RECOGNITION OF WORD-COMPONENT LETTERS IS SUBJECT TO WHOLE-STIMULUS PROCESSING: A RESPONSE-COMPETITION ACCOUNT OF FIRST-LETTER NAMING PERFORMANCE

Martin van Leerdam

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Begeleiding:

Prof. dr A.M.B. de Groot
Faculteit der Psychologie
Vakgroep Psychonomie
Universiteit van Amsterdam

Dr A.M.T. Bosman
Department of Psychology
Cognitive Systems Group
Arizona State University

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A study of Bosman and de Groot (1995) suggested that effects obtained with the first-letter-naming task, a variant of the Reicher-Wheeler paradigm, are due to response competition, not orthographic facilitation. In five experiments two critical assumptions of this response-competition hypothesis were tested. The assumptions were that first-letter naming is subject to interference from whole-stimulus processing, and that processing of the entire stimulus must come to an end before the subject can execute the first-letter response. A prediction implicated by the latter assumption was that if an entire letter string is processed fast, first-letter naming is also faster. The results of this study support the response-competition hypothesis, but counter the predictions of race models of word identification. The findings are interpreted as indicating that letter-recognition performance (i.e., letter detection, first-letter naming) does not necessarily reflect the process of word-identification.

Over the past few decades, many studies on visual word recognition have been concerned with the relation between word processing and processing of a word's component letters. According to one perspective, word-level codes are formed through recognition of the constituent letter units. Thus in this view, letter-level encoding mediates word identification (e.g., Gough, 1972; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schwaneveldt, 1982). An alternative to this analytic approach is that perceivers tend to process words holistically. That is, word encoding always occurs at the whole-word level first, and encoding of component letters only occurs after whole-word encoding is completed (e.g., Johnston & McClelland, 1980; Smith, 1971), and only under particular task demands (see also Johnson, Allen, & Strand, 1989). This holistic view on how word processing comes about is analogous to the direct-access route in dual-process theory, one of the current dominant theories of visual word identification (e.g., Coltheart, 1978; Coltheart, Curtis, Atkins & Haller, 1993). In terms of dual-process theory, the process of direct access is construed as a set of word-specific rules that map orthographic representations to lexical entries in the mental lexicon. In the second (nonlexical) route, words are read by means of discrete grapheme-phoneme correspondence rules (see Van Orden, Stone, & Pennington, 1990, for a critical discussion of dual-process theory).

The letter-identification task is a frequently used paradigm to study the relation between letter and word processing. In this task, subjects are presented with a target letter of which they have to decide whether it matches a predesignated letter of a subsequently presented word. Generally, experimental results obtained with the letter-identification paradigm have been interpreted as evidence for certain models of visual word identification.

A recent example of this approach is the work of Allen and his colleagues (Allen & Emerson, 1991; Allen & Madden, 1990; Johnson, Allen, & Strand, 1989). They proposed a race model of word identification in which analytic and holistic processes are combined (i.e., the Parallel Input Serial Analysis (PISA) Model of Allen & Emerson, 1991). It is generally assumed in the class of race models (see also Healy & Drewnowski, 1983) that during word recognition word-level and letter-level codes are processed independently and in parallel. Furthermore, the level of encoding that is completed first is assumed to constrain performance on the experimental task at hand (e.g., letter detection). If, for example, the *word level* wins the race, the letter string will be functionally represented as a single word and the component letters will not be immediately available without further processing. If on the other hand the *letter level* wins the race, the word code is not available until after the letter-level code has been processed. In the latter case, processing of the word-level code cannot delay processing of the letter-level code.

In support of the PISA race model, Johnson et al. (1989) obtained a curvilinear relationship between letter-detection response time and word frequency. According to these authors this curvilinear function supported the notion of a 'critical duration' of word-level processing. This is the point at which the word-level code just wins the processing race. After the critical duration is exceeded, for example by some adequate increase in word frequency, letter-detection response time should be decreasing because there is time to switch attention to the letter-level process. Letter-detection response time should also be decreasing when word frequency is adequately low. This is the case, because for low-frequency words the word-level code is not available until letter-level coding has completed. Hence, processing of the low-frequency word-level code cannot delay processing of the letter-level code (see Allen & Madden, 1990).

Another example of the use of the letter-identification paradigm in the field of word identification is a well known experiment by Reicher (1969; see also Wheeler, 1970). In this study it was found that tachistoscopical letter recognition was more accurate when the target letter was presented in a word than when presented in isolation or in an orthographically illegal nonword that at the same time is unpronounceable. This 'word-superiority effect' has been taken as evidence for the use of orthographic contextual information in recognizing individual letters if presented within an orthographically legal letter string, but not if presented within an orthographically illegal letter string. This finding has been replicated many times

(e.g., Henderson, 1975; Massaro, 1973, 1975; Krueger, 1975; Wheeler, 1970).

In a variant of the Reicher-Wheeler paradigm, Rossmeissl and Theios (1982) investigated the effects of orthographic context using a letter-pronunciation task. In their experiment, subjects were presented with three types of stimuli: a) words (e.g., PARK), b) orthographically legal nonwords (e.g., PURK), and c) orthographically illegal nonwords (unpronounceable letter strings; e.g., PKRA). The task of the subjects was to name the first letter of each stimulus. Rossmeissl and Theios reasoned that if letters in a word are processed in parallel and the orthographic context provides an independent source of information, the identification of a stimulus' initial letter should be facilitated when it is part of an orthographically legal letter string (PARK or PURK), but not when it is part of an illegal one (PKRA). This hypothesis was supported by their data. First-letter naming of words and legal nonwords was significantly faster than of illegal nonwords. According to Rossmeissl and Theios these results are compatible with a direct-access route in word identification. An indirect, phonological route in which letters are processed serially from left to right (i.e., through grapheme-to-phoneme correspondence processes) would not have predicted an effect of orthographic legality.

In a recent study, Bosman and de Groot (1995) replicated the first-letter-naming experiment of Rossmeissl and Theios and obtained identical results. Although their findings were in line with an orthographic-context explanation, they opted for an alternative explanation: The results could reflect an effect of *response competition*. They argued that a literate subject presented with a letter string cannot avoid reading it. In the first-letter-naming paradigm, however, the task of the subject is not to read the whole stimulus, but to ignore it and to name its first letter. If indeed processing the entire stimulus is obligatory, it is plausible that this process *interferes* with, rather than facilitates, first-letter naming.

In addition to postulating obligatory whole-stimulus processing, Bosman and de Groot assumed that processing of the entire stimulus must always come to an end before the subject can execute the first-letter response. According to the response-competition hypothesis, then, subjects name the first letter of words faster than that of illegal nonwords because processing of a word terminates faster than processing of an illegal nonword. In short, the two critical assumptions inherent to the response-competition hypothesis are that a) processing of the entire stimulus interferes with first-letter naming and that b) processing of the entire stimulus must come to an end before the subject can execute the first-letter response.

It can be argued that the response-competition hypothesis is similar to a holistic word-identification model in assuming that component-level encoding only occurs after word-level encoding has completed. In contrast to such a holistic model, however, the response-competition hypothesis does not assume that letter information must be derived from the word-level encoding; component letter information is merely concealed by a competing word-level code.

Departing from the response-competition hypothesis, Bosman and de Groot (1995, Experiment 2) tried to reveal the variables that cause the difference in first-letter-naming time between legal and illegal letter strings. They noted that in their Experiment 1 as well as in the experiment of Rossmeissl and Theios orthographic legality and pronounceability were generally confounded. In both these experiments the orthographically legal letter strings were always pronounceable (e.g., PURK), while the illegal ones were always unpronounceable (e.g., PKRA). Hence, their Experiment 2 was aimed at disentangling the variables orthographic legality and pronounceability. They observed that first-letter naming of orthographically illegal pseudohomophones (e.g., SLEAV) and legal nonwords (e.g., PURK) - both these types of stimuli are pronounceable - was faster than naming the first letter of orthographically illegal, unpronounceable nonwords (e.g., PKRA). According to Bosman and de Groot this result strongly suggests that *pronounceability* and not orthographic legality is the main underlying factor of first-letter-naming performance.

In a further experiment (Experiment 3), Bosman and de Groot obtained additional evidence for the response-competition hypothesis. They presented adult subjects with legal nonwords. In the 'congruent condition' the pronunciation of the first letter was similar to the pronunciation of the first phoneme in the complete stimulus (for example: /a/ in ARG). The pronunciation of the first letter in the 'incongruent condition', however, was different from that of the first phoneme in the complete stimulus (for example: /a/ in AUG). Bosman and de Groot argued that if response competition underlies the first-letter effect, it should be possible to reduce the effect by having the output of the (automatic) pronunciation process converge with the required first-letter response, thus decreasing the competition between the two processes. Indeed, they observed that in the congruent condition first-letter naming was faster than in the incongruent condition.

In sum, the results of Bosman and de Groot's study support a response-competition account of first-letter-naming performance.

As we noted earlier, psychologists have interpreted experimental results obtained with the letter-recognition paradigm as evidence for certain models of word identification. In making this inference, it is often assumed implicitly that the same cognitive processes involved in letter recognition, as yielded by subjects' task performance, occur in common word processing. For example, Allen and Madden (1990) proposed a race model that successfully explained their letter-detection data, and this model was suggested to account for word processing. Similarly, Rossmeissl and Theios (1982) took their first-letter-naming data as evidence for a particular view on word identification. In this article we question the idea that during word identification readers exploit processes that seem to be involved in the task of identifying word-component letters. The purpose of the present study, therefore, is to demonstrate that letter-identification performance does not necessarily reflect common word processing. Using the first-letter-naming paradigm, we aim to provide an account of first-letter-naming performance without committing to a particular view on word identification. To do so, we conducted a series of experiments that tested the assumptions of the response-competition hypothesis provided above. The response-competition account of subjects' first-letter-naming performance is subsequently compared to interpretations posed by the PISA race model of word identification.

In this study, subjects engaged in the first-letter-naming task in which the two critical assumptions of the

response-competition hypothesis were put to test. The first assumption is that naming the first letter of a letter string is subject to interference from whole-stimulus processing. This assumption was investigated in the present Experiment 2 by comparing first-letter-naming on word stimuli (e.g., BOOK) with that on non-letter character strings (e.g., B#&$), and with the performance of naming isolated letters (e.g., B). Assuming that non-letter character strings are unlikely to evoke a whole-stimulus response, first-letter naming is expected to be faster for these stimuli than for word stimuli. In turn, because in naming isolated letters there is no interference from some whole-stimulus level, and perceptual problems like lateral inhibition are not at hand, naming isolated letters is expected to be the fastest condition.

The second assumption of the response-competition hypothesis is that whole-word processing must come to an end before the subject can execute the first-letter response. Put differently, only when whole-stimulus level encoding has completed, information at the letter-level becomes available. Thus a general prediction of the response-competition hypothesis (one that is shared with holistic models, see Blum & Johnson, 1993; Healy & Drewnowski, 1983), is that anything that would speed up whole-stimulus processing should speed up first-letter-naming performance. Race models, conversely, generally predict that anything that would increase the speed of whole-word processing should increase the likelihood that word-level encoding would win the race. This should tend to conceal the availability of component-letter information (see Johnson, Allen, & Strand, 1989).

In Experiments 3A through 3D these predictions were tested by comparing first-letter-naming performance on letter strings that may be processed fast and letter strings that may be processed more slowly.

Before we examine the two critical assumptions of the response-competition hypothesis, we first return to the role of pronounceability in first-letter naming. Bosman and de Groot (1995) found that subjects named the first letter of words and legal nonwords faster than that of illegal nonwords. In terms of the response-competition hypothesis, this pattern of results was explained by assuming that the process of generating the (whole-stimulus) pronunciation terminates faster in the case of legal letter strings than in the case of illegal letter strings, that are virtually unpronounceable. However, the two types of stimuli not only differed in orthographic legality or pronounceability, but also in orthographic structure. Specifically, all legal nonwords in Experiment 1 of Bosman and de Groot had as initial letters a consonant and a vowel (e.g., BEEG), while all illegal nonwords had as initial letters an orthographically illegal pair of consonants (e.g., BGOO). Thus in Bosman and de Groot's Experiment 1 (and Experiment 2) pronounceability was confounded with the orthographic structure of the letter strings. To remedy this problem, Experiment 1 of the present investigation was set up to disentangle these variables.

EXPERIMENT 1

As explained above, the purpose of Experiment 1 was to check for a possible confounding in Bosman and de Groot's study between the variables pronounceability and orthographic legality of the first letter cluster. This was accomplished by comparing two types of illegal nonwords. The first type were illegal nonwords similar to those used by Bosman and de Groot. These stimuli had an initial letter cluster that was both orthographically illegal and unpronounceable (e.g., BDAAL). The second type were illegal nonwords of which only the final letter cluster was both orthographically illegal and unpronounceable (e.g., BREWR). Thus, the orthographic structure of the initial two letters in the latter type of nonword is similar to the orthographic structure of the word stimuli and legal nonword stimuli.

If the observed difference in first-letter-response time between legal letter strings and illegal letter strings was due to pronounceability of the complete string, no difference in response time should arise between the illegal nonwords of the types BREWR and BDAAL. On the other hand, if the difference in orthographic legality of the initial two letters between legal and illegal letter strings was responsible for the effect, the first-letter-response time of BREWR should drop to that of the legal letter strings BRIEF (words) and BROOG (legal nonwords). In either case, naming the first letter of the legal letter strings should be faster than that of the illegal nonwords such as BDAAL, a pattern that would mirror the results of Bosman and de Groot and of Rossmeissl and Theios (1982).

Method

Subjects. Twenty undergraduates from the Psychology Department of the University of Amsterdam participated to fulfil course requirements. All were native speakers of Dutch.

Materials. The total stimulus set consisted of four types of letter strings: 40 Dutch words (BRIEF), 40 orthographically legal, pronounceable nonwords (BROOG), 20 nonwords with an orthographically illegal (and unpronounceable) consonant cluster in the initial position (BDAAL), and 20 nonwords that had an orthographically illegal (and unpronounceable) consonant cluster in the final position (BREWR). All stimuli contained five letters and the first letter was always a consonant. The complete set of stimuli is shown in Appendix A.

Equal numbers of words, legal nonwords, and illegal nonwords were presented to the subjects, as in the Experiment 1 of Bosman and de Groot. In each stimulus condition the consonants 'b', 'd', 'l', 'm', 'n', 'p', 'r', 't', 'v', and 'w', twice served as the initial letter of a stimulus. As a consequence, differences emerging between conditions cannot be due to differential use of initial letters. The critical difference between the word BRIEF and the legal nonword BROOG is lexicality. Between BROOG and the illegal nonwords BREWR and BDAAL, in contrast, it is pronounceability. Finally, the critical difference between BREWR and BDAAL is the locus of the orthographically illegal letter cluster.

Procedure. At the beginning of a session, the subject was seated at a table in a normally lit room, facing a computer screen at a comfortable reading distance. All subjects were tested individually in a session lasting about 10 minutes, and the experimenter sat beside them during the testing. The subject was instructed to name as quickly as possible the first letter of each stimulus that would appear on the screen, and ignore the stimulus that the

letter was part of. The experimenter asked the subject to concentrate on responding rapidly on all trials - highlighting that the experiment only took a few minutes. The subjects were further instructed to use the letter name rather than its sound to specify their responses, and they were informed that only consonants would appear as the initial letter. Following the instructions, the subjects received 10 practice trials.

The stimuli were presented in lowercase letters on a Macintosh 12" Monochrome Display attached to a Macintosh LC II computer. The initial letter of the stimuli was always located at a fixed point on the centre of the screen. An Authorware program controlled stimulus presentation, randomisation of the stimuli, response latency measurement, and recording of the data.

Each trial started with an auditory warning signal. Shortly after this signal the stimulus was presented and it remained visible until the subject responded. The subjects' responses were registered by a microphone that activated a voice-operated key. A millisecond timer calculated response times in milliseconds from the moment the stimulus appeared on the screen to the onset of the subject's response. In each of the experiments reported in this study a stimulus only appeared once to any given subject.

The experimenter recorded pronunciation errors and failures of the voice-key to respond to the subjects' response and triggering by another sound. After the subject made a response, the experimenter pushed a button initiating the next trial.

Results and Discussion

For each subject mean response times were calculated for each of the four stimulus types (BRIEF, BROOG, BREWR, and BDAAL). In calculating these means, naming errors, errors due to voice-key failure, extremely long (more than 3 *SD* above the mean), and extremely short responses (less than 100 ms) were excluded from the data set. This was a standard procedure for all experiments in this study. Table 8 shows the proportion of trials removed in each experiment.

The subjects' mean response times are presented in Table 1. As can be seen in the table, the first letter of words was named faster than that of legal nonwords, but a planned comparison indicated that this difference was not reliable (F (1,19) = 1.78, p = .20). The important comparison between the two types of illegal nonwords BREWR and BDAAL, further, showed that the 1 ms difference was nonsignificant (F < 1). Finally, two other planned comparisons were conducted in which the two types of illegal nonwords (BREWR and BDAAL) were collapsed. Both the 5 ms difference between legal nonwords and illegal nonwords, and the 8 ms difference between words and illegal nonwords reached significance (F (1,19) = 5.87, p < .05 and F (1,19) = 18.95, p < .01, respectively).

The results can be summarized as follows. First, a small but unreliable difference in first-letter-naming time emerged between words and legal nonwords. Further, a somewhat larger difference in first-letter-naming time emerged between words and illegal nonwords, and between legal nonwords and illegal nonwords. This pattern exactly replicates the results obtained by Rossmeissl and Theios (1982) and Bosman and de Groot (1995; Experiment 1).

Table 1
First-letter Response Times in Ms (*SDs* in parentheses)

Stimulus (with example)			
Word	Legal Nonword	Illegal Nonword	Illegal Nonword
BRIEF	BROOG	BREWR	BDAAL
454 (40)	457 (43)	462 (41)	463 (44)

Finally, the important result was that there was virtually no difference in response time between the illegal nonwords BREWR and BDAAL that are highly comparable except for orthographic structure. It seems thus justified to conclude that it is the pronounceability of the complete letter string that underlies the difference between legal and illegal letter strings in the first-letter-naming task.

As opposed to the response-competition hypothesis, race models of word identification (i.e., the PISA race model of Allen and Madden, 1990) seem unable to account for this pattern of first-letter-naming data. According to the PISA race model (see Introduction section), there is a curvilinear relationship between word frequency and speed of letter-level processing. If the word-level encoding is slow, as in the case of low-frequency words, the letter-level wins the race and hence the word-level encoding cannot delay letter-level processing. Consequently, in terms of this race model, letter-level processing of orthographically legal and illegal nonwords also should not be delayed by the word-level encoding, because the 'word-level' encoding of nonwords is relatively slow. Now suppose that the word stimuli of the present Experiment 1 consisted of words of an intermediate frequency range, that is, a frequency range in which the word-level code just wins the processing race (i.e., the 'critical duration' of word-level processing), then the PISA race model would have predicted *shorter* first-letter-naming times for legal and illegal nonwords. On the other hand, if we would assume that the word stimuli of Experiment 1 consisted of words of any other frequency range, equally fast first-letter-naming times should have been expected for words, legal nonwords, and illegal nonwords. In short, whatever we would assume regarding the frequency range of the word stimuli of Experiment 1, it would never follow from the PISA race model that response times should be shorter for words than for nonwords.

In contrast to the response-competition hypothesis and the PISA race model, it is unclear what predictions holistic models would make. On the one hand holistic models assume that encoding of component letters only occurs after whole-word encoding is complete, thereby making the same assumptions as the response-competition hypothesis. However, because holistic models resemble the direct-access route in dual-process theory of word identification (see Introduction section), the predictions of the former could also be viewed in terms of orthographic-context effects (e.g., the word-superiority effect; see also Rossmeissl & Theios, 1982). In either case, holistic models assume that letter information must be derived from word-level encoding. In this respect these models differ from the response-competition hypothesis, in which it is assumed that the process of first-letter naming is interfered by a competing word-level-encoding process.

There is one observation, however, that may be problematic for the response-competition hypothesis. Because words are processed faster than legal nonwords, it would be expected, in terms of this hypothesis, that first-letter naming is faster for words than for legal nonwords. However, in none of the experiments mentioned so far the difference in first-letter-naming time between words and legal nonwords reached statistical significance.

Yet a comparison of the mean response times of words and legal nonwords of a number of individual studies indicated that in all experiments subjects named the initial letter of words faster than that of legal nonwords. To illustrate, in Experiment 1 of the present study, in Bosman and de Groot's Experiments 1 and 2, and in the experiment of Rossmeissl and Theios, the differences were 3 ms, 4 ms, 2 ms, and 3 ms, respectively. Furthermore, we collected additional first-letter data using the original stimuli of Bosman and de Groot's Experiment 1. The relevant observation was that in three experiments a significant 5 ms difference occurred between words and legal nonwords. Finally, when the subjects were instructed to use phonemes, rather than letter names, in pronouncing the first letter of the stimuli, a reliable 10 ms difference between words and legal nonwords was obtained (Bosman & de Groot, Experiment 1).

We conjecture that these small and often nonsignificant differences between words and legal nonwords are real, but hard to detect in the first-letter-naming task. If these differences were due to random variation, we should have expected to run into at least some opposite effects. In none of the eight experiments just mentioned, however, the first letter of legal nonwords was named faster than that of words.

To substantiate our belief that first-letter naming of words is faster than that of legal nonwords, we statistically summarised the results of all individual first-letter-naming studies we performed in which words were compared with legal nonwords. The statistical method in which results of independent tests of the same hypothesis are combined is called meta-analysis. The meta-analysis we conducted (see Footnote 1) showed that the difference in first-letter-naming time between words and legal nonwords was highly significant[1] . Thus the small and often unreliable differences between words and legal nonwords seem genuine.

In sum, according to the response-competition interpretation of first-letter-naming performance, naming the initial letter of words should be faster than naming the initial letter of legal nonwords because whole-stimulus processing terminates faster for words than for legal nonwords. Similarly, naming the first letter of these legal letter strings should be faster than that of illegal nonwords, because whole-stimulus processing of the former stimuli is in turn faster than that of the latter. These predictions were confirmed by two main findings. The first was the important result of Experiment 1 that subjects named the first letter of legal letter strings faster than that of illegal ones. Moreover, the difference between legal and illegal letter strings was apparently not due to some effect of the orthographic structure of the initial two letters, which might have been a confounding in the Bosman and de Groot study, and possibly also in that of Rossmeissl and Theios. The second main finding was the small but consistent difference between first-letter-response time of words and legal nonwords. Although these differences were not significant in individual experiments, a meta-analysis on the results of a number of similar first-letter experiments confirmed our suggestion that these differences were real but difficult to detect in the first-letter task.

An important assumption of the response-competition hypothesis is that faster first-letter naming for words than for legal nonwords, and faster for legal nonwords than for illegal nonwords, means that legal nonwords should cause more interference than words, and that illegal nonwords should cause more interference than legal nonwords. One experiment of Bosman and de Groot (1995 see Note 7) indeed strongly suggests that *interference* underlies the differences between words, legal nonwords, and illegal nonwords. In this experiment subjects were not only presented with word stimuli, but also with isolated letters. The important finding of this experiment was that isolated letters were named substantially and significantly faster than the first letter of any other stimulus. Bosman and de Groot suggest that this result is due to the fact that in the isolated letter condition there is no competition from processing of some whole-stimulus level. Plausibly, this isolated letter condition may be the neutral condition from which all other effects should be assessed. The fact that naming isolated letters was the fastest condition suggests that responding in all other conditions is inhibited.

The purpose of the next experiment is to replicate the imperative finding of Bosman and de Groot that isolated letters are named faster than the initial letters of words. Furthermore, to investigate our argument that if interference from some whole-stimulus level is present, letter naming should be relatively slow, we included a third condition in the stimulus list. The stimuli in this condition ('visual-noise' stimuli) consisted of a letter followed by three non-letter characters (e.g., B#&$). Because the visual-noise stimuli predominantly contain non-letter characters it is unlikely that they will evoke a whole-stimulus response. This may be assumed because not only do these non letters lack correspondences with phonemes, but they are also highly unfamiliar in the context of word-like letter strings. Consequently, without the assumed interference from the whole-stimulus level, first-letter naming of these stimuli should be faster than naming the first letter of a word. The visual-noise condition may be a an even more suitable baseline than the isolated-letter condition, because it is plausible that first-letter naming of both words and visual-noise stimuli,

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1 One method, based on the product of probabilities from different trials, is presented by Fisher (1948). If the natural logarithms of these probabilities (p) are calculated, multiplied by minus two (-2), and then summed, a χ^2 statistic is obtained with a sampling distribution which is approximated by the chi square distribution. The degrees of freedom of this statistic equal to $2n$ where n is the number of tests combined and p is the one-tailed probability associated with each test (adopted from Wolf, 1986). The results of seven independent tests are summarised in Table 7. The Rossmeissl and Theios study was not included in the meta-analysis because the one-tailed probability associated with the contrast of interest could not be determined. Applying the formula of the Fisher procedure to the data of the seven experiments offers a summary overall test of the hypothesis that first-letter naming of words is faster than of legal nonwords. The Fisher procedure confirmed this hypothesis; the difference between words and legal nonwords was highly significant on the chi square test, $\chi^2 = 40.94$ ($df = 14$), $p < .001$.

but not the naming of isolated letters, is affected by lateral inhibition.

Thus, both naming isolated letters and naming the initial letters of the visual-noise stimuli should be faster than first-letter naming of words. Furthermore, naming isolated letters should be faster than naming the initial letters of the visual-noise stimuli, due to the presence of additional characters in the latter stimuli. In contrast, the orthographic-context explanation of the first-letter-naming effects (Rossmeissl and Theios, 1982; see the Introduction section) would predict faster letter naming for words than for visual-noise stimuli and isolated letters, because in the latter stimulus types no orthographic context is provided that could help in the identification of the to-be-named letters.

EXPERIMENT 2

Method

Subjects. The subjects were a new group of 20 Dutch-speaking undergraduates from the same population as used in Experiment 1. All participated to fulfil course requirements.

Materials. The subjects were presented with 20 words, 20 letters, and 40 visual-noise stimuli. The word stimuli were all four-letter monosyllabic Dutch words (e.g., BOEK). The set of letters (e.g., B) was created by taking the initial letters of the word stimuli. These same letters were used to construct the set of visual-noise stimuli. Each visual-noise stimulus consisted of a letter followed by three non-letter characters (keyboard symbols; '§', '¥', 'Δ', '&', '#', or '$'). The visual-noise stimuli equalled the word stimuli in number of characters. There were two types of visual-noise stimuli. In one type the initial letter was followed by the same character repeated three times (e.g., B&&&), and in the other type it was followed by a series of three different characters.

In each stimulus condition subjects had to name the consonants 'b', 'd', 'f', 'h', 'k', 'l', 'm', 'n', 'p', 'r', 'v', 'w', and 'z'. The complete set of materials is presented in Appendix B.

Procedure. The procedure and apparatus were the same as those used in Experiment 1.

Results and Discussion

The data of Experiment 2 are summarised in Table 2. A post-hoc analysis was conducted on the two types of visual-noise stimuli (B#&$ vs. B&&&). The analysis showed that the difference in first-letter-naming time between them was not significant (Newman-Keuls: $p > .05$).

Following this post-hoc analysis three mean response times were calculated for each subject, one for each of the three stimulus types (letters, words, and visual-noise stimuli). These means were the input for the statistical analyses. As can be seen in Table 2, isolated letters were named considerably faster than the initial letters of the other two stimulus types. The difference between isolated-letter-naming time and first-letter-naming time of words was 24 ms, and that between naming an isolated letter and naming the first letter of a visual-noise stimulus was 17 ms. These effects were highly significant in two planned comparisons, $F(1,19) = 37.47$, $p < .001$, and $F(1,19) = 19.63$, $p < .001$, respectively. Moreover, a third planned comparison confirmed that the initial letter of the visual-noise stimuli was named faster than that of words (7 ms; $F(1,19) = 9.14$, $p < .01$).

Table 2
First-letter Response Times in Ms (*SDs* in parentheses)

Isolated Letter	Nonletter String	Word
B	B&#$	BOOG
416 (35)	433 (31)	440 (30)

Experiment 2 aimed at replicating Bosman and de Groot's finding that isolated letters are named faster than the initial letter of words. Moreover, to support our reasoning that the slower response times for naming the first letter of words is due to interference from whole-stimulus processing, and at least not entirely to lateral inhibition, we included visual-noise stimuli that were unlikely to evoke a whole-stimulus response. The results of Experiment 2 confirm this reasoning. Evidently, when whole-stimulus properties are highly unfamiliar, as in the case of the visual-noise stimuli, naming the first letter is relatively unhindered. Note however that the difference between first-letter-naming time of isolated letters and visual-noise stimuli (most likely due to lateral inhibition) is still quite large (17 ms) as compared to the difference between visual-noise stimuli and words (7 ms). However, note also that the visual-noise stimuli resemble the word stimuli in physical appearance. Both types of stimuli consist of four characters and the component of the stimulus to which the subjects must attend is always a consonant in the first position of the string. It can be argued, therefore, that because subjects sometimes expect to be presented with words, they may initially be biased to process the visual-noise stimuli as strings of letters, resulting in relatively shorter first-letter-naming times than as expected when they were less similar to words. Nonetheless, the results of Experiment 2 indicate that the advantage in naming isolated letters over naming the first letter of words reflects both whole-stimulus interference and lateral inhibition.

To conclude, the data of Experiment 2 are in accordance with the interference assumption of the response-competition hypothesis. It therefore seems reasonable to conclude that the effects discussed in Experiment 1 originate from interference due to competing whole-stimulus processing.

In order to explain the differences in first-letter-naming time, as obtained in Experiment 1, between words, legal nonwords, and illegal nonwords, it is assumed that processing of the entire letter string has to be completed before the subject can execute the primary first-letter response. In other words, according to the response-competition hypothesis, speed of whole stimulus processing is correlated with the first-letter-naming time of the same stimulus. Therefore, anything that would speed up processing of the entire stimulus should result in

faster first-letter-naming performance. This second assumption of the response-competition hypothesis was put to test in the experiments 3A through 3D. In Experiments 3A and 3B, first-letter naming of high-frequency words is compared to that of low-frequency words. From numerous studies on word processing we know that high-frequency words are processed faster than low-frequency words. In terms of the response-competition hypothesis this would imply that naming the first letter of high-frequency words should be faster than that of low-frequency words. Experiment 3C compared first-letter-naming times of three types of words that differ with respect to their spelling pattern. As in Experiment 3A, a word-naming task is administered to determine which word types are processed fast and which are processed more slowly. According to the response-competition hypothesis, the pattern of first-letter-naming times should reflect that of word-naming times. That is, the shorter the word-naming time, the faster performance on the first-letter-naming task. Finally, in Experiment 3D, subjects name the first letter of short legal nonwords (three letters) and of longer legal nonwords (five letters). Assuming that short letter strings are processed faster than long letter strings, the response-competition hypothesis would predict shorter first-letter-naming times for the shorter letter string.

EXPERIMENT 3A

The main purpose of Experiment 3A was to test the prediction of the response-competition hypothesis that first-letter naming of high-frequency words is faster than of low-frequency words. Furthermore, to ascertain that indeed the high-frequency words are processed faster than the low-frequency ones, all subjects performed a word-naming task on the set of stimuli of the first-letter-naming task. The word-naming task was administered immediately following the latter task.

Attempting to detect a frequency effect in first-letter-naming may be difficult. Recall that the detection of a statistically reliable difference in first-letter-naming RT between words and legal nonwords required multiple experiments and meta-analysis techniques. This RT difference between words and legal nonwords was on average smaller than 5 ms. However, in many *word-naming* studies reasonable large RT differences (approximately 30 ms; see e.g. Rayner & Pollatsek, 1989) are observed between naming words and naming pseudowords. To confirm this pattern, in a pilot study we had subjects name the word and legal nonword stimuli of Bosman and de Groot's Experiment 1. In this study we observed a reliable 27 ms difference in naming time between these stimulus types. Differences in naming time between words and pseudowords, however, are generally larger than between high-frequency words and low-frequency words. Consequently, it may be even more difficult to detect a frequency effect than to detect a difference between words and legal nonwords in the first-letter-naming task. Nevertheless, we pursued this experiment.

Method

Subjects. A new group of 20 undergraduates from the same population as used in the previous experiments participated to fulfil course requirements.

Materials. The stimulus materials consisted of 80 Dutch one-syllable words and were based on De Vries (1986). All words contained four letters and the first letter was always a consonant and the second always a vowel. Half of the stimuli were high-frequency words and the other half were low-frequency words. The word frequency of the stimuli was based on the CELEX word-frequency count (corpus size approximately 42 million words; Burnage, 1990). The mean log word frequency of the high-frequency words was 3.9 and of the low-frequency words it was 2.3.

A corpus of word familiarity ratings (De Vries, 1986) was also consulted in creating the stimulus set. The selection constraint was that the high-frequency words should also be more familiar than the low-frequency words. The mean familiarity ratings of the 40 high-frequency words and the 40 low-frequency words were 8.0 and 6.0, respectively (ratings were based on a 9-point scale). The stimuli were also matched on word imageability (Van Loon-Vervoorn, 1985; in De Vries, 1986). The mean imageability ratings for the high-frequency and low-frequency words were 5.3 and 5.4, respectively (ratings were based on a 7-point scale).

In each condition the letters 'b', 'd', 'f', 'g', 'h', 'k', 'l', 'm', 'n', 'p', 'r', 'v', 'w', and 'z' served as the initial letter of the stimuli. The total set of stimuli is listed in Appendix C.

Procedure. Each subject took part in two experiments that were run in the same session. First they participated in the first-letter naming task. The 80 words were presented in a random order and the task of the subject was to name the initial letter. A few minutes later the subjects performed the word-naming task. The same 80 words were presented in a new random order and the subjects were now asked to name the words both rapidly and accurately. The apparatus of Experiment 3A was identical to that in Experiments 1 and 2.

Results and Discussion

For each subject in both the word-naming task and the first-letter naming task mean response times were calculated for the two levels of the variable word frequency (High vs. Low). The data are summarized in Table 3. The table shows that high-frequency words were named faster than low frequency words. A planned comparison indicated that the 9 ms difference in word-naming time was significant, F (1,19) = 24.49, $p < .001$. A planned comparison on the RT-data of the first-letter naming task, however, showed that in that test there was no word-frequency effect ($F < 1$).

The performance of the subjects on the word-naming task was used as an indication to ensure that there was a positive correlation between word frequency and speed of word processing. The results of Experiment 3A indicate that such was indeed the case. Subjects named high-frequency words faster than low-frequency words.

Table 3
First-letter- and Word-naming Response Times in Ms (SDs in parentheses)

	High Frequency	Low Frequency
Word Naming	420 (33)	429 (36)
First-letter Naming	454 (34)	454 (29)

Although the frequency effect was quite reliable, it was not particularly large; the difference between high and low frequency words was only 9 ms.

With respect to first-letter-naming time, no frequency effect emerged. Therefore, the results of the present experiment do not confirm the prediction of the response-competition hypothesis that naming the first letter of high-frequency words is faster than of low-frequency words. However, as put forward earlier, we were not sure whether the first-letter-naming task would be sensitive enough to detect a word-frequency effect. Recall that detecting a difference in first-letter-naming RT between words and legal nonwords had already been difficult (see Experiment 1). It could therefore be expected that to detect a word-frequency effect in this task would be even more difficult.

Before introducing the next experiment, in which an attempt was made to improve the sensitivity of the first-letter-naming task, a potential problem concerning the stimulus materials of Experiment 3A has to be discussed. In preparing that stimulus set we tried to prevent a confounding with word properties such as word imageability and word length. Unfortunately though, it turned out later that the spelling pattern of the letter strings had not been taken into account. In the stimulus set of Experiment 3A there were 47 words with a CVC-structure (e.g., RAAM) and 33 words with a CVCC-structure (e.g., RASP). If whole-word processing of stimuli like RAAM is faster than that of stimuli like RASP (for instance, because the former stimuli contain less phonemes; /r/-/A/-/m/ vs. /r/-/a/-/s/-/p/), interpreting the present results may not be unequivocal. Fortunately though, a count indicated that word frequency had not been confounded with the number of CVCC-words in the stimulus set. The number of CVCC-words in the high-frequency and low-frequency conditions were 17 and 16, respectively.

To find out whether the factor spelling pattern might correlate with speed of whole-word processing, we conducted a post-hoc comparison on the word-naming time of the CVC-words and the CVCC-words. It showed that CVC-words were indeed named faster than CVCC-words (6 ms; Newman-Keuls: $p < .01$). With regard to first-letter-naming performance, the response-competition hypothesis would therefore predict that first-letter naming should be faster for CVC-words than for CVCC-words. A post-hoc comparison indeed showed this to be the case, but the difference (8 ms) did not reach significance (Newman-Keuls: $p > .05$).

To summarize, the word-naming data indicated that two word properties affected word-naming speed: word frequency and spelling pattern. The first-letter-naming data, however, showed that neither factor significantly affected performance in the first-letter-naming task.

The reason for this null effect may be that the conditions for detecting effects in the first-letter-naming task were not optimal. Recall that in presenting the stimuli to the subjects the initial letter was always located at a fixed point on the computer screen, allowing the subjects to fixate on that position permanently, ignoring the remaining letters. This may have enabled the subjects to bypass whole-stimulus processing. If true, any change in presentation conditions that would support whole-stimulus processing should increase effects caused by the word level. Therefore in Experiment 3B we again looked for a frequency effect in the first-letter-naming task, but we used a different stimulus-presentation procedure.

EXPERIMENT 3B

Method

Subjects. In this experiment twenty undergraduates from the same population as in the previous experiments participated to fulfil course requirements. All subjects were native Dutch speakers and none had participated in Experiment 3A.

Materials. The stimulus materials were the same as in Experiment 3A.

Procedure. The procedure and apparatus were as in Experiment 3A, except for two differences. In the foregoing experiments the initial letter of the stimuli was always located at a fixed point on the computer screen. In Experiment 3B the location of the stimuli on the computer screen was randomly varied between trials. A stimulus could appear anywhere between two margins on a horizontal line of approximately 5 centimetres, circumventing the subjects to predict the exact location of the first letter of a stimulus. As a result, focusing on the first letter of the stimuli should be harder and, possibly, whole-stimulus processing would be more difficult to suppress. The other difference with Experiment 3A was that no word naming task was administered.

Results and Discussion

Again, for each of the two word-frequency conditions mean response times were calculated. The data are presented in Table 4. As can be seen, first-letter naming was 5 ms faster for high-frequency words than for low-frequency words. A planned comparison showed that this effect was significant, $F(1,19) = 5.80$, $p < .05$.

Furthermore, the same Newman-Keuls post-hoc analysis as in Experiment 3A was conducted on the CVC-words and the CVCC-words. The analysis showed that, again, the first letter of CVC words was named faster (by 7 ms) than the first letter of CVCC words. This effect was also significant (Newman-Keuls: $p < .01$).

The main purpose of Experiment 3B was to investigate whether a frequency effect can be detected in the first-letter-naming task under stimulus-presentation circumstances that discourage fixating on the initial position of the letter strings. The data showed this indeed to be the case. Thus, as the findings of Experiments 1 and 2, this result

supports the response-competition account of first-letter-naming performance[2].

Table 4
First-letter Response Times in Ms (*SDs* in parentheses)

	High Frequency	Low Frequency
First-letter Naming	474 (42)	479 (46)
(Replication)	476 (31)	480 (32)

Recall that the naming data of Experiment 3A indicated that CVC-words are named faster than CVCC-words. This effect of spelling pattern was subsequently taken as a measure of speed of whole-stimulus processing. With respect to first-letter-naming performance, the data showed that under the stimulus-presentation circumstances of Experiment 3B first-letter-naming was significantly faster for CVC-words than for CVCC-words. Consequently, this finding may also be taken as support for the response-competition hypothesis. However, conclusions regarding the effect of spelling pattern should not be generalised, because we did not experimentally control the initial letters of the list of CVC-words and CVCC-words. To examine whether the effect of spelling pattern can be generalised across experiments, we set up a new study in which we experimentally manipulated this factor.

EXPERIMENT 3C

The purpose of Experiment 3C was to examine whether words that differ in spelling pattern also yield differences in word-naming and first-letter-naming performance. Therefore, two comparisons were focused on. The first was a planned comparison between words with a CVC-structure (e.g., BAAS) and words with either a CVCC-structure (e.g., BARS) or a CCVC-structure (e.g., BRAK; see Method section). This comparison is also a test of number of phonemes: Words of the type BAAS consist of three phonemes (/b/-/A/-/s/), and words of the types BARS and BRAK all consist of four phonemes (/b/-/a/-/r/-/s/ and /b/-/r/-/a/-/k/). It is expected that CVC-words are processed faster than CVCC- and CCVC-words, because in these four-phoneme words the phonological assembly process should be more demanding. Consequently, according to the response-competition hypothesis, naming the first letter of a CVC-word should be faster than naming the first letter of CVCC- and CCVC-words.

The purpose of the second comparison was to test the influence of the locus of the consonant cluster in the four-phoneme words. Words of the types BAAS and BARS were already compared in the Experiments 3A and 3B. In this experiment we included words with a CCVC-structure. Although both the CVCC- and the CCVC-words consist of four phonemes, the former type may be easier to pronounce, because the onset of naming a CCVC-word may be hindered by the more demanding coarticulation of the initial consonant cluster. In the case of a word-naming time difference between CVCC-words and CCVC-words, the response-competition hypothesis would predict an analogous effect in first-letter-naming time.

Method

Subjects. A new group of undergraduates was recruited from the same population as in the previous experiments. They were all native Dutch speakers and they all took part to fulfil course requirements.

Materials. The total set of stimuli consisted of 80 Dutch monosyllabic words. All words contained four letters and the first letter was always a consonant. Half of the words (40) had a CVC-structure (BAAS). Twenty stimuli had a CVCC-structure (BARS), and the remaining 20 stimuli had a CCVC-structure (BRAK). The crucial difference between the CVCC-words and the CCVC-words was the locus of the consonant cluster. The three stimulus types (CVC vs. CVCC vs. CCVC) were matched on word frequency (based on a frequency count of Uit den Boogaart, 1975). The mean word frequencies for the three conditions were 34, 34, and 35, respectively (based on a corpus size of 620,000 words).

In each of the three conditions the letters 'b', 'd', 'f', 'g', 'k', 'p', 's', 't', 'v', and 'w' served as the initial letter of one stimulus. Appendix D presents the total set of materials.

Procedure. The procedure and apparatus were identical to those in Experiment 3A. Thus, again, all subjects performed a word-naming task immediately following the first-letter-naming task, and the initial letter of the stimuli was always located at a fixed point on the computer screen.

Results and Discussion

For each subject in both the word-naming task and the first-letter naming task mean response times were calculated for the three types of spelling pattern (CVC, CVCC, and CCVC). Pair-wise comparisons were performed on the subjects' mean word-naming RTs. The same analyses were conducted on their mean RTs of the first-letter-naming data. Both data sets are summarised in Table 5.

A planned comparison on the word-naming data showed that CVC-words were indeed named faster than words with either a CVCC- or CCVC-structure. The

[2] We decided to replicate Experiment 3B with a new group of 20 subjects drawn from the same population as in the previous experiments. Similarly, we observed a 4 ms difference in first-letter-naming time between high-frequency and low-frequency words. This time, however, the support of the statistical analysis was not particularly strong: The planned comparison showed that the frequency effect only approached significance, $F(1,19) = 3.05, p = .10$.
However, a post-hoc comparison between CVC-words and CVCC-words again indicated that first-letter naming of the CVC-words was significantly faster (6 ms; Newman-Keuls: $p < .05$).
Finally, an overall statistical analysis on the combined data of the two experiments (Experiment 3B and this replication experiment: $n = 40$) yielded a significant effect of word frequency, $F(1,38) = 8.83, p < .01$. The post-hoc comparison between CVC-words and the CVCC-words on the combined data also showed a significant effect (Newman-Keuls: $p < .01$).

difference was 12 ms and it was highly significant, $F(1,19) = 44.33$, $p < .001$. Furthermore, a Newman-Keuls post-hoc analysis was conducted on the difference in word-naming time between CVCC-words and CCVC-words. The test indicated that the former type of words were named significantly faster (17 ms; $p < .01$). Additional planned comparisons showed that the 21 ms difference in word-naming time between CVC-words and CCVC-words was highly significant, $F(1,19) = 69.05$, $p < .001$, but the 4 ms difference between CVC-words and CVCC-words did not reach significance, $F(1,19) = 1.63$, $p = .22$.

The RT pattern of the first-letter-naming task mirrors that of the word-naming task (see Table 5). First-letter naming of CVC-words was faster than of CVCC- and CCVC-words. A planned comparison showed that the 4 ms difference was significant, $F(1,19) = 5.07$, $p < .05$. A second planned comparison showed that the difference between CVC-words and CVCC-words was nonsignificant (2 ms difference; $F < 1$).

Because a Newman-Keuls test indicated that CVCC-words were pronounced faster than words with a CCVC-structure, a planned comparison was performed on the first-letter-naming times of these words. The analysis showed that the first letter of CVCC-words was named significantly faster than that of CCVC-words (12 ms difference; $F(1,19) = 18.47$, $p < .001$). A final planned comparison showed that first-letter naming of CVC-words was also significantly faster than for CVCC-words (10 ms difference; $F(1,19) = 20.06$, $p < .001$).

Table 5
First-letter- and Word-naming Response Times in Ms (SDs in parentheses)

	CVC BAAS	CVCC BARS	CCVC BRAK
Word Naming	414 (36)	418 (38)	435 (41)
First-letter Naming	448 (41)	446 (38)	458 (42)

The results of Experiment 3C show that, as indicated by subjects' performance on the word-naming task, words that are processed fast (CVC- and CVCC-words) yield shorter first-letter-naming times than words processed more slowly (CCVC-words). These results do *not* replicate the a posteriori findings of Experiments 3A and 3B. In the word-naming task administered in Experiment 3A, a significant difference in naming time was observed between CVC-words and CVCC-words, and in the first-letter-naming task of Experiments 3B a significant difference in first-letter naming time emerged between these types of words. In the present Experiment 3C, however, we did not observe a reliable difference between CVC-words and CVCC-words, neither in the word-naming task nor in the first-letter-naming task. But conclusions regarding the effect of spelling pattern may be unjustified in Experiments 3A and 3B, because the initial letters of the stimuli of these two experiments were not experimentally controlled.

In a word-naming experiment run for other purposes we also compared a set of CVC-words with a set composed of both CVCC-words and CCVC-words. Replicating the word-naming results of Experiment 3C, we found a reliable difference in word-naming time between the two stimulus types. Moreover, a post hoc comparison on the three word types (CVC-CVCC-CCVC) showed that CCVC-words were named significantly slower than the other two word types. The difference in naming time between the latter two was not significant.

Thus it seems that in our experiments word-naming performance is constrained by the orthographic pattern of the letter strings (CCVC vs. CVC/C), and not so much by the number of phonemes (CVC vs. CVCC). The effect of orthographic pattern on word naming is obviously a complicated issue. But, whatever may have caused the differential word-naming times, the slower processing of the CCVC-stimuli was reflected in subjects' first-letter-naming performance, and this was predicted by the response-competition hypothesis.

In the next experiment, we turn to a final test of the effect of speed of whole-stimulus processing on first-letter naming.

EXPERIMENT 3D

Experiment 3D was designed to serve two purposes. The first was to test again the critical assumption of the response-competition hypothesis that anything that would speed up whole-stimulus processing should facilitate first-letter naming. In this experiment we manipulated whole-stimulus processing by varying word length. Assuming that short letter strings are processed faster than long ones (e.g., see Hudson & Bergman, 1985), the response-competition hypothesis predicts shorter first-letter-naming times for the shorter letter strings. The PISA race model (see Experiment 1) does not predict a difference in first-letter-naming time between long and short legal nonwords. Recall that if processing of the word-level code is slow, as in case of low-frequency words or nonwords, then according to the PISA race model the letter-encoding should tend to win the race. In this case the letter-level encoding will not be affected by the word-level encoding. Returning to the present experiment, as *both* the long and the short legal nonwords are processed relatively slow, the letter-level encoding should not be differentially affected by processing long versus short nonword letter strings.

The second purpose of Experiment 3D was to replicate the findings of Bosman and de Groot's Experiment 3 (see Introduction section). In this experiment, subjects named the first letter of three types of legal nonwords, namely, stimuli with a VCC-structure ('single-cluster'; e.g., AST), stimuli with a V1V1C-structure ('double-cluster'; e.g., AAF), and stimuli with a V1V2C-structure ('mixed-cluster'; e.g., AUD). The subjects had to respond with either letter names or phonemes in naming the first letter of the stimuli. The critical finding was that if the pronunciation of the initial letter (/a/ vs. /A/) was congruent with the sound of the first phoneme in the entire stimulus (e.g., /a/ in AST, or /A/ in AAF), first-letter naming was facilitated as compared to the situation in which the pronunciation of the initial letter and the sound of the first phoneme were incongruent (e.g., /a/ in AAF, /A/ in AST, or /a/ and /A/ in AUF).

These congruency effects are important, because they support the response-competition account of first-letter-naming performance. As Bosman and de Groot argued, if response competition indeed underlies the first-letter effect,

then decreasing the competition between the process of generating the pronunciation of the entire letter string and the process of generating the first-letter response should reduce the first-letter effect.

Method

Subjects. A new group of 20 Dutch-speaking undergraduates was recruited from the same population as in the previous experiments. They all took part to fulfil course requirements.

Materials. The stimulus materials were 120 legal, pronounceable nonwords. Half of the stimuli were monosyllabic nonwords, each containing three letters (e.g., AST). They made up the short-stimulus condition. These stimuli were the set of 60 legal nonwords employed in Experiment 3 of Bosman and de Groot.

The remaining half were two-syllable nonwords each containing five letters (long-stimulus condition; e.g., ASTEP). The 60 three-letter stimuli of the short-stimulus condition served as the starting point for the construction of the 60 five-letter stimuli of the long-stimulus condition. To each of the short stimuli a two-letter string with a VC-structure was added (e.g., 'ep', 'or' and 'el').

Both the short-stimulus and the long-stimulus condition consisted of three types of stimuli. Twenty stimuli had a VCC-structure ('single cluster'; e.g., AST), 20 had a V1V1C-structure ('double cluster'; e.g., AAF), and 20 had a V1V2C-structure ('mixed cluster'; e.g., AUD). Stimulus length (long vs. short) was orthogonally varied with cluster type (AST[EP] vs. AAF[OR] vs. AUD[EL]).

The initial letter of the stimuli was always a vowel, either 'a', 'e', 'o', or 'u', and was presented equally often in every stimulus condition. The stimuli of Experiment 3D are presented in Appendix E.

Procedure. The procedure and apparatus were the same as in Experiments 1, 2, 3A, and 3C (the first letter was presented on a fixed position on the computer screen). The only exception was that in the present experiment subjects were required to use phonemes, rather than letter names (see previous experiments), to specify their responses.

Results and Discussion

For each subject mean response times were calculated for the six conditions formed by the variables word length (long vs. short) and cluster type (AST[EP] vs. AAF[OR] vs. AUD[EL]). A 2 by 3 analysis of variance on the subjects' mean RTs, treating both word length and cluster type as within-subjects variables, showed that only the main effects were significant. The results are shown in Table 6. The main effect of cluster type (F (2,38) = 19.76, $p < .001$) indicated that the first letter of single-cluster and double-cluster stimuli was named faster than that of mixed-cluster stimuli (18 ms and 16 ms, respectively; Newman-Keuls: $p < .01$). The 2 ms difference between single-cluster stimuli and double-cluster stimuli was not significant (Newman-Keuls: $p > .05$).

More important was the significant main effect of stimulus length. Table 1 shows that the initial letter of short letter strings (AST) was named 12 ms faster than that of the corresponding long letter strings (ASTEP), F (1,19) = 13.44, $p < .01$.

Table 6
First-letter Response Times in Ms (*SDs* in parentheses)

	Single Cluster	Double Cluster	Mixed Cluster	*M*
Long String	500 (69)	501 (79)	519 (87)	507
Short String	488 (75)	491 (63)	506 (67)	495
M	494	496	512	

Bosman and de Groot found in their Experiment 3 that when subjects have to produce phonemes as first-letter responses (e.g., /a/ in AST), the congruent single-cluster condition (AST) produced the shortest first-letter-naming times. The double-cluster stimuli (AAF), in turn, yielded shorter first-letter-naming times than the mixed-cluster stimuli (AUD). The congruency effects of the present Experiment 3D partly replicate these findings. Subjects named the first letter of both the single-cluster and the double-cluster stimuli faster than that of the mixed-cluster stimuli. These congruency effects were unaffected by stimulus length, as indicated by the nonsignificant interaction between stimulus length and cluster type.

However, in contrast to what Bosman and de Groot observed, the small first-letter-naming advantage for single-cluster stimuli as compared to the double-cluster stimuli did not reach significance. Nonetheless, the general pattern of congruency effects is rather consistent. What seems to determine performance in this version of the task is whether or not the first-letter response is congruent with the pronunciation of the first phoneme in the stimulus.

This conclusion is further supported in a recent study by Goutbeek-Kuyper (1994). In this study subjects performed a first-letter-naming task on two sets of Dutch words. The first set consisted of words with the initial letter being a long vowel (e.g., ADEM), and the second consisted of words with the initial letter being a short vowel (e.g., ALBUM). The subjects responded with either letter names or phonemes. When the subjects had to produce phonemes to indicate their response, first-letter naming was faster in the congruent short-vowel condition (e.g., /a/ in ALBUM). In contrast, when the subjects had to use letter names to indicate their responses - a task that is congruent with the long-vowel words - first-letter naming was faster in the long-vowel condition (e.g., /A/ in ADEM).

Thus the congruency effects observed in Experiment 3D again support the response-competition account of first-letter-naming performance. Furthermore, additional evidence was gathered for one of the assumptions of the response-competition hypothesis, namely, that anything that would affect whole-stimulus processing should also affect first-letter-naming performance: Subjects named the first letter of short letter strings considerably faster than of long letter strings. This finding was not predicted by the PISA race model. According to this race model, both the long and the short legal nonwords are processed relatively slowly. The letter-level encoding should therefore not be

differentially affected by processing long versus short nonword letter strings.

GENERAL DISCUSSION

The purpose of the experiments reported in this article was to give an account of letter-identification performance that does not link to a particular view of word perception. More specifically, we aimed to challenge the assumption that the cognitive processes involved in letter recognition also emerge in common word processing. In our view, if subjects engage in the task of identifying letters, they exploit cognitive processes fit to that particular task. To us, it is not clear why these specific processes should transfer to the common task of word identification: Models that explain letter-identification data need not simultaneously account for word reading.

In this study we tried to demonstrate that results obtained with the letter-identification task may also be interpreted in terms of a mechanism specific for (word-component) letter identification. To exemplify this, we took the response-competition hypothesis of Bosman and de Groot (1995) as a guideline.

In five experiments we put the two assumptions of the response-competition hypothesis to test. The first assumption was that naming the first letter of a letter string is subject to interference from whole-stimulus processing, not to facilitation from the orthographic context, as implicated by the word-identification interpretation of Rossmeissl and Theios (1982). The second was that processing of the entire stimulus must come to an end before the subject can execute the first-letter response. A general prediction implicated by this second assumption was that anything that would speed up whole-stimulus processing should speed up first-letter-naming performance.

Both these assumptions were confirmed by our data. The observation in Experiment 2 that first-letter naming was faster for non-letter strings (stimuli that are unlikely to evoke a whole-stimulus response) than for words indeed suggested that the first-letter-naming effects are due to interference from whole-stimulus processing, and not to facilitation from the orthographic context. Furthermore, the major overall finding in the subsequent experiments was that first-letter naming was faster for letter strings that are processed fast than for letter strings processed more slowly (high-frequency vs. low-frequency words, CVCC- and CVVC-words vs. CCVC-words, and short vs. long letter strings).

The PISA race model of word identification (e.g., Allen and Madden, 1990), in contrast, was not able to account for the first-letter-naming effects. First, it would never follow from the PISA race model that response times should be shorter for words than for nonwords (see Experiment 1). Secondly, this model did not predict the observation in Experiment 3D that subjects named the first letter of short legal nonwords faster than of long legal nonwords.

The results of these experiments, taken together, demonstrate that in contrast to race models of word identification, a response-competition mechanism can satisfactory account for first-letter-naming effects. This suggests that the performance of recognizing or naming word-component letters does not necessarily reflect common word processing.

As an illustration, take again the PISA race model. This model of word-recognition is motivated sheerly by experimental findings obtained with the letter-detection task. However, the conception of word identification as a race between independent levels of encoding is not verified in studies in which subjects are engaged in some 'genuine' form of word processing, such as word naming or lexical decision. It is thus quite plausible that a race between a letter-level and a word-level codes is manifested only during the particular task of detecting word-component letters. We argue, therefore, that the usefulness of the letter-recognition task in modelling word recognition may be limited, and that the task should be put to practise only with caution.

This of course does not imply that the letter-recognition task does not provide information on processes underlying word perception. On the contrary, if one would assume that in a letter-identification task subjects also process the entire word, and some property of the entire word would affect letter-identification performance, one may infer that this property is important in word perception. For example, the congruency effects observed by Goutbeek-Kuyper (1995; see Experiment 3D of this study) indicated that in the first-letter-naming task subjects automatically generate the pronunciation of the entire stimulus. According to Goutbeek-Kuyper this suggests that phonology is important in visual word recognition. However, these congruency effects do *not* implicate that in *word identification* congruency of the pronunciation of a component letter with the sound of this letter in the word's context (e.g., /a/ in ALBUM) is important : The congruency effects may only occur in the first-letter-naming task.

We end this section by returning to the response-competition hypothesis of Bosman and de Groot (1995). Explaining the first-letter-naming effects in terms of response competition does immediately raise the question whether in fact the first-letter-naming task is a variant of the Stroop task (see also Bosman, 1994). In the classic Stroop task (Stroop, 1935; see also MacLeod, 1991), subjects are presented with words and their task is to name the colour of the ink the words are printed in. Thus, as in the first-letter-naming task, the entire stimulus is a word, and the relevant task is to name a component of the stimulus (the colour of the ink). In general, automatic processing of the word is assumed to interfere with naming the colour of the letter string. In one variant of this paradigm, the picture-word-interference task, subjects are presented with pictures on which words are superimposed. Similarly, processing of the superimposed word is also assumed to affect the primary response (naming the picture). In these modified Stroop tasks a number of variables have been investigated. Among them are some that are of relevance to us : lexicality and pronounceability in the picture-naming task (e.g., Lupker, 1982; Guttentag & Haith, 1978), and pronounceability in the Stroop task (Bakan & Alperson, 1976).

In a modified version of the Stroop paradigm, Bakan and Alperson (1967) presented subjects with stimuli that differed in the degree of pronounceability. They found that colour naming of unpronounceable stimuli was faster as compared to colour naming of pronounceable nonwords. Furthermore, naming the ink colour of pronounceable, legal nonwords was in turn faster than that of words. This same pattern was also found in a picture-word-interference

study of Guttentag and Haith (1978). They observed that naming a picture on which a unrelated word was superimposed took longer than if a pronounceable nonword was superimposed. Furthermore, picture naming in case of superimposed pronounceable nonwords took longer than in case of unpronounceable nonwords. Finally, the finding that responding to pronounceable nonwords is faster than responding to unrelated words was replicated in a picture-naming study of Lupker (1979, 1982). Recall that in the first-letter-naming task it was observed that responding to unpronounceable nonwords was slower than in case of pronounceable nonwords, and that responding to pronounceable nonwords, in turn, was slower than in case of words.

Thus, in general, it occurs that in these modified Stroop-interference tasks effects are observed that point in the opposite direction from the effects obtained in the first-letter-naming task.

The standard explanation of both the Stroop and picture-word interference phenomena has focused on response competition processes (e.g., Klein, 1964; Lupker, 1979; see also Lupker, 1982; MacLeod, 1991). The idea is that when the subject is processing the relevant dimension, he or she is also processing the word (note the similarity with the response-competition hypothesis regarding first-letter naming). Because words are read faster than colours or pictures are named, the word's name will become available before the name of the relevant input. This creates a situation where the word's name will occupy a pre-eminent position in a limited-capacity response channel that is assumed to handle only one potential response at a time. In order to produce the required response the subject must clear this channel by suppressing the tendency to name the word - a process that is time consuming.

The suppression of the tendency to say a word does appear to be sensitive to factors that affect the strength of this tendency. Nonwords would not be expected to produce the same tendency towards pronunciation as normal words (see Lupker, 1982). Thus this could explain the finding that nonwords produce less interference in colour or picture naming than words (e.g., Bakan & Alperson, 1976; Guttentag & Haith, 1978; Lupker, 1982). Returning to the first-letter-naming task, observing that nonwords produce *more* interference than words in first-letter naming (see Discussion Section of Experiment 2) would thus suggest, in terms of this Stroop account, that the tendency to name pronounceable (and unpronounceable) nonwords would be *stronger* than the tendency to name words. To us this notion does not really make sense. It nevertheless illustrates that a general Stroop framework may be inappropriate to account for first-letter-naming effects.

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Table 7

Statistical summary of first-letter-naming studies in which performance on words is compared to that on legal nonwords. The second and third column show mean first-letter-naming RTs in ms.

Experiment	Word	Legal NW	t	df	one-tailed p	-2LOGeP
B&G* Experiment 1.1	465	469	1.342	19	.0976	4.65
B&G Experiment 1.2	508	518	1.418	19	.0862	4.9
B&G Experiment 2	515	517	.497	19	.3126	2.33
Exp 1	454	457	1.334	19	.099	4.63
Pilot a	433	438	2.725	19	.0067	10.01
Pilot b	436	441	2.325	19	.0156	8.32
Pilot c	438	443	1.759	19	.0473	6.1

* Bosman & de Groot (1995)

Table 8

Proportion of first-letter-naming trials excluded from the data. Column I shows the proportion of extremely slow responses (more than 3 SD above the mean), Column II the proportion of extremely fast responses (less than 100 ms), Column III the proportion of errors due to voice-key failure, and Column IV shows the proportion of naming errors.

		I	II	III	IV	Total
Experiment	1	.011	.000	.019	.000	.030
	2	.006	.000	.029	.000	.035
	3A	.008	.000	.027	.001	.036
	3B	.005	.000	.027	.000	.032
	3C	.010	.000	.017	.023	.050
	3D	.007	.000	.012	.002	.021

Appendix A

Stimuli Experiment 1

Word		Legal Nonword		Illegal Nonword	
brief	baard	broog	balgs	bdaal	brewr
bloem	beurt	blark	beern	btuns	blakl
draad	doorn	droos	doers	dkral	dripm
dicht	droom	dirst	dreip	dvlit	dinkb
laars	lijst	laaps	limst	lmsin	lapdf
lucht	loops	lunks	lorch	lpuuk	lurtl
markt	maand	marfs	mauks	mstup	mabsg
meeuw	meest	meesp	mernt	mzort	merkr
naald	nieuw	naalm	niemp	ntlei	natmw
nacht	niets	naups	nirch	nborf	nalpr
plant	plots	plood	pleek	pklirs	plodg
prins	paars	pralk	paarp	pbijp	prupv
recht	roest	reemt	roops	rmsal	reljw
rijst	raaks	rienk	ralst	rklij	rizlr
traan	tocht	trijp	toorp	tbluk	trepl
taart	trein	taafs	trijf	tmwag	taptr
vlees	voorn	vloem	vorps	vmerf	vlifg
vraag	vocht	vrast	voeng	vtark	vrakb
woord	wacht	wopst	waarf	wkeup	wonpl
wraak	wrang	wruuk	wried	wprap	wraln

Appendix B

Stimuli Experiment 2

Letter	Word	Characters: Same	Characters: Different
b	boek	b###	b&#§
f	feit	f###	f#§¥
h	huis	h$$$	h§¥Δ
k	kind	k$$$	k¥Δ$
m	mooi	m¥¥¥	mΔ$&
n	naam	n¥¥¥	n$&#
p	paar	pΔΔΔ	p&#¥
v	vast	vΔΔΔ	v#§$
w	week	w&&&	w§¥&
z	zaak	z&&&	z¥Δ#
b	baai	b§§§	bΔ$§
d	duit	d§§§	d$&Δ
f	fort	f###	f&§¥
g	gaai	g§§§	g#Δ&
h	honk	h¥¥¥	h§$#
k	keet	kΔΔΔ	k¥&Δ
l	lans	l&&&	lΔ#§
m	moer	m$$$	m$¥&
r	raap	r###	r§¥&
v	valk	v&&&	v&#§

Appendix C

Stimuli Experiment 3A and 3B

Words: High-frequency		Low-frequency	
boek	bank	boei	baai
doel	dier	doop	duit
feit	film	fort	fuif
gang	golf	gaai	gift
hoop	huis	honk	huls
keer	kind	keet	kiel
kerk	kort	korf	kuis
last	lijn	lans	lies
maal	mooi	mais	moer
naam	norm	naad	nors
paar	pijn	part	pier
paus	punt	pauw	port
raam	raad	raap	rasp
rond	reis	roes	rein
rood	rust	romp	ruig
voet	vast	vonk	vaal
vorm	vuur	vork	valk
week	warm	waan	wiek
wens	wijn	waas	wier
zorg	zaak	zink	zoom

Appendix D

Stimuli Experiment 3C

CVC	CVC	CVCC	CCVC
beer	baas	bars	brok
bier	boer	bord	blok
dijk	doos	dorp	drop
doel	daad	dans	drum
fooi	faam	fats	fles
feit	fout	fors	flat
gauw	goud	golf	gras
geit	gaar	gast	glas
kaak	keel	kern	krap
koud	koek	kost	klas
paal	paus	pand	pril
peil	poot	post	plek
saai	sein	sets	stuk
soos	soep	soms	slot
teen	taal	tank	trap
toer	tuin	tulp	trek
veer	vies	vink	vrek
vuur	voet	vork	vlak
wees	wijn	wind	wrak
wiel	waar	wand	wrok

Appendix E

Stimuli Experiment 3D

Single Cluster: Long	Single Cluster: Short	Double Cluster: Long	Double Cluster: Short	Mixed Cluster: Long	Mixed Cluster: Short
antal	ant	aabat	aab	aufol	auf
argen	arg	aatun	aat	aulin	aul
astep	ast	aafor	aaf	audel	aud
arpel	arp	aamer	aam	aupo	aup
aspor	asp	aades	aad	aukir	auk
elgol	elg	eebes	eeb	eumi	eum
ersur	ers	eepan	eep	eufis	euf
epsul	eps	eekos	eek	eulun	eul
erpos	erp	eesin	ees	eugap	eug
estur	est	eegil	eeg	eukon	euk
ostal	ost	oosup	oos	outen	out
orpar	orp	oober	oob	oufop	ouf
olfot	olf	oopit	oop	oukar	ouk
orgup	org	ooful	oof	oupap	oup
orfil	orf	oolus	ool	oulop	oul
ulsut	uls	uufut	uuf	uikis	uik
urpas	urp	uumep	uum	uipon	uip
ustet	ust	uudet	uud	uisus	uis
urgip	urg	uunip	uun	uifan	uif
urmas	urm	uutit	uut	uidat	ui