, a pseudoword was derived by changing two letters in the base word. This resulted in an additional set of 268 items. All pseudowords consisted of orthographically and phonotactically legal letter strings. The pseudowords in the lists were compared with regard to their bigram frequencies, which were found to be highly similar across the lists with no exceptional bigram sequences occurring within the lists.

The resulting stimulus materials were divided over two experimental lists of 268 items each: 134 words and 134 pseudowords. In order to prevent participants to see the singular and plural form of one and the same stem, the singular form of each word pair was incorporated in one list and the plural form in the other. The numbers of singular and plural forms in each list were kept constant. Of each list six pseudo-randomized versions were made, making sure that not more than three items of the same type (either word or pseudoword) occurred in sequence, and that no semantic associations of any kind existed between consecutive items. Finally, 36 practice items (18 words and 18 pseudowords, including singular and plural forms) were selected to precede the test materials.

1.1.3. Procedure

The participants were tested individually in a separate room within the school.[1] They received a standard lexical decision instruction, specifying that they had to decide as quickly and as accurately as possible whether a presented letter string was a Dutch word or not. If it was a word, they had to push the right one of two response keys, otherwise the left one. For left handed participants, the order of the response buttons was reversed. The experimenter explained the task and checked with the practice items to see that the child had understood the instructions. Short breaks were included in the experiment: between the practice and test lists, and one between the lists of items. After each break, the

[1] The authors thank Silvia Jansen and Kim Lemmen for their help in data collection.

participants were asked to continue whenever they were ready. The total duration of the experimental session was approximately 30 min.

For each trial, an asterisk was presented in the middle of the screen as a fixation mark. After 750 ms it was followed by the stimulus centered at the same position. Stimuli were presented on Nec Multisync color monitors in white uppercase letters (font: triplex; size: 40 mm) on a dark background. They remained on the screen until the participant pressed one of the two response buttons, or disappeared after a time period of 2 s in case no response was given. A new trial was initiated 1200 ms after responding or time-out.

1.2. Results

Table 2 presents the mean reaction times and error scores for the different test conditions are presented for the 9-year-old children.

By-participant and by-item analyses of variance showed that high frequency plurals were responded to faster than low frequency plurals ($F1(1,30) = 111.27$, $p < .01$; $F2(1, 128) = 34.74$, $p < .01$). The data show that the reaction times of the low frequency plurals in the subset of vowel change word patterns are relatively large. However, the differences in reaction times between the three subtypes of items were not significant. The interaction between Word Type and Frequency Class showed a tendency to be significant at subject level only ($F1(2,60) = 5.04$, $p < .10$; $F2(2,128) = 0.99$, $p > .10$).

The pattern of the error data is of interest. For plural frequency, the differences turned out to be significant ($F1(1,30) = 39.69$, $p < .01$; $F2(1,128) = 30.28$, $p < .01$). The low frequency plurals showed a much larger error proportion than the high frequency plurals. The differences between word types are also significant ($F1(2,60) = 7.47$, $p < .01$; $F2(2,128) = 4.73$, $p < .05$). The class of plurals which undergo vowel change shows the highest proportion of errors. The interaction between word type and plural word form frequency turned out to be significant at the level of subject ($F1(2,60) = 4.73$, $p < .05$), and marginally significant at the level of items ($F2(2,128) = 2.79$, $p < .10$).

In Table 3 the mean reaction times and error scores for the different test conditions are presented for the 12-year-old children.

By-participant and by-item analyses of variance showed that high frequency plurals were responded to faster than low frequency plurals ($F1(1,33) = 61.03$, $p < .01$; $F2(1, 128) = 44.41$, $p < .01$). The data show that the reaction times of the low frequency plurals in the subset of vowel change word patterns are relatively large. However, the differences in reaction times between the three subtypes of items were not significant. The interaction between Word Type and Frequency Class showed a tendency to be significant ($F1(2,66) = 3.03$, $p < .10$; $F2(2,128) = 3.99$, $p < .10$).

Of interest again, is the pattern of the error data. For plural frequency, the differences turned out to be significant ($F1(1,33) = 66.34$, $p < .01$; $F2(1,128) = 30.39$, $p < .01$). The low frequency plurals showed a much larger error proportion than the high frequency plurals. The differences between word types are also significant ($F1(2,66) = 11{,}32$, $p < .01$; $F2(2,128) = 4.47$, $p < .05$). The class of plurals which undergoes vowel change shows again the highest proportion of errors. The interaction between word type and plural word form frequency turned out to be significant at the level of subject ($F1(2,66) = 6.04$, $p < .01$), and marginally significant at the level of items ($F2(2,128) = 2.58$, $p < .10$).

1.3. Conclusions

The results of this study show that the accuracy of lexical decision of plural nouns is determined by the surface frequency of the full word patterns. There was also a clear tendency for the interaction between word frequency and orthographic word complexity to be significant. For the low frequency plurals, we found lexical decision to be less accurate for patterns which undergo a vowel change as a consequence of pluralization. It can tentatively be

Table 2
Means and standard deviations of latencies (in milliseconds) and percentages of errors for plurals by 9-year-old children

	Latency-high	Latency-low	Error-high	Error-low
Regular	1187 (133)	1311 (168)	4	10
Consonant doubling	1172 (155)	1350 (154)	4	16
Vowel change	1182 (135)	1402 (222)	7	23

Table 3
Means and standard deviations of latencies (in milliseconds) and percentages of errors for plurals by 12-year-old children

	Latency-high	Latency-low	Error-high	Error-low
Regular	818 (79)	912 (121)	1	8
Consonant doubling	821 (97)	982 (67)	2	7
Vowel change	814 (95)	1003 (163)	3	17

concluded that in the process of learning to read, graphotactic adaptation rules complicate the reading of words with such vowel reductions taking place.

2. Study 2: processing graphotactic rules in skilled adult word recognition

From the former study, we may conclude that graphotactic rules tend to be hard to acquire for children learning to read Dutch. In the present study, we want to find out to what extent such rules are troublesome and time-consuming in visual word identification even for experienced readers of Dutch.

2.1. Method

2.1.1. Participants

24 adult participants, mostly undergraduates at Nijmegen University, were paid to take part in the experiment. All participants were native speakers of Dutch.

2.1.2. Materials

The same sets of stimuli as in Experiment 1 were used for the adults. The stimulus materials were divided over six blocks: one of 18 items, four blocks of 54 items, and one block of 34 items. The numbers of words and pseudowords in each block were kept constant. In order to prevent participants from seeing the singular and plural form of one and the same stem, the singular form of each word pair was incorporated in one block and the plural form in another. Of each list six pseudo-randomized versions were made, making sure that not more than three items of the same type (either word or pseudoword) occurred in sequence and that no semantic associations of any kind existed between consecutive items. Finally, 36 practice items (18 words and 18 pseudowords, including singular and plural forms) were selected to precede the test materials.

2.1.3. Procedure

Participants were tested in individual noise-proof experimentation booths. They received a standard lexical decision instruction, specifying that they had to decide as quickly and as accurately as possible whether a presented letter string was a Dutch word or not. If it was a word, they had to push the right one of two response keys, otherwise the left one. For left handed participants, the order of the response buttons was reversed.

For each trial, an asterisk was presented in the middle of the screen as a fixation mark. After 500 ms it was followed by the stimulus centered at the same position. Stimuli were presented on Nec Multisync color monitors in white uppercase letters (font: triplex; size: 24 mm) on a dark background. They remained on the screen until the participant pressed one of the two response buttons, or disappeared after a time period of 2 s in case no response was given. A new trial was initiated 1200 ms after responding or time-out.

Two pauses were included in the experiment: one between the practice and test set, and one halfway through the experiment. After each break, participants continued the experiment when they were ready. The total duration of the experimental session was approximately 20 min.

2.2. Results

In Table 4 the mean reaction times and error scores for the different test conditions are presented.

By-participant and by-item analyses of variance showed that high plural frequency forms were responded to faster than low plural frequency forms ($F1(1,23) = 124.24$, $p < .01$; $F2(1, 128) = 44.67$, $p < .01$). The differences in reaction times between the three subtypes of items were also significant ($F1(2,46) = 15.01$, $p < .01$; $F(2,128) = 5.36$, $p < .01$). The data show that the reaction times of the low frequency plurals in the subset of vowel change word

Table 4
Means and standard deviations of latencies (in milliseconds) and percentages of errors for plurals by adults

	Latency-high	Latency-low	Error-high	Error-low
Regular	549 (38)	593 (44)	3	7
Consonant doubling	561 (30)	603 (67)	1	9
Vowel change	546 (42)	674 (60)	3	12

patterns are relatively large. Significant interactions were found between Word Type and Frequency Class ($F1(2,46) = 25.67$, $p < .01$; $F2(2,128) = 7.24$, $p < .01$).

Given the almost similar frequencies of the low frequency words in the consonant doubling (RT = 603) and the vowel change condition (RT = 674), we also tested the difference in reaction times between the two groups by means of *t*-tests. The *t*-tests showed a significant difference in mean scores between these word groups ($t2(34) = -3.30$, $p < .01$).

Because of the fact that family size was not perfectly matched in the three groups of words, additional analyses of variance were conducted with family size as covariable. In all cases the effects of Frequency Class were still significant.

The pattern of the error data is similar to that in the reaction time data. For plural frequency the differences turned out to be significant ($F1(1,23) = 40.25$, $p < .01$; $F2(1,128) = 15.52$, $p < .01$).The low frequency plurals showed a larger error proportion than the high frequency plurals. The differences between word types were not significant, nor were the interaction between word type and plural word form frequency. The latter results may be due to a restriction of range in the error data.

We also computed the Spearman rank order correlations between reaction time (in ms) and plural word frequency over total number of words and words in different word types. Over all word types we found a substantial, significant correlation between reaction time and plural frequency ($r = .54$, $p < .01$). However, within word types the correlation was much higher for the group of vowel change plural word patterns ($r = .70$, $p < .01$) in comparison with the group of consonant doubling plural word patterns ($r = .33$, $p < .05$) and the group of regular words ($r = .48$, $p < .01$). Thus, we may conclude that the frequency effect is mostly relevant in the category of vowel change plural word patterns being governed by graphotactic adaptation rules.

2.3. Conclusions

The results of this experiment show that the speed of lexical decision of plural nouns is determined by the surface frequency of the full word patterns. More importantly, we found a significant interaction between plural word form frequency and orthographic word complexity. In the low frequency domain, the lexical decision latency was found to be longer for patterns with syllables ending with a long vowel in which case it is reduced to a short vowel grapheme. Apparently, graphotactic adaptation rules apply for the reading of such words.

3. Discussion

From the present research, several conclusions can be drawn. First of all, it can be concluded that the surface frequency of inflected words is related to the speed and accuracy of lexical decision. For the children's data, we found that the accuracy of lexical decision of plural nouns is determined by the surface frequency of the full word patterns. For the low frequency word patterns, we found lexical decision to be less accurate for plural word forms which undergo vowel change as a consequence of pluralization. For the adult data, we found that the speed of lexical decision of plural nouns is determined by the surface frequency of the full word patterns. More importantly, we found a significant interaction between word frequency and orthographic word complexity. In the low frequency domain, the lexical decision latency was found to be longer for plurals in the vowel change condition. It is interesting to note that both for children and adults we found no significant differences in the accuracy or latency for the identification of plural word forms with short vowels and consonant doubling as compared to regular plural word forms. One possible explanation for this finding is the fact that the plurals of word stems with short vowels do not principally deviate from their singulars.

The data in the present study turn out to be fairly consistent for beginners and for advanced readers. Both types of readers show problems in the identification of long vowels in low frequency plural nouns. For the school children, the identification problems can be derived mainly from their larger error percentages. For adult readers, the problems can be derived mainly from their greater latencies. Fig. 1 presents the mean error proportions for low frequency regular,

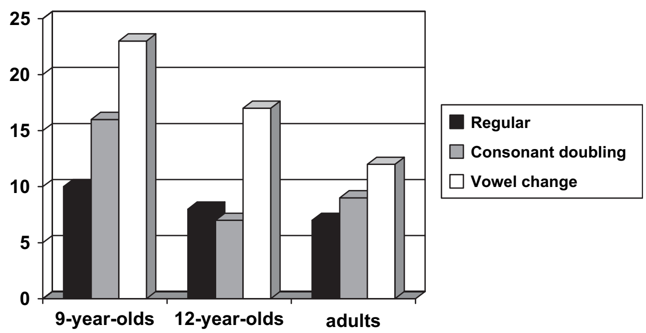

Fig. 1. Mean error proportions for low frequency regular, consonant doubling and vowel change plural word patterns in 9- and 12-year-old children and adults.

consonant doubling and vowel change plural word forms for the adult group and the two groups of school children. Analysis of variance yields a significant main effect for Age and Word Type (in both cases $p < .01$) with no interaction between the two factors.

Fig. 2 shows the mean latencies for low frequency regular, consonant doubling and vowel change plural word forms for the three groups of participants. Analysis of variance shows a significant main effect for Age and Word Type (in both cases $p < .01$) with no interaction between the two factors.

Current models of visual word identification fail to fully explain the results of the present study. First of all, the data are not fully commensurate with phonological coherence models, such as the one brought forward by Van Orden (1987). According to this model, reading requires knowledge of the statistical relations between graphemes and phonemes. Van Orden and Goldinger (1994, 1996) describe how a recurrent network model can establish orthographic–phonological relations at the (sub)word level. However, it is not just a frequency effect that accounts for the present findings. The present data show beginning and advanced readers of Dutch to apply not only grapheme-to-phoneme correspondence rules but also autonomous graphotactic rules as well. In case they encounter low frequent plural word patterns, the graphotactic cue of single vs double consonants needs to be applied in order to arrive at the interpretation of a syllable containing a short vs long vowel. No mechanism is proposed in phonological coherence models which accounts for such facts.

Recent parallel-distributed processing models (Plaut et al., 1996) and dual-route models (Coltheart et al., 2001) also do not fully explain the present findings. In line of such models, the present study indicates that full storage of words occurs even in the case of regular noun plurals, showing that it is more efficient to store frequent full forms than to process them on-line by rule. The finding that surface frequency of inflected words affects the speed and accuracy of lexical decision also fits with a parallel dual route model that includes both abstract grapheme-to-phoneme correspondence rules and lexical representations (cf. Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart et al., 2001). However, none of these models are sensitive to the fact that in case less frequent exemplars are encountered, the reader may be dependent on intermediate fine-grained analysis of orthographic patterns on the basis of graphotactic rules.

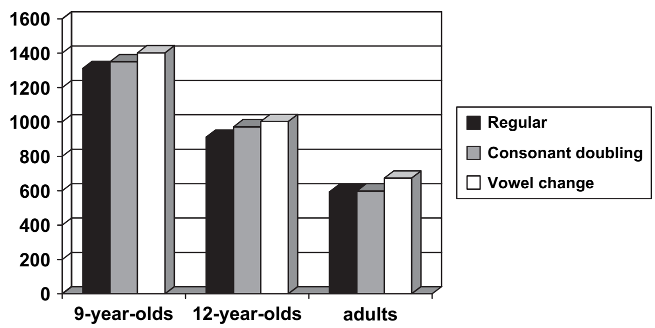

Fig. 2. Mean latencies for low frequency regular, consonant doubling and vowel change plural word patterns in 9- and 12-year-old children and adults.

None of these models have any mechanism that would lead them to be sensitive to the fact that the root of *ramen* is *raam* and not *ram* and that this may complicate its identification in the mental lexicon.

Of theoretical interest is the question, what properties a model of visual word identification in Dutch needs to have if it were to have any chance of explaining these results. Taft (1991, 1994) argues for a cascaded dual route model in which an obligatory parsing route precedes full word retrieval in the mental lexicon. This model explains the role of stem frequency effects at the access level, although the fact that in the higher frequency domains such effects tend to disappear cannot be explained. Another model in which a direct route and a parsing route are combined is the augmented addressed morphology model (Burani & Caramazza, 1987; Burani & Laudanna, 1992). However, neither in this model nor in Taft's model an explanation is given for the identification of graphotactic rules in low frequency plural word forms.

In order to explain the findings of the present study we propose an Extended Dual Route Cascaded Model which allows for a graphotactic bypass look-up in case of graphotactically governed visual word forms. This model is presented in Fig. 3.

The model shows that after a first step of orthographic analysis, frequently encountered word forms are processed via the direct route while rare or complex word forms are processed via the parsing route—which is construed as a backup route. It is assumed that via the direct route, a full-form representation is accessed and mapped onto its associated lemma node, which then activates the relevant representations from the semantic system. In a parallel parsing route, the representations of morphological units (i.e., stem and plural ending) can be activated through a process of segmentation. A similar model conception for the processing of regular morphologically complex words comes from Schreuder and Baayen (1997). However, for the identification of words following spelling adaptation rules not governed by phonology the input of a graphotactic rule system is in order. For Dutch, the identification of a vowel change in a word stem or a double consonant at the end of a word stem can be seen as critical for finding the right phonological representation in the case of plural formation. By making a connection with the morpho-phonological output lexicon, the compatibility of the subcategorization features of the activated constituents is checked along with the assignment of word stress. In our case, the unstressed suffix −*en* is subcategorized for attaching to nouns in order to specify the

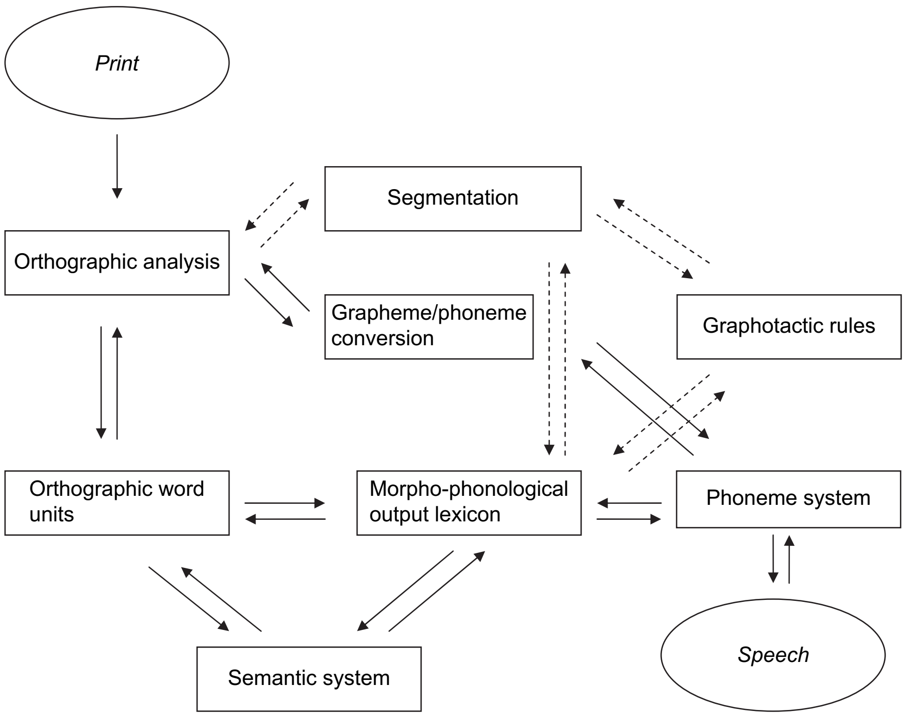

Fig. 3. Basic architecture of the Extended Dual Route Cascaded Model (dotted lines show the extensions as compared with the standard DRC model).

plural form. The meaning of the complex word can then be computed from the meanings of its constituents so that a lexical decision can be made. The parsing route includes an activation feedback mechanism which accounts for the cumulative frequency effects observed for transparent complex words. The activation feedback mechanism predicts an advantage of the parsing route for transparent words. Our finding that the plurals of word stems with short vowels are not harder to identify than plurals of regular word forms can be explained from the feedback these plurals may receive from their singulars, given that these plural forms are fully compositional with respect to their singulars.

There are, of course, a number of limitations in the present study. First, in the examination of lexical decision, we have limited ourselves to inflected nouns. The lexical decision of words of other syntactic classes has not been taken into account. Second, we have focused on the contrast between long and short vowels in open syllables. However, it should be mentioned that not in all cases in Dutch orthography this contrast is expressed by the alternation of single and double consonants. In the case of the long vowels /*eu*/ and /*ie*/ the singular form and its plural complement follow the same spelling. In future research, the status of such regularities should also be taken into account. Third, our data are confined to children with considerable reading experience. In our present study it is shown that orthographic syllabification rules are hard to acquire (cf. Treiman, 1992). To gain greater insight into the possible limits of cognitive processing during the acquisition of reading, longitudinal reading data of beginning readers should be examined.

This study also has some important educational implications. The evidence of independent lexical and rule-based procedures makes clear that during the process of teaching children to read, attention should be paid to the two alternative – often complementary – processing routes. On the one hand, children should be taught the relevant grapheme–phoneme correspondence rules with sufficient practice to automatize the rules in question. Computer-based flash card programs with words of various lengths appear to be particularly well suited for this purpose (see Torgeson, 2001). On the other hand, an attempt should be made by the teacher to enhance children's awareness of the constituent parts of longer words. Morphological skills become particularly relevant when polysyllabic and thus – in many cases – multimorphemic word patterns are addressed within the reading curriculum. The present study makes clear that children must also become aware of the fact that graphotactic rules may determine the morpho-phonological structure of complex words. And in previous studies, it has been shown that morphological awareness contributes significantly to the reading abilities of not only beginning readers (Carlisle, 1995, 2000; Carlisle & Nomanbhoy, 1993) but also more advanced readers as well (Leong, 2000; Nagy, Diakidoy, & Anderson, 1993).

Finally, with an eye on spelling reform the question of learnability of graphotactic rules should also be addressed. Psycholinguistic studies like the present one clearly show that historically bound autonomous spellings complicate word identification from an early stage of development, and continue to play a problematic role in word identification by skilled adult readers. The adaptation of such rules should therefore be critically considered by language policy makers.

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