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The Locus of Length Effects in Visual Word Recognition

by

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A Thesis

submitted to the Faculty of Graduate Studies and Research

in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

Department of Psychology

Carleton University

Ottawa, Ontario

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Fred Lichacz

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ABSTRACT

The purpose of the present research was to assess the locus of length effects associated with the pronunciation of visually presented words and nonwords. Length was defined as the number of letters that comprise a letter string. Four experiments were conducted, all of which used an online naming task. The first two experiments showed that length does not affect the initial encoding stage of the word recognition system for either words or nonwords. However, Experiment 1 did show that length affects lexical access as observed through a length x frequency interaction with word stimuli. That length affects lexical access was further supported by interactions between length and word frequency and length and stimulus format in Experiment 3 with word stimuli. In Experiment 4, length interacted with stimulus format when nonwords were used. The results of these experiments support the assertion that length affects lexical access. These findings were interpreted within Norris' (1994, Herdman, Chernecki, & Norris, in press) multiple-levels model of word recognition.

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Introduction

For over 100 years (see Huey, 1908), researchers involved in the study of visual word recognition have known that responses are longer and more error prone to words that are long as compared to words that are short. This effect of length has been observed in naming tasks (Balota & Chumbley, 1984, Experiment 3; Bruyer & Janlin, 1989; Butler & Hains, 1979, Experiment 1; Forster & Chambers, 1973; Frederiksen & Kroll, 1976, Experiment 1; Iacoboni & Zaidel, 1996; Jared & Seidenberg, 1990; Mason, 1978; Mason, Pilkington, & Brandau, 1981, Experiment 1; McGinnies, Comer, & Lacey, 1952; Postman & Adis-Castro, 1957; Richards & Heller, 1976; Seidenberg & McClelland, 1989; Spoehr & Smith, 1973; Young & Ellis, 1985), lexical decision tasks (Balota & Chumbley, 1984, Experiment 2; Butler & Hains, 1979, Experiment 2; Forster & Chambers, 1973; Frederiksen & Kroll, 1976 (nonwords only); Whaley, 1978), and word classification and category verification tasks (Balota & Chumbley, 1984, Experiment 1; Terry, Samuels, & LaBerge, 1976, Experiment 1; Whaley, 1978). Despite these findings, most theorists have not included a role for length in their models of visual word recognition.

There are two (related) reasons why length has been ignored by theorists in the word recognition literature. First, theorists have focused primarily on accounting for how experiential factors, such as word frequency, affect the representation and accessing of lexical knowledge. From a historical perspective, this focus on experiential variables makes sense: The early and influential models of word recognition (e.g., Morton, 1969) were formulated at a time when much of the human experimental research was oriented toward examining the relations between frequency of exposure and learning. Second, by default, most researchers likely view length as

a pre-lexical variable that affects processing in an early encoding stage. Insofar as researchers are concerned with modelling lexical processing (i.e., the representation and accessing of word knowledge), variables that influence encoding are of limited theoretical interest. As described below, however, it is not altogether clear whether the effects of length are isolated to encoding or whether length affects lexical access. Accordingly, the present research was designed to determine the locus of length effects in the word recognition system. Over the past several years, most new and revised models of visual word recognition have been designed to explain performance in tasks that involve phonological coding. For this reason, although length effects in tasks such as lexical decision and category verification are discussed, the primary focus of the present research is on length effects in naming tasks where the accessing and generation of phonology is explicit.

Defining Length

Researchers have employed three different indices of length: number of letters (Balota & Chumbley, 1984; Butler & Hains, 1979; Forster & Chamber, 1973; Frederiksen & Kroll, 1976; Richardson, 1979; Weekes, 1997; Whaley, 1978), number of phonemes (Weekes, 1997; Whaley, 1978), and number of syllables (Balota & Chumbley, 1984; Butler & Hains, 1979; Eriksen, Pollack, & Montague, 1970; Richardson, 1979; Whaley, 1978). Across all three indices of length, recognition latencies increase as the number of letters, phonemes, and syllables increase. Not surprisingly, the three indices are highly correlated. As noted below, however, for naming latencies, there is a trend toward number of letters being a better predictor than number of phonemes or number of syllables.

In a comparison between the effect of number of letters and number of syllables on word naming, Forster and Chambers (1973) and Richardson (1979) demonstrated that only number of letters had a significant effect on naming latencies. Butler and Hains (1979) showed that number of letters accounted for a larger proportion of variance in both a word naming task and lexical decision task than number of syllables. Similarly, Balota and Chumbley (1984) showed that number of letters, not number of syllables, was a predictor of response latencies in naming, lexical decision and category verification tasks and Young and Ellis (1985) demonstrated that number of letters was better than number of syllables in predicting pronunciation errors. Interestingly, Whaley (1978) showed that although number of letters was a better predictor than number of syllables for nonword naming latencies, number of syllables was the better predictor of word naming latencies. However, Whaley also found that number of letters was a better predictor than number of phonemes for both word and nonword naming latencies. Weekes (1997) corroborated Whaley's findings with nonword items. Weekes showed that although number of letters did not account for a significant proportion of variance in a word naming task, number of letters did account for a significant proportion of variance in a nonword naming task; number of phonemes did not account for significant proportions of variance in either the word and nonword naming tasks.

In sum, although not perfectly unequivocal, research suggests that in both word (except Whaley, 1978) and nonword naming, number of letters is a better predictor of performance than number of syllables and number of phonemes. Accordingly, researchers have traditionally accounted for length effects in terms of the sequential processing of letters (Besner, 1996; Coltheart, 1978; Coltheart, Curtis,

Atkins, & Haller, 1993; Coltheart & Rastle, 1994; Frederiksen, 1981; Paap & Noel, 1991; Weekes, 1997).¹ By this account, recognition latencies are directly related to the number of letters in a word. This letter-based account, however, does not specify either an encoding or a lexical locus for length effects in the word recognition system.

Stages of Processing, Processing Variables, and Length

The word recognition system can be broadly divided into three stages of processing: encoding, lexical access, and response output (Meyer, Schvaneveldt, & Ruddy, 1975). Length may influence processing in any one or more of these stages. In order to isolate length effects to a particular stage, additive factors logic (Sternberg, 1969) can be used. In accord with additive factors logic, variables that affect different stages should have additive effects on performance whereas those affecting the same stage should have interactive effects. In the present research, additive factors logic was used (a) to assess previous findings concerning the locus of length effects in the word recognition system and (b) to combine length with variables believed to affect either encoding or lexical access.²

Encoding

Stimulus Quality and Encoding. The role of encoding is to extract the sensory features (e.g., lines, angles, curves) of incoming letter strings in order to activate corresponding lexical representations (Becker, 1976, 1980, Becker & Killion, 1977; McClelland & Rumelhart, 1981; Morton, 1969; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Rumelhart & McClelland, 1982). The efficiency with which encoding occurs is mediated by stimulus quality (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Hughes, Layton, Baird, & Lester, 1984; Meyer et al., 1975; Schmitter-Edgecombe, Marks, Fahey, & Long, 1992; Stanners, Jastrzembski, &

Westbrook, 1975). Degrading the stimulus quality of letter strings (e.g., presenting letter strings in low-illumination intensity or superimposed with a random dot pattern) has two main effects on encoding: 1) to decrease the rate of feature extraction, thereby slowing the overall speed with which a letter string is encoded, and 2) to render the sensory features ambiguous, thereby decreasing the accuracy of feature extraction.

Evidence supporting the claim that encoding is mediated by stimulus quality is found in studies showing that stimulus quality is additive with variables believed to influence lexical access: word frequency (see discussion about lexical access and word frequency below) and regularity. In both naming and lexical decision tasks, stimulus degradation slows responses to high- and low-frequency words equally (Becker & Killian, 1977; Besner & Chapnik Smith, 1992; Herdman, Chernecki, & Norris, in press; Meyer et al., 1975; Stanners et al., 1975). Similarly, stimulus degradation slows naming of regular and irregular words equally (Herdman et al., in press). Because stimulus quality is additive with both frequency and regularity, researchers have postulated that the effects of stimulus quality are pre-lexical and isolated within the encoding stage.

Length and Encoding. To date, two studies have provided evidence suggesting that length influences processing prior to lexical access. However, the question of whether length influences encoding has not been directly tested.

According to Butler and Hains (1979), "word length may be restricted to the stage at which the visual features are recoded into a functional stimulus for lexical retrieval" (p. 75). This claim was based upon their observation that length (i.e., number of letters) and word frequency were additive in both word naming and lexical

decision tasks. Although Butler and Hains do not specifically identify the encoding stage as the locus of length effects, they do infer a pre-lexical locus of length effects. However, Butler and Hains did not directly test whether word length affects encoding in that they did not combine length with a variable believed to affect encoding (e.g., stimulus quality). In fact, one could make the equally plausible claim that length has a post-lexical effect (e.g., response output).³ Moreover, the notion that length exerts an effect during encoding is challenged by Terry et al. (1976, Experiment 1) who found that length was additive with stimulus quality.

Terry et al. (1976, Experiment 1) used a category-verification task to examine the effects of stimulus quality and length on response latencies. Two manipulations of stimulus quality were used (1) mirror image transformation, and (2) deleting portions of letters in a word. Their results yielded main effects of stimulus quality and word length, and an interaction between length and stimulus quality. However, length effects were only observed when words were presented in mirror image format. Length did not influence response latencies when stimulus quality was degraded by deleting portions of the target words' letters. It is likely, however, that the mirror image manipulation influenced processing beyond the encoding stage. Mirror image transformations maintain the sensory features of the letters in words: Although the letters appear in their mirror image, the lines, curves, and angles of the letters do remain intact. This is similar to the situation where words are presented in case-alternated format. Thus, it may be more appropriate to characterize words presented in mirror image transformations in terms of a change in stimulus format rather than a change in stimulus quality. On this view, the interaction between length and mirror image presentation in Terry et al.'s study suggests that length influences lexical

access. Terry et al.'s letter deletion condition is a more pure manipulation of stimulus quality because deletion degrades the sensory features such that letters become ambiguous, as has been demonstrated when the stimulus quality of a word is impaired by a superimposed random dot pattern. The additivity between length and letter deletion found by Terry et al. suggests that length does not influence processing during encoding.

A second concern with the Terry et al. (1976) study is that the effects of length may have been mediated by a semantic component of the categorization task. Researchers (Balota and Chumbley, 1984, Balota, Ferraro, & Connor, 1991) have postulated that a binary decision stage, a component of semantic tasks, is responsible for mediating the effects of orthography as compared to tasks that do not (necessarily) require semantic processing (e.g., naming). It is possible, therefore, that had Terry et al. used a task such as word naming, a different pattern of length effects would have emerged.

In sum, firmly locating length effects in an encoding stage cannot be made based on the findings of Butler and Hains (1979) and Terry et al. (1976, Experiment 1). Butler and Hains suggested that length influences encoding, but did not directly test for interactions between length and other variables known to affect encoding. Terry et al.'s results may have been confounded by the stimulus quality/format manipulations and task that they used. In fairness to these researchers, the Butler and Hains, and Terry et al. research was not specifically designed to isolate the locus of length effects to encoding.

Lexical Access

Lexical access is a generic term that has been used to refer to the second stage in the word recognition system whereby a word accesses its orthographic, phonological, and semantic dimensions. It is important to acknowledge that although lexical access is integral to virtually all models of word recognition, the specific use of this term differs according to one's theoretical view. For example, dual-route theorists adhere to the term lexical access because they believe that words can be stored and retrieved as whole-word representations (Coltheart, 1978; Paap, McDonald, Schvaneveldt, & Noel, 1987; Paap & Noel, 1991). In contrast, parallel-distributed-processing (PDP) theorists reject the term lexical access because of their belief that the word recognition system does not store and retrieve words as distinct whole-word representations (Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Instead, PDP theorists postulate that all lexical stimuli are represented as patterns of activation across sublexical orthographic, phonological, and semantic attributes. For the present purposes, the term lexical access is used to indicate the stage in word recognition where a letter string's orthographic, phonological and semantic dimensions are activated.

Word Frequency and Lexical Access. Researchers have demonstrated that words appearing more frequently in written English (e.g., told) are responded to faster and more accurately than words that appear less frequently (e.g., fold) (Balota & Chumbley, 1984, 1985; Forster & Chambers, 1973; Frederiksen & Kroll, 1973; Rubenstein, Garfield, & Millikan, 1970). Because word frequency has been shown to be additive with stimulus quality (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Stanners et al., 1975) and little evidence exists for the claim that frequency mediates processing during output (Lichacz & Herdman, 1995, McRae, Jared, &

Seidenberg, 1990; Monsell, Doyle, & Haggard, 1989), researchers generally assume that word frequency influences lexical access. The ubiquitous nature of this assumption is embodied within virtually all models of lexical access (Coltheart, 1978; Coltheart et al., 1993; Coltheart & Rastle, 1994; Forster, 1976; Morton, 1969; Norris, 1994; Paap et al., 1987; Paap & Noel, 1991; Plaut et al., 1996; Seidenberg & McClelland, 1989).

The manner in which word frequency is believed to influence lexical access is mediated by one's theoretical view. For example, lexical search adherents (Becker, 1976, 1980; Becker & Killian, 1977; Forster, 1976; Paap et al., 1982) view the word-frequency effect as a frequency-ordered search from high- to low-frequency words from a set of candidate target words. In activation models (e.g., Morton, 1969), word frequency mediates the amount of information that must be accumulated by representations for word recognition to occur; less information is required for high- than for low-frequency words. In the multiple-levels model (Norris, 1994), high-frequency words benefit from activation at a lexical level whereas low-frequency words must rely more on sublexical information. Parallel-distributed-processing theorists (Plaut et al., 1996; Seidenberg & McClelland, 1989) suggest that word frequency mediates connections between orthographic and phonological units such that stronger, more stable connections are associated with high- than low-frequency words. Despite the differences in approach, all of these theorists postulate that word frequency affects processing during lexical access.

Length and Lexical Access. The literature on the effects of length on lexical access is larger than the aforementioned literature examining length effects during encoding. However, the studies examining length effects in lexical access are fraught

100 per million occurrences in the Thorndyke-Lorge (1944) word count. Subjects performed the recognition threshold task on half of the words on one day (Day 1) and on the rest of the words on the next day (Day 2). An effect of frequency was observed only on Day 2. There was no effect of length nor an interaction between frequency and length on either day. According to Dogget and Richards, the lack of effects, specifically the effect of length, may have been due to their subjects being of high-verbal ability (subjects were third and fourth year college students). To test this, Dogget and Richards (Experiment 2) had first year college students (presumed to be of lower verbal ability relative to the upper year students) perform a recognition threshold task with the low-frequency words of the study. Although there was a trend toward an effect of length, the effect was not statistically significant. Therefore, even when taking reading ability into account, the Dogget and Richards' findings suggest that word length does not influence lexical access.

As with the earlier studies of McGinnies et al. (1952) and Postman and Adis-Castro (1957), conclusions about the locus of length effects based on Dogget and Richards' (1975) study must be made with caution. It is disconcerting that with a word length range of 3-11 letters there were no significant effects of length nor robust effects of word frequency. Although Dogget and Richards (1975) claimed that the lack of length effects may have been due to the high-verbal ability of the subjects, they did not provide any relevant information about the stimuli (e.g., syllables, onset) beyond length and frequency that may have attenuated any potential length effects and the null effect of word frequency on Day 1 of their study. Furthermore, if the subjects in this study were predominantly high-verbal subjects (verbal ability was not measured), it is not surprising that Dogget and Richards obtained null effects of word

frequency (on Day 1) (Lichacz & Herdman, 1995; Marr & Kamil, 1981; Mason, 1978; Richards & Platnik, 1974; Spielberger & Denny, 1963; Waters, Seidenberg, & Bruck, 1984) and length (Mason, 1978; Mason et al., 1981). However, given previous research that has examined verbal ability, if the subjects in Experiment 2 were of low-verbal ability, then these subjects would have been expected to have demonstrated larger and statistically significant effects of word frequency (Lichacz & Herdman, 1995; Marr & Kamil, 1981; Mason, 1978; Spielberger & Denny, 1963; Waters et al., 1984) and length (Butler & Hains, 1979; Mason, 1978; Mason et al., 1981). Thus, with a potentially confounded set of stimuli and a possibly high-verbal group of participants used by Dogget and Richards in both experiments, it is difficult to make a clear and general inference about the locus of length effects from their research.

Using a standard naming task, Mason (1978, Experiment 3) observed an effect of length with words of four and six letters in length. However, Mason did not observe the ubiquitous word frequency effect nor an interaction between length and frequency. The lack of these effects may have resulted from Mason's use of an unconventional index of word frequency: single-letter spatial redundancy. This measure of frequency may not be as sensitive to word experiences as the more relied upon frequency measures where frequency is determined by the number of times a word occurs in print (see Carroll, Davies, & Richman, 1971; Kucera and Francis, 1967; Thorndyke & Lorge, 1944). With this in mind, Mason observed essentially the opposite findings from those observed by Dogget and Richards (1975). Whereas Dogget and Richards found some weak evidence for an effect of frequency and no evidence for an effect of length for words ranging from 3 to 11 letters, Mason had no

evidence of an effect of frequency and a significant effect of length between words of four and six letters. Consistent in each study, however, was the null interaction between length and frequency. As noted, however, Mason's findings may be compromised by the index of frequency that was used and the findings of Dogget and Richards are plagued by potential problems of stimulus set and verbal ability of their subjects.

Frederiksen and Kroll (1976, Experiment 1) found main effects of both length (four to six letters) and frequency (see Kucera & Francis, 1967) in an online naming task but no interaction between the two variables. In their second experiment in which they used a lexical decision task, Frederiksen and Kroll observed a large effect of frequency, no effect of length, and no interaction between the two variables. According to Frederiksen and Kroll, length does not affect lexical decision performance because this task is sensitive to whole word attributes (e.g., frequency) and not sublexical information (e.g., constituent letters). For Frederiksen and Kroll, the naming task represents a measure of sublexical processing. Because length had a significant effect on naming latencies, their findings led them to conclude that length can influence any stage of processing that utilizes sublexical information.

Butler and Hains (1979), suggested that Frederiksen and Kroll (1976) did not observe an effect of length in lexical decision because their range of word length (four to six letters) was too small to be detected using a lexical decision task. To test this, Butler and Hains used a set of words that ranged in length from 2-14 letters. In their first experiment using an online naming task, Butler and Hains replicated the findings of Frederiksen and Kroll (1976, Experiment 1), that is, they observed main effects of length and frequency but no interaction between the two variables. However, using a

lexical decision task, Butler and Hains found both main effects of length and frequency and no interaction between length and frequency. Because the slope of the length effect was similar in the naming and lexical decision tasks, and because length did not interact with frequency, Butler and Hains postulated that the effect of length on word recognition must reside in a stage of the word recognition process independent from lexical access and response preparation: encoding. Unfortunately, Butler and Hains did not test this hypothesis directly by combining length with a variable believed to influence encoding.

The lexical decision results observed by Frederiksen and Kroll (1976) and Butler and Hains (1979) (see also Balota & Chumbley, 1984) must be interpreted with caution. The lexical decision task has long been used to study the effects of different variables on lexical access. Recently, however, there have been challenges to the utility of the lexical decision task (and other semantic tasks such as category verification) as an effective tool for studying lexical access (Balota & Chumbley, 1984; Balota et al., 1991; Monsell, 1991). According to these researchers, the lexical decision task contains an extra processing stage (absent in the online naming task) that may exaggerate effects of variables such as word frequency. This extra stage of processing involves making a binary decision about the lexicality of a letter string; is the letter string a word or a nonword? It has been demonstrated that this decision stage is influenced by semantic properties of words (e.g., number of meanings, familiarity) and that this semantic information may exaggerate effects in the lexical decision task (Balota et al., 1991). It is plausible, however, that not controlling for certain semantic properties of words could also attenuate the effects of different variables as well. Monsell (1991) demonstrated that high-frequency words tend to

possess more meanings than low-frequency words. Thus, part of the frequency effect observed in the lexical decision task may be due to confounding with the semantic variable, number of meanings. Furthermore, because word frequency represents a kind of familiarity judgement (Monsell, 1991), observed frequency effects in the lexical decision task may be artifactual of a familiarity variable. In studies that have found significant length effects in lexical decisions (e.g., Butler & Hains, 1979; Balota & Chumbley, 1984), the researchers did not report whether their stimuli were matched for semantic properties such as number of meanings and familiarity. According to Campos and González (1992), there is a negative correlation between word length and semantic variables. Campos and González have demonstrated that longer nouns are associated with lower ratings of imagery, concreteness, emotionality, and meaningfulness than short nouns. These ratings of imagery, concreteness, and emotionality have been replicated even when the meaning of words is controlled. Thus, it is possible that any significant or null effect of length reported from lexical decision tasks are artifacts of confounding semantic attributes of their stimuli.

As mentioned above, the findings from Terry et al. (1976, Experiment 1) provide some evidence that length may influence processing during lexical access in that length interacted with stimulus format (i.e., mirror-image transformations). Given previous findings that have shown that stimulus format (i.e., case alternation) interacts with word frequency in naming tasks (Besner, Davelaar, Alcott, & Parry, 1984; Besner & McCann, 1987; Herdman et al., in press), signifying that these two variables influence the same stage of processing (i.e., lexical access), we can infer from the interaction between length and stimulus format observed by Terry et al., that length also influences lexical access. However, given the problems associated with

using a semantic task (e.g., category verification) to study the effects of variables on lexical access and the tenuous strength of mirror-image transformations as a stimulus format manipulation, it is difficult to draw firm conclusions about the relation between length and lexical access from the Terry et al. research.

To summarize, the small body of research examining the relation between length and lexical access suggests that length does not affect processing during lexical access. Of the nine experiments discussed, six experiments (Butler & Hains, 1979, Experiments 1 & 2; Dogget & Richards, 1975; Frederiksen & Kroll, 1976, Experiments 1 & 2; Mason, 1978, Experiment 3) yielded additive effects of length and frequency, two experiments (McGinnies et al., 1952; Postman & Adis-Castro, 1957) reported interactive effects between length and frequency, and one experiment (Terry et al., 1976, Experiment 1) showed an interaction between length and stimulus format. However, these experiments can be challenged on the basis of small stimulus set size (McGinnies et al., 1952; Postman-Adis, 1957), uncontrolled phonological and semantic variables (McGinnies, et al., 1952; Balota & Chumbley, 1984, Experiments 1 & 2; Frederiksen & Kroll, 1976, Experiment 2), index of word frequency (Mason, 1978), verbal ability (Dogget & Richards, 1975), and task validity (Balota & Chumbley, 1984, Experiments 1 & 2; Butler & Hains, 1979, Experiment 2; Frederiksen & Kroll, 1976, Experiment 2).

Case Alternation and Lexical Access. Virtually every model in the word recognition literature has been designed to account for the fact that processing is faster to high-frequency than to low-frequency words (For an exception see Masson, 1991, 1995, and also Borowsky & Masson, 1996). For example, in localist models, frequency is assumed to either affect the level of activation of word entries in the

lexicon (e.g., Morton, 1969) or the verification/search (e.g., Paap et al., 1982) of a set of entries. In connectionist models (e.g., Plaut et al., 1996; Seidenberg & McClelland, 1989), frequency is assumed to affect the weights of connections between layers in a distributed system. Another variable that is also believed to affect lexical access, but which cannot be easily incorporated into all models, is case alternation.

Words that are presented in case alternated format are named slower than words presented in lower-case format (for review see Mayall & Humphreys, 1996). Evidence that case alternation affects lexical access comes from McCann and Besner (1987) who found an interaction between case alternation and word frequency: Presenting words in case alternated format slowed naming more to low- than to high-frequency words. This finding was replicated and extended by Herdman et al. (in press) who found a three-way interaction between case alternation, frequency, and regularity. In the Herdman et al. study, case alternation slowed naming equally to low-frequency regular and irregular words. For high-frequency words, however, the effects of case alternation were greater for irregular than regular items.

The fact that case alternation interacts with lexical (network) factors is very problematic for PDP theory (Plaut et al., 1996; Seidenberg & McClelland, 1989) because in connectionist models the orthographic-input layer is an abstract representation of letter strings: Whether a word is presented in lower-, upper-, or mixed-case format cannot affect processing at the input layer. In accord with a PDP approach, therefore, the disruptive effects of case alternation are presumably located in a pre-network stage and thus should not interact with frequency and/or regularity. A dual-route approach also does not provide a full account of case alternation effects on word processing. For example, on the assumption that case alternation primarily

slows processing along the lexical route via disruption of whole-word patterns (see Besner, 1990), processing should be slowed more to low-frequency irregular words than to low-frequency regular words: This pattern was not found in the Herdman et al. study. Interestingly, as discussed below, incorporating the assumption that case alternation disrupts whole-word processing into Norris' (1994) multiple-levels model provides an account that closely matches the human data. Because Norris' approach can be used to account for case alternation effects while also providing a complete account of frequency and stimulus quality effects, the multiple-levels model is used as the theoretical framework for the present research.

Theoretical Approach

The multiple-levels model of word recognition proposed by Norris (1994) represents a computational extension of the original dual-route model (Coltheart, 1978). The dual-route model is comprised of a fast, visually addressable lexical-route and a slower sublexical, assembly-route. The multiple-levels model is also comprised of a lexical route, but contains five sublexical levels which correspond to various orthography-to-phonology correspondences (OPCs). These different levels conform to a letter string's initial consonant cluster, vowels, final consonant clusters, initial cluster plus vowel (CV), vowel plus final cluster (body), and whole-word representations (the lexical level).

The architecture of the multiple-levels model consists of two layers of processing nodes. The bottom layer contains nodes for the different levels of orthographic input units and the top layer contains the corresponding phonological output units. The connection weights between the input and output units are based on a system of mapping rules that are specific to the various OPCs rather than a single

learning algorithm for all inputs (see Plaut et al., 1996). The connection weights are determined by the size of the orthographic units and the frequency with which orthographic units are used. If the pairing of the orthographic unit and its pronunciation have not been encountered before, it is added to the list of rules when encountered. If the rule has been encountered before, then the frequency of the rule is updated. Furthermore, the representations in this model are not viewed as distributed patterns of activity, but instead, are perceived as local representations of orthographic and phonological structure.

To generate a pronunciation, output from the different levels combine to inhibit and reinforce conflicting and similar outputs, respectively, until a specified amount of phonological information exceeds a critical threshold level. For any one pronunciation to be generated, its phonological output must exceed any competing pronunciation by a certain margin in order to provide the least ambiguous pronunciation from a set of competing phonological units. This process of generating a pronunciation has allowed Norris' (1994) model to achieve success in simulating a subset of the word naming data such as word frequency, regularity, the interaction between frequency and regularity, and some aspects of nonword naming.

Similar to dual-route theory, word-level information within the multiple-levels model facilitates the processing of high-frequency words: For high-frequency words, the activation of word-level information dominates the activation process, thereby producing a fast naming response which is minimally influenced by sublexical activation and thus is insensitive to regularity. For low-frequency words, activation at the word level will be weak and sublexical information will play an important role. If the low-frequency word is irregular, then competing outputs among the sublexical

levels will take longer to resolve than for low-frequency, regular words. That sublexical information does not play much of a role in the processing of high-frequency words is reflected in the fact that high-frequency words do not show regularity effects on naming tasks.

Norris' (1994) model has also had success simulating nonword naming. According to Norris, nonword naming is achieved by parsing the letter string into the various levels of OPCs one level at a time from the largest to the smallest units until an appropriate pronunciation is achieved. This belief is rooted in the findings of other theorists (Paap & Noel, 1991; Shallice & McCarthy, 1985; Shallice & Warrington, 1980; Shallice, Warrington, & McCarthy, 1983) who have postulated that individuals utilize various perceptual units of analysis to process words. Norris does acknowledge that this processing procedure is not the optimal way of processing nonwords because of its 'rigid sequential decision process' (p. 1216), but it **nevertheless** provides a simple account of nonword naming.

A number of plausible explanations have been put forth to account for the influence of case alternation on naming latencies (for discussions see Herdman et al., in press; Mayall & Humphreys, 1996). Most theorists have postulated that case alternation disrupts the use of lexical (whole-word) information more than sublexical information. Herdman et al., have extended this perspective by asserting that case alternation disrupts the integrity of the inter-letter patterns of holistic units (i.e., lexical information) which diminishes the contribution of lexical-level information to word processing and forces the word processing system to rely more on sublexical information. As mentioned earlier, Herdman et al. predicated this perspective based on a three-way interaction between case alternation, word frequency, and regularity

on naming latencies where case alternation and frequency had interactive effects with regular words but were additive with irregular words.

According to Herdman et al. (in press), diminishing the contribution of lexical-level information to the processing of the high-frequency regular words had little effect on naming latencies because the sublexical information is consistent enough to allow naming latencies for these words to remain similar to when lexical information can be used. For low-frequency regular words, the increase in naming latencies in the case-alternated condition revealed that, although to a lesser degree, low-frequency words do rely on lexical information. When this lexical-level information is diminished via case alternation, these words must rely entirely on sublexical information which slows down processing time relative to when lexical-level information can be used. In contrast to the high-frequency words, complete reliance on sublexical information for processing is slower for the low-frequency words.

Under normal presentation format (i.e., lower-case letters), naming high-frequency irregular words is based predominantly on lexical-level information. When the contribution of lexical-level information is diminished, processing must rely on sublexical information which generates regular pronunciations. Consequently, more cycles are required to resolve the pronunciation than is required when lexical-level information is available. As with the pattern of naming latencies for high-frequency irregular words, the pattern of naming latencies associated with the low-frequency irregular words demonstrated that these words make use of lexical-level information: When the lexical-level information is diminished, naming latencies increase. Although the magnitude of the effect of case alternation remained stable across low-frequency regular and irregular words, the effect of case alternation was greater for

the high-frequency irregular than regular words. Thus, it was the differential effect of case alternation on high-frequency words that was the reason for the interactive and additive effects across regularity.

To test the hypothesis that case alternation influences naming latencies by mediating the contribution of lexical and sublexical information within the word processing system, Herdman et al. (in press) attempted to replicate the three-way interaction of case alternation, word frequency, and regularity on naming latencies within Norris' (1994) multiple-levels model. By simply modifying the model to diminish the role of lexical information, Herdman et al. were able to simulate the interactive pattern of effects between case-alternation, word frequency, and regularity on naming latencies. Thus, Herdman et al. were able to demonstrate that case alternation influences naming latencies by mediating the relative contribution of lexical and sublexical information during lexical access.

Present Research

To date, research has left us with an impoverished and unclear picture concerning the locus of length effects in word recognition. Evidence for length mediating processing in either encoding or lexical access has been sporadic, inconsistent, and sometimes flawed. In the present research, four experiments were conducted to examine length effects. In all of the experiments a naming task was used: Unlike lexical decision, word classification and word categorization tasks, naming does not require the use of a binary decision stage that is susceptible to semantic attributes of words (e.g., number of meanings, familiarity) and which may exaggerate the effects of orthographic variables (e.g., word frequency) (Balota & Chumbley, 1984; Balota et al., 1991; Monsell, 1991). As a control, delayed naming

tasks were used to isolate the effects of extraneous stimulus attributes (e.g., voicing) on response output that may confound online naming performance (see Balota & Chumbley, 1985; Monsell et al., 1989).

To assess the affect of length on the different stages of processing, length was factorially combined with variables believed to affect processing in either encoding or lexical access. Illumination intensity was used as the stimulus quality variable to examine processing during encoding. To index processing during lexical access, both word frequency and stimulus format (i.e., case alternation) were used.

Experiment 1

The primary purpose of Experiment 1 was to examine whether length (number of letters) affects the processing of words during encoding or during lexical access. To this end, length was factorially manipulated along with stimulus quality and word frequency. Researchers have demonstrated that stimulus quality, as manipulated using illumination intensity, influences processing during encoding (Becker & Killion, 1977; Besner & Chapnik Smith, 1992, Hughes et al., 1984; Meyer et al., 1975; Schmitter-Edgecombe et al., 1992; Stanners et al., 1975). In accord with additive factors logic, an interaction between length and stimulus quality would show that length affects processing during encoding. Additivity between length and stimulus quality would indicate that length does not affect encoding. On the assumption that word frequency influences processing during lexical access (Coltheart, 1978; Coltheart et al., 1993; Coltheart & Rastle, 1994; Morton, 1969; Paap et al., 1987; Paap & Noei, 1991; Plaut et al., 1996; Seidenberg & McClelland, 1989) an interaction between length and word frequency would show that length also influences lexical access. If, however,

the effects of length and word frequency are additive, this would provide evidence that length and frequency influence different stages of processing.

Method

Participants. Thirty first year psychology students from Carleton University participated to fulfil partial course credit. Participants had normal or corrected-to-normal vision and were fluent in the English language.

Stimuli. The 200 words used in this experiment are shown in Appendix 1. There were 100 high- and 100 low-frequency words chosen from the Kucera and Francis (1967) word counts. The high-frequency words have frequencies of 91 or more occurrences per million words and low-frequency words have frequencies of 10 or fewer occurrences per million words. Each group of high- and low-frequency words were comprised of an equal number ($n = 20$) of three, four, five, six, and seven letter words. Within each word-length group, the high- and low-frequency words were balanced for number of syllables, initial onset, orthographic neighbourhood size (N)⁴, and bigram frequency. Across each word-length group, the words were matched on initial onset and bigram frequency.⁵

Stimulus quality was manipulated using illumination intensity. Half of the words in each length group were presented in degraded stimulus quality (illumination intensity = 23.9 cd/m^2) while the rest of the words were presented in nondegraded stimulus quality (illumination intensity of 90.8 cd/m^2).⁶ Stimulus quality was counterbalanced across items and each participant received a different randomly ordered set of stimuli. In order to increase the contrast between the degraded and nondegraded conditions, participants were placed in a dark room (in a lit room, words presented in the low-illumination intensity were not visible on the monitor).

Apparatus. An IBM-type 80286 computer equipped with a Digitek Electronics input-output (I/O) board was used to present the stimuli on a Samsung model SM-12SFA7 monochrome video monitor and to record responses. Naming responses were detected using a Beyerdynamic DT109 boom microphone interfaced to a Soundblaster 8-bit audio card.

Procedure. All participants performed an online naming task condition followed by a delayed naming condition (see Herdman, LeFevre, & Greenham, 1994; Monsell et al., 1989). The delayed naming condition was included to control for extraneous stimulus attributes (e.g., voicing) on response output that may confound online performance. Participants were seated approximately 60 cm from the video monitor. At the start of each trial a fixation asterisk was presented centrally on the screen. Participants initiated trials using a micro-switch located on a three-key response panel. For the online naming task the asterisk was replaced by a word after a 600 ms delay. The participants were instructed to pronounce the word as quickly and as accurately as possible. The word remained on the screen until a response was detected. The experimenter entered a code into the computer indicating whether the word was pronounced correctly, incorrectly, or whether the trial was invalid due to apparatus failure or extraneous vocalizations.

For the delayed naming task, the fixation asterisk disappeared and was replaced 600 ms later by a word which remained on the screen for 250 ms. Following an interstimulus interval (ISI) of 1500 ms, a response cue (e.g., --> <-->) appeared centrally on the screen. The participants were instructed to prepare a naming response and upon seeing the arrow cues, to pronounce the word as quickly and as accurately as possible. The arrows remained on the screen until a response

was detected. The experimenter entered a code into the computer indicating whether the stimulus was pronounced correctly, incorrectly, too fast (i.e., before the arrow cue was presented), or whether the trial was invalid due to apparatus failure or extraneous vocalizations. In both the online and delayed naming tasks, each participant received 12 practice trials followed by the 200 experimental trials.

Results and Discussion

Means of the median response latencies for correct trials and percent errors for both the online and delayed naming tasks are shown in Table 1. In the online naming condition, 2% of the trials were coded as invalid whereas 4% of the delayed naming trials were coded as invalid. The latency and error data were analyzed separately.

Online Naming Latencies

Multiple Regression Analysis. Table 2 shows the intercorrelations among the variables for the online naming task. Number of letters was positively correlated with number of syllables and negatively correlated with N. Number of letters did not interact with frequency nor stimulus quality. These variables were entered into a multiple regression to determine whether length, as defined as number of letters, influenced naming latencies independent of N and number of syllables. This analysis was important because 1) N and number of syllables could not perfectly be matched across all stimulus groups, and 2) research has shown that number of letters is correlated with N (Weekes, 1997) and number of syllables (Butler & Hains, 1979). As shown in Table 3, number of letters, stimulus quality, and frequency accounted for significant proportions of variance. Neither N nor number of syllables accounted for a significant proportion of variance. Thus, the observed effects of length in this

Table 1

Mean Correct Latencies (in ms) and Percent Error (%Err): Experiment 1

	<u>High Frequency</u>				<u>Low Frequency</u>			
	<u>Norm-Illumin</u>		<u>Low-Illumin</u>		<u>Norm-Illumin</u>		<u>Low-Illumin</u>	
	RT	%Err	RT	%Err	RT	%Err	RT	%Err
Length	Online Naming							
three	620	0.3	717	0.6	677	2.0	823	6.6
four	622	0.0	704	1.0	701	4.6	821	4.0
five	649	0.3	727	0.3	712	3.0	817	5.3
six	663	0.3	726	0.6	754	1.6	841	6.6
seven	661	1.3	758	0.3	768	3.3	865	4.3
	Delayed Naming							
three	477	0.0	497	3.0	478	2.3	501	3.3
four	489	0.0	488	1.3	484	3.0	497	3.3
five	405	0.3	493	2.0	502	1.6	486	6.0
six	502	0.3	505	1.6	487	3.0	496	3.3
seven	483	0.0	492	0.3	493	2.3	501	3.3

Note. Illumin = Illumination and RT = Response Latency

Table 3

Regression Analysis for Online Naming Latencies: Experiment 1

Variable	B	SE B	β	t	Sig t
# Syllables	13.79	15.07	0.07	0.92	0.356
Stimulus Quality	49.31	6.80	0.28	7.25	0.000
Word Frequency	83.33	6.83	0.47	12.20	0.000
Neighbours	0.21	0.89	0.03	0.44	0.663
# Letters	16.15	7.03	0.26	2.29	0.022

$R^2 = .40$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

experiment were interpreted as reflecting number of letters.

ANOVA. Preliminary analyses revealed no significant effects of presentation order so the data were collapsed across this variable. Correct median latencies were analyzed in a 5 (Length) x 2 (Stimulus Quality) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the latency data (see Table 4) showed a significant effect of length where latencies increased with number of letters (see Figure 1). The overall magnitude of this length effect was 54 ms. There was also an effect of stimulus quality where responses were faster to words presented in the normal- than the low-illumination condition (683 vs 779 ms), and an effect of frequency whereby latencies were faster to high- than low-frequency words (685 vs 777 ms). Stimulus quality and word frequency were additive, thus replicating previous research findings (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Hughes et al., 1984; Meyer et al., 1975; Schmitter-Edgecombe et al., 1992; Stanners et al., 1975). None of the interactions were significant in the subjects analysis. For the item analysis, the length by stimulus quality interaction was significant, but this was qualified with a significant 3-way interaction between length, stimulus quality and frequency. As shown in Figure 2, this 3 three-way interaction is driven by the fact that response latencies were faster to five-letter, low-frequency words in the low-illumination condition. Close inspection of the five-letter, low-frequency items did not reveal any particular aspect of these words or subset of words (e.g., some orthographic/phonological structure unique to a subset of these words) that would account for this pattern of responses. Consequently, this interaction appears to be of a spurious nature.

Table 4

ANOVA by Subjects and Items for Online Naming Latencies: Experiment 1

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	10.53***	4	11.00***
MSE	116	(5945.44)	190	(6811.38)
Stimulus Quality	1	19.70***	1	145.66***
MSE	29	(72236.65)	190	(1669.10)
Word Frequency	1	38.28***	1	138.14***
MSE	29	(34013.29)	190	(6811.38)
Length x Stimulus Quality	4	1.87	4	8.48***
MSE	116	(4424.17)	190	(1669.10)
Length x Frequency	4	1.24	4	2.22
MSE	116	(4566.51)	190	(6811.38)
Stimulus Quality x Frequency	1	2.75	1	1.73
MSE	29	(10223.25)	190	(1669.10)
Length x Stimulus Quality x Frequency	4	0.66	4	12.69***
MSE	116	(3669.36)	190	(1669.10)

* $p < .05$ ** $p < .01$ *** $p < .001$

Insert Figure 1 about here⁷

Insert Figure 2 about here

Online Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Quality) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the error data (see Table 5) showed a significant effect of stimulus quality such that participants made more errors to words presented in low- than normal-illumination intensity (2.9% vs 1.6%). There was also a significant effect of frequency such that participants made more errors to low- than to high-frequency words (4.1% vs 0.5%). The interaction between frequency and stimulus quality was significant. As shown in Figure 3, the effect of stimulus quality was greater for low- than for high-frequency words. This interaction does not replicate previous research findings in which these two variables have been additive (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Herdman et al., in press; Meyer et al., 1975; Stanners et al., 1975).

Insert Figure 3 about here

Delayed Naming Latencies

The primary purpose of the delayed naming paradigm was to control for effects in online naming that may arise during output because of extraneous

Table 5

ANOVA by Subjects and Items for Online Naming Errors: Experiment 1

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	0.03	4	0.03
MSE	116	(17.22)	190	(41.86)
Stimulus Quality	1	15.59***	1	7.78**
MSE	29	(16.26)	190	(18.51)
Word Frequency	1	40.88***	1	32.12***
MSE	29	(48.44)	190	(41.86)
Length x Stimulus Quality	4	2.37	4	1.49
MSE	116	(19.92)	190	(18.51)
Length x Frequency	4	3.92	4	0.07
MSE	116	(18.31)	190	(41.86)
Stimulus Quality x Frequency	1	12.31***	1	6.15**
MSE	29	(16.58)	190	(18.51)
Length x Stimulus Quality x Frequency	4	2.27	4	1.54
MSE	116	(21.11)	190	(18.51)

* $p < .05$ ** $p < .01$ *** $p < .001$

interactions between the stimuli and the apparatus.

Multiple Regression Analysis. Table 6 shows the intercorrelations between the variables for the delayed naming task. As with the online naming condition, number of letters was positively correlated with number of syllables, and negatively correlated with N. Number of letters was not significantly correlated with frequency nor stimulus quality. A multiple regression analysis (see Table 7) showed that none of the variables under study accounted for a significant proportion of variance.

ANOVA. Preliminary analyses revealed no significant effects of presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Quality) x 2 (Frequency) ANOVA with repeated measures on each variable. As shown in Table 8, there were no significant effects.

Delayed Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Quality) x 2 (Frequency) ANOVA with repeated measures on each variable. Analysis of the error data (see Table 9) revealed a significant effect of frequency such that more errors were made to low- than to high-frequency words (3.1% vs 0.8%). This finding is compatible with previous research showing frequency effects in delayed naming latencies (Balota & Chumbley, 1985; Herdman et al., 1994) and suggests that frequency influences some aspect of response output. There was also a significant effect of stimulus quality whereby subjects made more errors to words presented in the low- than the normal-illumination condition (2.7% vs 1.3%). The effect of stimulus quality on delayed naming was unexpected. Because the effect of stimulus

Table 6

Intercorrelations among Variables for Delayed Naming Latencies: Experiment 1

Correlations	# Letters	Neighbours	Word Frequency	Stimulus Quality	# Syllables
# Letters	1.0000				
Neighbours	-0.7890**	1.0000			
Word Frequency	0.0000	-0.0481	1.0000		
Stimulus Quality	0.0000	0.0000	0.0000	1.0000	
# Syllables	0.8660**	-0.5640**	0.0000	0.0000	1.0000

1-tailed Significance: * = .01, ** = .001

Note. # Letters = number of letters, Neighbours = orthographic neighbourhood, # Syllables = number of syllables

Table 7

Regression Analysis for Delayed Naming Latencies: Experiment 1

Variable	B	SE B	β	t	Sig t
# Syllables	3.79	10.78	0.04	0.35	0.725
Stimulus Quality	7.27	4.86	0.07	1.49	0.135
Word Frequency	3.76	4.88	0.04	0.77	0.441
Neighbours	-0.21	0.64	-0.03	-0.33	0.745
# Letters	-0.32	5.03	-0.00	-0.06	0.948

$R^2 = .01$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

Table 8

ANOVA by Subjects and Items for Delayed Naming Latencies: Experiment 1

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	0.82	4	0.36
MSE	116	(1861.61)	190	(2555.57)
Stimulus Quality	1	0.94	1	2.41
MSE	29	(9002.94)	190	(2192.07)
Word Frequency	1	0.12	1	0.60
MSE	29	(2516.53)	190	(2555.57)
Length x Stimulus Quality	4	1.14	4	0.46
MSE	116	(1712.53)	190	(2192.07)
Length x Frequency	4	1.18	4	0.84
MSE	116	(1714.37)	190	(2555.57)
Stimulus Quality x Frequency	1	0.00	1	2.31
MSE	29	(1747.03)	190	(2192.07)
Length x Stimulus Quality x Frequency	4	0.82	4	1.35
MSE	116	(1655.92)	190	(2192.07)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 9

ANOVA by Subjects and Items for Delayed Naming Errors: Experiment 1

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	0.78	4	0.23
MSE	116	(20.65)	190	(14.99)
Stimulus Quality	1	5.45*	1	13.01***
MSE	29	(59.22)	190	(12.34)
Word Frequency	1	17.07***	1	24.95***
MSE	29	(45.15)	190	(14.99)
Length x Stimulus Quality	4	1.35	4	0.67
MSE	116	(22.74)	190	(12.34)
Length x Frequency	4	0.48	4	0.55
MSE	116	(19.68)	190	(14.99)
Stimulus Quality x Frequency	1	0.67	1	0.32
MSE	29	(16.53)	190	(12.34)
Length x Stimulus Quality Frequency	4	1.38	4	0.73
MSE	116	(18.27)	190	(12.34)

* $p < .05$ ** $p < .01$ *** $p < .001$

quality is presumably restricted to encoding (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Hughes et al., 1984; Meyer et al., 1975; Schmitter-Edgecombe et al., 1992; Stanners et al., 1975), it is unclear how stimulus quality could first influence encoding, bypass lexical access (as evidenced by the null interaction between stimulus quality and frequency in the online naming task), and then mediate processing during output. A more likely possibility is that the observed effects of stimulus quality are an artifact of the 250 ms word presentation that was used in the delayed naming procedure. In particular, the 250 ms stimulus presentation in the delayed naming task may have been too short to allow for full encoding for words presented at low-illumination intensity. On this view, the observed effect of stimulus quality in delayed naming presumably does not reflect stimulus quality mediating processing during output, but instead reflects the fact that post-encoding stages of processing had to proceed with an impoverished representation of the stimulus.

In sum, the results of the delayed naming task in this experiment must be interpreted with caution. The effect of stimulus quality in delayed naming is probably due to ~~insufficient~~ insufficient time to encode the words rather than to stimulus quality directly mediating ~~processing~~ processing during response output.

Online vs residual production effects

Researchers are aware that the effects observed during online naming tasks can be contaminated by post-lexical processes such as articulation. For example, when using a delayed naming task to isolate the output stage of the word processing system, Balota and Chumbley (1985) and Herdman et al. (1994, Experiment 3) observed that subjects named high-frequency words significantly faster than low-frequency words. Furthermore, Herdman, LeFevre, and Greenham (1996) and Seidenberg, Petersen,

MacDonald, and Plaut (1996) have shown that the effects of lexical similarity may be due to processes associated with output (e.g., articulation): In these studies, pseudohomophones were named faster than nonpseudohomophones in delayed naming tasks, demonstrating that at least some portion of lexicality effects can be attributed to output processes. The importance of these findings is in showing that the effect of a variable in online naming may reflect attributes of response output rather than pre-output stages of processing. An appropriate manner to determine whether effects are due to lexical access rather than output is to partial out delayed naming responses from online naming responses and examine whether the residual effects are statistically significant. To this end, latencies in the delayed naming condition were subtracted from those in the online naming condition. These corrected scores were computed on an item-by-item basis for each subject: If a subject had made a naming error to a given item in either the online or the delayed naming condition, then the latency for that item was excluded from the analysis of the corrected score. These corrected latencies are presented in Table 10.

As shown in Table 11, the analyses of the corrected data replicates the findings from the noncorrected data for both subjects and items. There was a significant effect of length such that response latencies increased with number of letters in the words. Naming latencies were slower to words presented in the low- than the normal-illumination intensity condition (285 vs 195 ms) and slower to low- than to high-frequency words (286 vs 194 ms). Similar to the noncorrected data, the 2-way interaction between length and stimulus quality and the 3-way interaction were significant only in the by-item analyses: As with the explanation accorded these

Table 10

Online Naming Latencies Corrected for Delayed Naming Latencies: Experiment 1

<u>Length</u>	<u>High Frequency</u>		<u>Low Frequency</u>	
	<u>Normal-Illumin</u>	<u>Low-Illumin</u>	<u>Normal-Illumin</u>	<u>Low-Illumin</u>
three	143	220	199	322
four	133	216	217	324
five	164	235	209	331
six	161	220	266	345
seven	177	275	285	365

Note. Illumin = Illumination

Table 11

ANOVA by Subjects and Items for Corrected Naming Latencies: Experiment 1

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	8.19***	4	9.03***
MSE	116	(7493.05)	190	(6821.75)
Stimulus Quality	1	21.12***	1	47.28***
MSE	29	(57161.33)	190	(3737.10)
Word Frequency	1	42.75***	1	91.89***
MSE	29	(29650.12)	190	(6821.75)
Length x Stimulus Quality	4	0.70	4	2.72*
MSE	116	(6384.19)	190	(3737.10)
Length x Frequency	4	1.46	4	2.13
MSE	116	(6090.31)	190	(6821.75)
Stimulus Quality x Frequency	1	3.15	1	0.08
MSE	29	(6851.22)	190	(3737.10)
Length x Stimulus Quality x Frequency	4	1.12	4	2.73*
MSE	116	(5021.46)	190	(3737.10)

* $p < .05$ ** $p < .01$ *** $p < .001$

findings in the noncorrected data, these interactions were explained as due to spurious response latencies associated with the five-letter, low-frequency words in the low-illumination intensity condition. Of interest is the finding that the magnitude of effects between the corrected and noncorrected data are very similar. The overall magnitude of the length effect in the noncorrected data is 54 ms and also 54 ms in the corrected data. The magnitude of the effect of stimulus quality was 96 ms in the noncorrected data and 90 ms in the corrected data. Furthermore, there was a 92 ms effect of word-frequency in both the noncorrected and corrected data. Because the pattern of results from the corrected data parallel the results of the noncorrected data, a response output interpretation of the results can be dismissed. It is concluded therefore that the effects observed in the online naming portion of this experiment reflect the influence of these variables on encoding and lexical access.

Summary

The results of Experiment 1 showed significant main effects of length, stimulus quality, and frequency in online naming: The pre-output locus of these effects were confirmed by partialling out delayed naming latencies from online responses. The regression analysis revealed that the observed effects of length were attributable to number of letters rather than N or number of syllables. Because length was additive with stimulus quality, it is concluded that length does not influence encoding. Interestingly, the alternative conclusion that length has a post-encoding lexical affect, is not supported insofar as length was also additive with word frequency in the overall analyses of the online and the corrected data. However, as shown in Tables 1 (uncorrected latency data) and 10 (corrected latency data), the effect of length is much larger for low- than for high-frequency words (91 vs 41 ms,

respectively, and 86 vs 34 ms, respectively) in the normal-illumination condition:

Separate 5 (Length) x 2 (Frequency) analyses of this data confirmed these interactions ($F_s(4,116) = 4.07$, $MSe = 1579.31$, $p < .01$; $F_i(4,190) = 2.37$, $MSe = 8894.76$, $p < .054$, for the uncorrected data, and $F_s(4,116) = 5.04$, $MSe = 2337.49$, $p < .001$; $F_i(4,190) = 1.73$, $MSe = 8709.63$, $p = .145$, for the corrected data). These findings suggests that length exerts an influence on lexical access. In accord with Norris' (1994; Herdman et al., in press) multiple-levels model, length influences processing primarily at sublexical levels. In contrast to high-frequency words, phonological coding of low-frequency words relies more on sublexical mappings and thus are more affected by length.

Experiment 2

Research has shown that length effects are greater for nonwords (e.g., grack) than for words (Mason, 1978; Weekes, 1997). One possible reason for this finding is that the processes underlying encoding (e.g., feature extraction) may be different for letter strings that form nonwords than for those that form words. Accordingly, although length appears not to affect the encoding of words (Experiment 1), length may affect the encoding of nonword letter strings.

Experiment 2 was designed to examine whether length affects the encoding of nonword letter strings. As in Experiment 1, length was factorially combined with stimulus quality: An interaction between stimulus quality and length would indicate that length affects encoding of nonwords. Additivity between stimulus quality and length would show that length effects in nonword naming have a post-encoding locus.

Method

Participants. Thirty first year psychology students from Carleton University participated to fulfil partial course credit. Subjects had normal or corrected-to-normal vision and were fluent in the English language.

Stimuli. The 200 nonword stimuli used in Experiment 2 are shown in Appendix 2. The majority of the nonwords were derived by changing one or two letters in the word stimuli of Experiment 1. This was done to keep the nonword stimuli as orthographically similar to words as possible. The nonwords were comprised of five groups of three, four, five, six, and seven letter nonwords with 40 nonwords in each group. The nonwords were matched on initial onset (i.e., voiced vs unvoiced) and bigram frequency. As with the word stimuli, the nonwords could not all be matched on N and the three, four, and five letter nonwords were monosyllabic whereas the six and seven letter nonwords were bisyllabic. Half of the nonwords were presented in degraded stimulus quality (i.e., illumination intensity = 23.9 cd/m^2) while the rest of the nonwords were presented in nondegraded stimulus quality (i.e., illumination intensity = 90.8 cd/m^2). Stimulus quality was counterbalanced across nonwords.

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

Results and Discussion

Means of the median response latencies for correct trials and percent errors for both the online and delayed naming tasks are shown in Table 12. In the online naming condition, 2% of the trials were coded as invalid whereas 4% of the delayed naming trials were coded as invalid. The latency and error data were analyzed separately.

Online Naming Latencies

Table 12

Mean Correct Latencies (in ms) and Percent Error (%Err): Experiment 2

	<u>Normal-Illumination</u>		<u>Low-Illumination</u>	
	RT	%Err	RT	%Err
Length	Online Naming			
three	763	3.8	875	6.8
four	825	6.0	922	8.6
five	835	4.0	943	7.0
six	915	5.3	1040	5.3
seven	1003	3.3	1124	5.6
	Delayed Naming			
three	535	1.3	558	3.3
four	545	3.8	458	5.2
five	549	2.6	546	4.0
six	564	2.6	573	7.0
seven	559	3.2	566	8.8

Note. RT = Response Latency

Multiple Regression Analysis. Table 13 shows the intercorrelations among the variables for the online naming task. Number of letters was positively correlated with number of syllables and negatively correlated with N. Number of letters and stimulus quality were additive. A multiple regression analysis (see Table 14) showed that all of the variables accounted for unique proportions of variance.

Of importance to the interpretation of length effects in this experiment were the β s associated with number of letters, number of syllables, and N. The regression analysis showed that the β for number of letters was larger than the β for N, indicating that number of letters was a better predictor of length effects than N. However, the β for number of syllables (0.23) was similar to the β for number of letters (0.24). A stepwise regression analysis showed that number of letters accounted for 33% of the variance whereas number of syllables only accounted for a small (yet significant), additional 0.8% of the variance. Thus, the observed effects of length in this experiment are discussed in terms of number of letters rather than number of syllables.

ANOVA. Preliminary analyses revealed no significant effects of presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Quality) ANOVA with repeated measures on both variables. The analysis of the latency data (see Table 15) showed a significant effect of length whereby response latencies increased with number of letters in the nonwords (see Figure 4). The overall magnitude of this length effect was 244 ms. There was also a significant effect of stimulus quality where responses were faster to nonwords presented in the normal- than the low-illumination condition (868 vs 981 ms). The interaction between length and stimulus quality was not significant,

Table 14

Regression Analysis for Online Naming Latencies: Experiment 2

Variable	B	SE B	β	t	Sig t
# Syllables	64.53	22.10	0.23	2.92	0.004
Stimulus Quality	82.46	10.45	0.29	7.88	0.001
Neighbours	-4.33	1.50	-0.17	-2.88	0.004
# Letters	23.74	9.81	0.24	2.42	0.016

$R^2 = .44$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

Table 15

ANOVA by Subjects and Items for Online Naming Latencies: Experiment 2

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	86.23***	4	43.29***
MSE	116	(6433.39)	195	(15340.08)
Stimulus Quality	1	23.72***	1	97.20***
MSE	29	(39919.91)	195	(6995.79)
Length x Stimulus Quality	4	0.61	4	1.10
MSE	116	(2950.91)	195	(6995.79)

* $p < .05$ ** $p < .01$ *** $p < .001$

suggesting that these two variables exert their effects at different stages within the word recognition system.

Insert Figure 4 about here

Online Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Quality) ANOVA with repeated measures on each variable. The analysis of the error data (see Table 16) showed that participants made more errors to nonwords presented in the low- than the normal-illumination condition (6.6% vs 4.5%). None of the other effects were significant.

Delayed Naming Latencies

Multiple Regression Analysis. Table 17 shows the intercorrelations for the variables in the delayed naming task. As with the online naming condition, number of letters was positively correlated with number of syllables and negatively correlated with N. There was a null relationship between number of letters and stimulus quality. A multiple regression analysis (see Table 18) showed that none of the variables under study accounted for a significant proportion of variance.

ANOVA. Preliminary analyses revealed no significant effects of stimulus presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Quality) ANOVA with repeated measures on each variable. As shown in Table 19, there were no significant main effects nor interactions.

Delayed Naming Errors

Table 16

ANOVA by Subjects and Items for Online Naming Errors: Experiment 2

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	2.18	4	1.14
MSE	116	(30.11)	195	(72.98)
Stimulus Quality	1	12.43***	1	7.90**
MSE	29	(29.21)	195	(48.95)
Length x Stimulus Quality	4	1.06	4	0.69
MSE	116	(22.58)	195	(48.95)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 17

Intercorrelations among Variables for Delayed Naming Latencies: Experiment 2

Correlations	# Letters	Neighbours	Stimulus Quality	# Syllables
# Letters	1.0000			
Neighbours	-0.7772**	1.0000		
Stimulus Quality	0.0000	0.0000	1.0000	
# Syllables	0.8660**	-0.5917**	0.0000	1.0000

1-tailed Significance: * = .01, ** = .001

Note. # Letters = number of letters, Neighbours = orthographic neighbourhood, #

Syllables = number of syllables

Table 18

Regression Analysis for Delayed Naming Latencies: Experiment 2

Variable	B	SE B	β	t	Sig t
# Syllables	8.82	13.00	0.07	0.67	0.497
Stimulus Quality	10.28	6.15	0.08	1.67	0.095
Neighbours	0.58	0.88	0.05	0.66	0.509
# Letters	0.94	5.77	0.02	0.16	0.871

$R^2 = .01$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Syllables = number of syllables

Table 19

ANOVA by Subjects and Items for Delayed Naming Latencies: Experiment 2

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	2.26	4	0.85
MSE	116	(2415.41)	195	(3733.03)
Stimulus Quality	1	2.51	1	2.75
MSE	29	(2958.36)	195	(3843.90)
Length x Stimulus Quality	4	1.24	4	0.80
MSE	116	(1024.57)	195	(3843.90)

* $p < .05$ ** $p < .01$ *** $p < .001$

The error data was analyzed in a 5 (Length) x 2 (Stimulus Quality) ANOVA with repeated measures on each variable. Analysis of the error data (see Table 20) showed a significant main effect of length where participants made more pronunciation errors to long than short nonwords. There was also a significant effect of stimulus quality with more incorrect responses to the nonwords presented in the low- than the normal-illumination condition (5.6% vs 2.7%). Finally, the analysis revealed a significant interaction between length and stimulus quality where length had a greater effect on nonwords in the low-illumination condition than for nonwords in the normal-illumination condition (see Figure 5).

 Insert Figure 5 about here

As discussed in Experiment 1, the significant effect of stimulus quality in the delayed naming task is likely due to an insufficient display duration, thereby preventing participants from fully encoding these items. This explanation also applies to the interaction between length and stimulus quality: It is more appropriate to view this interaction as an artifact of the procedure of the delayed naming task rather than the effect of stimulus quality combining with length to influence response output.

Online vs residual production effects

As in Experiment 1, the response latencies for online nonword naming in Experiment 2 were corrected for possible influences (e.g., voicing) from post-lexical processes by subtracting the delayed response latencies from the online response latencies (see Table 21). The analysis of the corrected data (see Table 22) showed significant main effects of length and stimulus quality, as well as the null interaction

Table 20

ANOVA by Subjects and Items for Delayed Naming Errors: Experiment 2

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	5.44 ^{***}	4	3.42 ^{**}
MSE	116	(21.96)	195	(41.61)
Stimulus Quality	1	10.85 ^{**}	1	33.20 ^{***}
MSE	29	(59.47)	195	(30.84)
Length x Stimulus Quality	4	3.16 [*]	4	1.67
MSE	116	(18.31)	195	(30.84)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 21

Online Naming Latencies Corrected for Delayed Naming Latencies: Experiments 2

<u>Length</u>	<u>Normal-Illumination</u>	<u>Low-Illumination</u>
three	227	316
four	279	364
five	286	395
six	352	467
seven	443	557

Table 22

ANOVA by Subjects and Items for Corrected Naming Latencies: Experiment 2

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	61.69***	4	45.32***
MSE	116	(7584.44)	195	(14017.73)
Stimulus Quality	1	25.32***	1	60.46***
MSE	29	(31063.40)	195	(8755.05)
Length x Stimulus Quality	4	0.85	4	1.12
MSE	116	(3895.28)	195	(8755.05)

* $p < .05$ ** $p < .01$ *** $p < .001$

between the two variables corresponding to the data obtained with the uncorrected data. The magnitude of the stimulus quality effect in the corrected data was similar to that with the uncorrected data (102 vs 113 ms, respectively). The magnitude of the length effect was similar across the corrected and noncorrected data (228 vs 245 ms, respectively). Interestingly, the magnitude of the length effect between the five and six letter nonwords was somewhat smaller in the corrected than noncorrected data (68 vs 88 ms, respectively). This suggests a post-lexical effect of number of syllables (the three, four and five letter nonwords were monosyllabic whereas the six and seven letter nonwords were bisyllabic) that may be responsible for the inflated syllable effect in the regression analysis (see Frederiksen, 1980; Sevald, Dell, & Cole, 1997; Sternberg, Monsell, Knoll, & Wright, 1978). This post-lexical syllable effect is discussed further in Experiment 4 and in the General Discussion.

Summary

To summarize, the effects of length and stimulus quality on nonword naming were additive. This finding corroborates the additive effects of length and stimulus quality on word naming in Experiment 1 and supports the conclusion that length does not influence encoding.

Experiment 3

In Experiments 1 and 2, the effects of length were additive with stimulus quality, suggesting that length has a post-encoding influence on processing letter strings. In Experiment 1, length interacted with frequency (under normal-illumination conditions): Insofar as frequency is believed to be a (post-encoding) lexical variable (Coltheart, 1978; Coltheart et al., 1993; Coltheart & Rastle, 1994; Forster, 1976; Morton, 1969; Norris, 1994; Paap et al., 1987; Paap & Noel, 1991; Plaut et al.,

1996; Seidenberg & McClelland, 1989), this suggests that length affects lexical access. In Norris' (1994; Herdman et al., in press) multiple-levels model, length influences processing primarily at sublexical levels. On this view, length interacts with frequency because low-frequency words have a greater reliance on sublexical levels of processing than do high-frequency words.

The purpose of the present experiment was to further investigate the affect of length on word naming by increasing the reliance on sublexical levels of processing. This was done by using a stimulus format manipulation where words were presented in either lower-case or cAsE-aLtErEd format. In accord with the multiple-levels model, presenting words in case-altered format diminishes the influence of whole-word mappings from orthography to phonology (Herdman et al., in press). This has a nonlinear effect in that case alternation slows naming more to low- than to high-frequency words: Whereas high-frequency words still benefit from whole-word mappings, low-frequency words lose whatever benefit that may have existed under lower-case presentation.

Based on the multiple-levels model, a three-way interaction between length, stimulus format, and frequency was predicted. This is best described in terms of three two-way interactions. First, as explained above and as found by Herdman et al. (in press, see also McCann and Besner, 1987), stimulus format should interact with frequency. Second, stimulus format should interact with length because case alternation should increase the reliance on sublexical levels of processing which are presumably sensitive to length. Third, as discussed in Experiment 1, the effects of length should be greater for low- than for high-frequency words because the impact of sublexical levels of processing is inversely related to frequency.

Method

Participants. Thirty first year psychology students from Carleton University participated to fulfil partial course credit. Participants had normal or corrected-to-normal vision and were fluent in the English language.

Stimuli. The words were the same as those used in Experiment 1. In this experiment, the stimulus quality of the words was not degraded. However, half of the words were presented in case-altered format and the rest of the words were presented in lower-case format. For the words presented in case-altered format, the first letter of each word was presented in lower-case and the following letters were case-altered accordingly (see Besner, 1983). Stimulus format was counterbalanced across subjects. All other characteristics of the words in Experiment 3 remained the same as in Experiment 1.

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

Results and Discussion

Means of the median response latencies on correct trials and percent errors for both the online and delayed naming tasks are shown in Table 23. In the online naming condition, 1% of the trials were coded as invalid whereas 2% of the delayed naming trials were coded as invalid. The latency and error data were analyzed separately.

Online Naming Latencies

Multiple Regression Analysis. Table 24 shows the intercorrelations between the variables for the online naming task. Number of letters was positively correlated

Table 23

Mean Correct Latencies (in ms) and Percent Error (%Err): Experiment 3

	<u>High Frequency</u>				<u>Low Frequency</u>			
	<u>Lower-Case</u>		<u>Case-Altered</u>		<u>Lower-Case</u>		<u>Case-Altered</u>	
	RT	%Err	RT	%Err	RT	%Err	RT	%Err
Length	Online Naming							
three	564	0.0	607	1.0	617	1.0	666	3.0
four	576	0.3	637	1.0	624	1.0	702	4.6
five	602	1.0	657	2.6	649	2.3	709	3.6
six	603	0.6	697	4.0	689	4.0	792	13.3
seven	607	0.3	699	0.6	708	3.3	829	5.3
	Delayed Naming							
three	425	0.0	431	0.0	424	0.3	435	0.0
four	427	0.0	424	0.3	418	2.0	426	2.3
five	430	0.0	431	0.6	442	0.3	429	1.0
six	427	0.0	437	1.3	433	1.3	437	5.3
seven	416	0.0	423	0.3	441	1.3	436	3.3

Table 24

Intercorrelations among Variables for Online Naming Latencies: Experiment 3

Correlations	# Letters	Neighbours	Word Frequency	Stimulus Quality	# Syllables
# Letters	1.0000				
Neighbours	-0.7890**	1.0000			
Word Frequency	0.0000	-0.0481	1.0000		
Stimulus Format	0.0000	0.0000	0.0000	1.0000	
# Syllables	0.8660**	-0.5640**	0.0000	0.0000	1.0000

1-tailed Significance: * = .01, ** = .001

Note. # Letters = number of letters, Neighbours = orthographic neighbourhood, #

Syllables = number of syllables

with number of syllables and negatively correlated with N. Number of letters did not interact with frequency nor stimulus format. A multiple regression analysis (see Table 25) showed that all of the variables except N accounted for significant proportions of variance. Importantly, because N did not account for a significant proportion of variance and the β for number of syllables was smaller than the β for number of letters, the observed effects of length are discussed in terms of number of letters.

Although the regression analysis showed that number of letters is a more important indicator of length effects than number of syllables, the β for number of syllables was large enough to warrant some attention. As shown in Figure 6, the magnitude of the length effect between the five and six letter words is approximately 41 ms; a magnitude of effect that is almost double the largest length effect between any adjacent word groups. This increase in slope may be the result of case alternation disrupting the syllabic break involved in the processing of bisyllabic words during response output. The resulting increase in response latency may be inflating the importance of number of syllables in the regression analysis. This is especially true when the magnitude in length effect between the six and seven letter words (i.e., 16 ms), is shown to be very similar to the length effects between the single syllable words. In fact, if the syllabic effect between the five and six letter word groups is removed, which would represent a decrease in response latency of approximately 18 ms (this numerical value represents the average of the three slopes subtracted from the length effect between the five and six letter word groups), the overall effect of length would still be a robust 79 ms. Thus, it can be argued that the contribution of number of syllables to the interpretation of the overall length effect during lexical

Table 25

Regression Analysis for Online Naming Latencies: Experiment 3

Variable	B	SE B	β	t	Sig t
# Syllables	35.65	16.30	0.18	2.15	0.029
Stimulus Format	63.15	7.35	0.34	8.58	0.000
Word Frequency	61.96	7.38	0.34	8.39	0.000
Neighbours	0.92	0.96	0.06	0.95	0.343
# Letters	16.22	7.60	0.25	2.13	0.034

$R^2 = .37$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

access is an artifact of post-lexical processing and that the effects of length observed during lexical access are attributable to differences in the number of letters across the word groups (the effect of syllables on response output is discussed in detail below).

Insert Figure 6 about here

ANOVA. Preliminary analyses revealed no significant effects of stimulus presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Format) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the latency data (see Table 26) showed a significant effect of length where latencies increased with the number of letters (see Figure 7). The magnitude of this length effect is 97 ms. There was also an effect of stimulus format where responses were faster to words presented in the lower- than the case-altered condition (624 vs 699 ms), and an effect of frequency whereby latencies were faster to high- than to low-frequency words (625 vs 698 ms). All of the two-way interactions were statistically significant. First, there was an interaction between length and stimulus format such that the effect of length was larger for words presented in the case-altered than the lower-case condition (127 vs 67 ms). Second, the interaction between length and word frequency demonstrated that the effect of length was larger for low- than high-frequency words (127 vs 67 ms). Third, there was an interaction between stimulus format and frequency where the effect of frequency was larger for words presented in the case-altered than the lower-case condition (82 vs 69 ms). This last interaction corroborates previous research that demonstrates that these two variables influence

processing during lexical access (Besner et al., 1984; Besner & McCann, 1987; Herdman et al., in press). The three-way interaction between length, stimulus format, and frequency was significant only by items. According to additive factors logic, if all of these variables influence lexical access, then a significant three-way interaction between these variables would be expected by both subjects and items.

Insert Figure 7 about here

Despite the null three-way interaction between length, stimulus format, and frequency with the subject data, this interaction was significant with the item analysis. Figure 8, however, shows that this interaction may be due to the response latencies associated with the five-letter, low-frequency, case-altered group. Inspection of this word group did not yield any obvious information (e.g., orthographic or phonological attributes) that could explain the unexpected response latencies for this word group. Thus, I conclude that this significant three-way interaction is not a meaningful effect in that it is not the result of any systematic effect(s) of any of the variables on response latencies in this experiment.

Insert Figure 8 about here

Online Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Format) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the

error data (see Table 27) showed a significant effect of length where participants made more errors to long than to short words. The magnitude of this length effect was 1.1%. There was also an effect of stimulus format where participants made more errors to words presented in the case-altered than the lower-case condition (3.9% vs 1.4%), and an effect of frequency whereby the participants made more errors to low- than to high-frequency words (4.1% vs 1.1%). Although the three-way interaction was not significant, all of the two-way interactions reached significance. The interaction between length and stimulus format revealed a larger effect of length for words presented in the case-altered than lower-case condition. The length by word frequency interaction showed a larger effect of length for low- than high-frequency words. Finally, the interaction between stimulus format and word frequency demonstrated that the effect of case alternation was greater for low- than high-frequency words.

Close inspection of the error data suggests that the significant effects may have been due to a disproportionately high percentage of errors associated with the low-frequency, six-letter words in case-altered format. Inspection of this word group showed that this group of words contained a subset of words where a lower case 'L' (i.e., 'l') could have easily been confused with an upper case 'I' (i.e., 'I') (see Appendix 3) within the context of case-altered presentation (the percent error for these items was beyond 2.5 standard deviations). The average percent error for these words is 36.67%. The error data were analyzed without these items (see Table 28). With these items removed, the percent error for this word group changed from 13.33% to 2.36% (see Figure 9). From this analysis, the only effects to achieve statistical significance were the main effects of stimulus format, word frequency, and the three-

Table 27

ANOVA by Subjects and Items for Online Naming Errors: Experiment 3

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	11.96***	4	3.62**
MSE	116	(27.59)	190	(58.66)
Stimulus Format	1	27.99***	1	18.75***
MSE	29	(34.39)	190	(34.23)
Frequency	1	27.00***	1	16.04***
MSE	29	(50.00)	190	(58.66)
Length x Stimulus Format	4	5.61***	4	2.30*
MSE	116	(24.85)	190	(34.23)
Length x Frequency	4	4.84***	4	1.21
MSE	116	(28.07)	190	(58.66)
Stimulus Format x Frequency	1	4.63*	1	1.57
MSE	29	(41.63)	190	(34.23)
Length x Stimulus Format x Frequency	4	1.56	4	0.62
MSE	116	(27.81)	190	(34.23)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 28

ANOVA by Subjects and Items for Online Naming Errors with Outliers Removed:Experiment 3

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	2.01	4	0.60
MSE	116	(22.27)	184	(34.41)
Stimulus Format	1	12.59***	1	10.96***
MSE	29	(24.57)	184	(23.90)
Frequency	1	15.72***	1	9.96**
MSE	29	(34.56)	184	(34.41)
Length x Stimulus Format	4	0.38	4	0.15
MSE	116	(19.18)	184	(23.90)
Length x Frequency	4	2.05	4	0.98
MSE	116	(20.51)	184	(34.41)
Stimulus Format x Frequency	1	0.01	1	0.09
MSE	29	(29.25)	184	(23.90)
Length x Stimulus Format x Frequency	4	3.34**	4	1.05
MSE	116	(21.08)	184	(23.90)

* $p < .05$ ** $p < .01$ *** $p < .001$

way interaction between length, stimulus format, and frequency.

Insert Figure 9 about here

Delayed Naming Latencies

Multiple Regression Analysis. Table 29 shows the intercorrelations between the variables for the delayed naming task. Number of letters was positively correlated with number of syllables and negatively correlated with N. Number of letters did not interact with frequency nor stimulus format. A multiple regression analysis (see Table 30) showed that only number of letters and N accounted for significant proportions of variance. Because the β for number of letters was larger than the β for N, the observed length effects in this experiment are discussed in terms of number of letters rather than N.

ANOVA. Preliminary analyses revealed no significant effects of stimulus presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Format) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the latency data (see Table 31) showed that there were no significant main effects nor interactions.

Delayed Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Format) x 2 (Frequency) ANOVA with repeated measures on each variable. The analysis of the error data (see Table 32) showed a significant effect of length such that participants made more incorrect pronunciations to long than short words. The magnitude of this

Table 29

Intercorrelations among Variables for Delayed Naming Latencies: Experiment 3

Correlations	# Letters	Neighbours	Word Frequency	Stimulus Quality	# Syllables
# Letters	1.0000				
Neighbours	-0.7890**	1.0000			
Word Frequency	0.0000	-0.0481	1.0000		
Stimulus Format	0.0000	0.0000	0.0000	1.0000	
# Syllables	0.8660**	-0.5640**	0.0000	0.0000	1.0000

1-tailed Significance: * = .01, ** = .001

Note. # Letters = number of letters, Neighbours = orthographic neighbourhood, # Syllables = number of syllables

Table 30

Regression Analysis for Delayed Naming Latencies: Experiment 3

Variable	B	SE B	β	t	Sig t
# Syllables	-5.27	9.43	-0.06	-0.55	0.576
Stimulus Format	2.13	4.25	0.02	0.50	0.617
Word Frequency	6.61	4.26	0.07	1.55	0.122
Neighbours	1.43	0.55	0.22	2.55	0.011
# Letters	9.85	4.39	0.33	2.24	0.025

$R^2 = .03$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

Table 31

ANOVA by Subjects and Items for Delayed Naming Latencies: Experiment 3

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	1.16	4	1.02
MSE	116	(1671.02)	190	(2312.95)
Stimulus Format	1	0.54	1	0.32
MSE	29	(1688.40)	190	(1402.78)
Frequency	1	2.05	1	1.40
MSE	29	(1980.02)	190	(2312.95)
Length x Stimulus Format	4	0.57	4	0.70
MSE	116	(1730.70)	190	(1402.78)
Length x Frequency	4	2.09	4	0.38
MSE	116	(986.80)	190	(2312.95)
Stimulus Format x Frequency	1	0.15	1	2.82
MSE	29	(1712.85)	190	(1402.78)
Length x Stimulus Format x Frequency	4	0.62	4	0.87
MSE	116	(1425.92)	190	(1402.78)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 32

ANOVA by Subjects and Items for Delayed Naming Errors: Experiment 3

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	5.03***	4	3.54**
MSE	116	(13.00)	190	(10.47)
Stimulus Format	1	11.51**	1	8.68**
MSE	29	(11.36)	190	(5.92)
Frequency	1	10.91**	1	18.29***
MSE	29	(29.56)	190	(10.47)
Length x Stimulus Format	4	3.27**	4	3.14*
MSE	116	(10.77)	190	(5.92)
Length x Frequency	4	3.43**	4	2.09
MSE	116	(11.33)	190	(10.47)
Stimulus Format x Frequency	1	2.52	1	0.57
MSE	29	(9.52)	190	(5.92)
Length x Stimulus Format x Frequency	4	1.23	4	0.80
MSE	116	(10.34)	190	(5.92)

* $p < .05$ ** $p < .01$ *** $p < .001$

effect was 1.2%. There was also an effect of stimulus format where participants made more errors to words presented in the case-altered rather than in the lower-case condition (1.4% vs 0.4%), and an effect of frequency whereby participants made more errors to low- rather than to high-frequency words (1.73% vs 0.3%). The analysis showed a significant interaction between length and stimulus format where the effect of length was greater for words presented in the case-altered than the lower-case condition (1.8% vs. 0.5%). Furthermore, there was an interaction between length and word frequency where there was a larger effect of length for low- than high-frequency words (2.2% vs. 0.1%).

Similar to the online naming errors, close inspection of the delayed naming errors showed that the observed effects appeared to be influenced by the processing of the six-letter, low-frequency words presented in case-altered format. Inspection of these items revealed that the same six words from the online naming task were likely responsible for the high error rate of this word group (see Appendix 3). When these items were removed from the analysis, the percent error for this word group changed from 5.33% to 2.77% (see Figure 10). With those items removed, the significant effect of length (for items) and the interaction between length and stimulus format changed to null effects (see Table 33).

Insert Figure 10 about here

Online vs residual production effects

In order to remove the effects of post-lexical processing from the online responses, the delayed naming latencies were subtracted from the online naming

Table 33

ANOVA by Subjects and Items for Delayed Naming Errors with Outliers Removed:Experiment 3

<u>Source</u>	<u>Subject</u>		<u>Item</u>	
	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	3.73**	4	2.19
MSE	116	(9.88)	184	(10.04)
Stimulus Format	1	9.33**	1	4.40*
MSE	29	(7.38)	184	(4.99)
Frequency	1	7.55**	1	12.95***
MSE	29	(29.13)	184	(10.04)
Length x Stimulus Format	4	1.35	4	0.92
MSE	116	(8.78)	184	(4.99)
Length x Frequency	4	3.20*	4	1.62
MSE	116	(8.02)	184	(10.04)
Stimulus Format x Frequency	1	0.36	1	0.06
MSE	29	(8.79)	184	(4.99)
Length x Stimulus Format x Frequency	4	0.57	4	0.14
MSE	116	(8.16)	184	(4.99)

* $p < .05$ ** $p < .01$ *** $p < .001$

latencies. The corrected response latencies are shown in Table 34. Analysis of the corrected data (see Table 35) showed that the significant main effects of length, stimulus format, and frequency parallel the findings with the noncorrected data. The magnitude of the length effect in the corrected data was similar to that with the noncorrected data (104 vs 97 ms, respectively). The magnitude of effect of stimulus format was similar across the corrected and noncorrected data (72 vs 75 ms, respectively) and the magnitude of the frequency effect in the corrected data was also similar to that with the noncorrected data (70 vs 73 ms, respectively). The statistical significance of the interactions remained the same except for the interaction between stimulus format and frequency, which did not reach statistical significance with the corrected data. Furthermore, the significant interaction between length, stimulus format, and frequency for online response latencies that was observed with the item data changed to a nonsignificant interaction in the corrected data. This finding suggests that these original interactions may have been due to an aspect of response output.

Summary

The results of Experiment 3 are consistent with Norris' (1994) multiple-levels model. In particular, the notion that length affects processing at sublexical levels of processing was directly supported in that length interacted with frequency and with stimulus format in both the online and the corrected latency data. After outliers were removed, the error data showed a three-way interaction between length, stimulus format, and frequency. This interaction provides further support for the assumption that length affects processing at sublexical levels.

Table 34

Online Naming Latencies Corrected for Delayed Naming Latencies: Experiments 3

<u>Length</u>	<u>High Frequency</u>		<u>Low Frequency</u>	
	<u>Lower-Case</u>	<u>Case-Altered</u>	<u>Lower-Case</u>	<u>Case-Altered</u>
three	138	176	193	230
four	149	214	205	276
five	172	226	207	279
six	175	260	256	354
seven	191	283	292	393

Table 35

ANOVA by Subjects and Items for Corrected Naming Latencies: Experiment 3

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	32.45***	4	18.22***
MSE	116	(6455.65)	190	(5352.75)
Stimulus Format	1	83.99***	1	88.52***
MSE	29	(9151.37)	190	(4183.23)
Frequency	1	41.13***	1	59.66***
MSE	29	(18047.97)	190	(5352.75)
Length x Stimulus Format	4	4.08**	4	7.51***
MSE	116	(4145.51)	190	(4183.23)
Length x Frequency	4	8.43***	4	2.95*
MSE	116	(2315.19)	190	(5352.75)
Stimulus Format x Frequency	1	1.07	1	0.00
MSE	29	(2763.93)	190	(4183.23)
Length x Stimulus Format x Frequency	4	0.09	4	2.19
MSE	116	(3976.03)	190	(4183.23)

* $p < .05$ ** $p < .01$ *** $p < .001$

Experiment 4

In the multiple-levels model, nonwords are named using sublexical levels of processing. The results of Experiment 2 support the notion that length affects processing at these sublexical levels in that there were robust effects of length on nonword naming. It is not clear, however, whether all of the sublexical levels of processing are influenced by length and if so, whether length effects are constant across all levels. It is logical to assume, however, that the effects of length would be directly related to the number of orthographic units that must be mapped onto phonology. On this view, levels containing many small units of information (e.g., the letter level) would be more influenced by length than levels containing fewer and larger units of information (e.g., word bodies). In the present experiment, stimulus format (lower- vs case-altered) was used to force the sublexical processing of nonwords toward lower levels of coding. If length has a greater influence on lower levels of coding, then length should interact with stimulus format: Length effects on nonword naming should be larger in case-altered than lower-case presentation conditions.

Method

Participants. Thirty first year psychology students from Carleton University participated to fulfil partial course credit. Participants had normal or corrected-to-normal vision and were fluent in the English language.

Stimuli. The nonword stimuli were the same as those used in Experiment 2. The stimulus quality of the nonwords in this experiment was not manipulated. As in Experiment 3, the stimulus format of the nonwords in this experiment was manipulated via case alternation. The rest of the characteristics of the nonword

stimuli in Experiment 4 were identical to the characteristics of the nonword stimuli in Experiment 2.

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

Results and Discussion

Means of the median response latencies for correct trials and percent errors for both the online and delayed naming tasks are shown in Table 36. In the online naming condition, 1% of the trials were coded as invalid whereas 3% of the delayed naming trials were coded as invalid. The latency and error data were analyzed separately.

Online Naming Latencies

Multiple Regression Analysis. Table 37 shows the intercorrelations between the variables for the online naming task. Number of letters was positively correlated with number of syllables and negatively correlated with N. Number of letters did not interact with stimulus format. A multiple regression analysis (see Table 38) showed that all of the variables except N accounted for significant proportions of variance. Importantly, the β for number of letters was larger than the β for number of syllables. Thus, the observed effects of length in this experiment were interpreted as reflecting number of letters.

ANOVA. Preliminary analyses showed that there were no significant effects of presentation order so the data were collapsed across this variable. Correct median response latencies were analyzed in a 5 (Length) x 2 (Stimulus Format) ANOVA with repeated measures on each variable. The analysis of the latency data (see Table 39) showed a significant effect of length where latencies increased with number of letters

Table 36

Mean Correct Latencies (in ms) and Percent Error (%Err): Experiment 4

	<u>Lower-Case</u>		<u>Case-Altered</u>	
	RT	%Err	RT	%Err
Length	Online Naming			
three	675	2.3	738	6.5
four	711	3.2	816	9.6
five	751	2.6	843	6.8
six	796	3.2	1055	22.2
seven	858	4.3	1065	7.3
	Delayed Naming			
three	463	1.2	467	2.0
four	458	1.6	464	1.8
five	465	2.5	464	2.3
six	475	2.3	477	15.3
seven	483	2.0	479	8.5

Table 38

Regression Analysis for Online Naming Latencies: Experiment 4

Variable	B	SE B	β	t	Sig t
# Syllables	69.88	25.21	0.21	2.77	0.005
Stimulus Format	121.07	12.11	0.37	9.99	0.000
Neighbours	0.68	0.45	0.05	1.52	0.129
# Letters	44.09	8.93	0.38	4.94	0.000

$R^2 = .46$

Note. # Syllables = number of syllables, Neighbours = orthographic neighbourhood,

Letters = number of letters

Table 39

ANOVA by Subjects and Items for Online Naming Latencies: Experiment 4

	<u>Subject</u>		<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	61.50***	4	66.09***
MSE	116	(11475.91)	195	(12728.01)
Stimulus Format	1	69.42***	1	134.18***
MSE	29	(22796.38)	195	(12346.84)
Length x Stimulus Format	4	25.21***	4	13.77***
MSE	116	(4122.17)	195	(12346.84)

* $p < .05$ ** $p < .01$ *** $p < .001$

(see Figure 11). The overall magnitude of the length effect was 222 ms. There was also an effect of stimulus format where latencies were faster to nonwords presented in the lower- than the case-altered condition (758 vs 903 ms). Furthermore, there was a significant interaction between length and stimulus format. As can be seen in Figure 11, the effect of length is greater for nonwords in the case-altered than the lower-case condition. This interaction supports Norris' (1994) multiple-levels model and suggests that length has a greater affect on processing as more units of information are required to be processed.

Insert Figure 11 about here

Figure 11 allows an examination of why number of syllables was observed to have a significant effect in the regression analysis. Number of syllables can be seen to be having its influence on the case-altered stimuli. This large effect of syllables with this nonword group is what appears to be responsible for the influence of number of syllables in the overall effect of length. Despite the appearance of an effect on syllables in this online naming task, as is discussed below in the Delayed Naming Latencies section of Experiment 4, this effect of syllables is likely due to response output processes.

Online Naming Errors

The error data were analyzed in a 5 (Length) x 2 (Stimulus Format) ANOVA with repeated measures on each variable. The analysis of the error data (see Table 40) showed a significant effect of length where errors increased with number of letters. There was also an effect of stimulus format where errors were greater in the

Table 40

ANOVA by Subjects and Items for Online Naming Errors: Experiment 4

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	19.34***	4	6.01***
MSE	116	(35.19)	195	(151.45)
Stimulus Format	1	139.28***	1	47.14***
MSE	29	(29.22)	195	(106.86)
Length x Stimulus Format	4	19.79***	4	8.55***
MSE	116	(33.28)	195	(106.86)

* $p < .05$ ** $p < .01$ *** $p < .001$

case-altered than the lower-case condition (3.1% vs. 10.5%) and an interaction between length and stimulus format where the effect of length on errors was greater for the nonwords presented in the case-altered than the lower-case condition.

Close inspection of the error data showed that the observed effects may have been the result of a disproportionately high error rate associated with the six-letter nonwords presented in the case-altered condition. The nonwords which are likely responsible for this error rate are shown in Appendix 4. When these nonwords were removed from the error analysis, the percent error for this group on nonwords changed from 22.23% to 8.63% (see Figure 12). The analysis of the error data with these outliers removed is presented in Table 41 and showed that the only effect to remain significant was stimulus format.

Insert Figure 12 about here

Delayed Naming Latencies

Multiple Regression Analysis. Table 42 shows the intercorrelations between the variables for the delayed naming task. Number of letters was positively correlated with number of syllables and negatively correlated with N. Number of letters did not interact with stimulus format. A multiple regression analysis (see Table 43) showed that none of the variables accounted for significant proportions of variance in this experiment.

ANOVA. Preliminary analyses showed that there were no significant effects of stimulus presentation order so the data were collapsed over this variable. Correct median latencies were analyzed in a 5 (Length) x 2 (Stimulus Format) ANOVA with

Table 41

ANOVA by Subjects and Items for Online Naming Errors with Outliers Removed:Experiment 4

	<u>Subject</u>		<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	1.65	4	0.77
MSE	116	(37.59)	186	(78.31)
Stimulus Format	1	50.47***	1	47.84***
MSE	29	(28.88)	186	(38.57)
Length x Stimulus Format	4	1.32	4	0.92
MSE	116	(24.44)	186	(38.57)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 42

Intercorrelations among Variables for Delayed Naming Latencies: Experiment 4

Correlations	# Letters	Neighbours	Stimulus Format	# Syllables
# Letters	1.0000			
Neighbours	-0.2195**	1.0000		
Stimulus Format	0.0071	0.1355*	1.0000	
# Syllables	0.8660**	-0.0741	0.0000	1.0000

1-tailed Significance: * = .01, ** = .001

Note. # Letters = number of letters, Neighbours = orthographic neighbourhood, # Syllables = number of syllables

Table 43

Regression Analysis for Delayed Naming Latencies: Experiment 4

Variable	B	SE B	β	t	Sig t
# Syllables	13.71	9.99	0.14	1.37	0.171
Stimulus Format	8.21	4.80	0.08	1.71	0.088
Neighbours	-0.14	0.17	-0.04	-0.78	0.434
# Letters	2.58	3.54	0.07	0.73	0.465

$R^2 = .05$

Note. # Syllables = number of syllables, Neighbourhood = orthographic neighbourhood, # Letters = number of Letters

repeated measures on each variable. The analysis of the latency data (see Table 44) showed a significance was length. As shown in Figure 13, it is difficult to discern whether the effect of length is due to number of letters or number of syllables.

Although the multiple regression analysis showed that neither number of letters or number of syllables accounted for any unique variance in the delayed naming task, the β for number of syllables was double the β for number of letters. This suggests that number of syllables may be a better predictor of delayed naming responses than number of letters. This was the only experiment in the present study where number of syllables was a better predictor of response latencies than number of letters. The role of number of syllables during output is discussed in the General Discussion.

Insert Figure 13 about here

Delayed Naming Errors

The error data was analyzed in a 5 (Length) x 2 (Stimulus Format) ANOVA with repeated measures on each variable. The analysis of the error data (see Table 45) showed a significant main effect of length where errors increased with number of letters. There was also an effect of stimulus format where participants made more errors to case-altered than to lower-case nonwords (5.9% vs 1.9%) and an interaction between length and stimulus format where participants made more errors to long than to short nonwords in the case-altered rather than the lower-case condition.

Similar to error data from the online naming task, it appeared that the large error rate associated with the case-altered six letter nonwords in this delayed naming

Table 44

ANOVA by Subjects and Items for Delayed Naming Latencies: Experiment 4

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	2.83*	4	3.86**
MSE	116	(1547.41)	195	(3072.04)
Stimulus Format	1	0.16	1	3.99*
MSE	29	(983.96)	195	(1476.24)
Length x Stimulus Format	4	0.26	4	0.41
MSE	116	(813.45)	195	(1476.24)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 45

ANOVA by Subjects and Items for Delayed Naming Errors: Experiment 4

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	24.47***	4	10.35***
MSE	116	(23.49)	195	(67.38)
Stimulus Format	1	54.94***	1	42.39***
MSE	29	(22.57)	195	(48.48)
Length x Stimulus Format	4	19.63***	4	13.53***
MSE	116	(24.70)	195	(48.48)

* $p < .05$ ** $p < .01$ *** $p < .001$

task may have mediated the observed effects for this experiment. Close inspection of the error data showed that it was the same nonwords from Appendix 4 that may be the cause of some of the observed effects. After removing these items from the analysis, the percent error for this nonword group changed from 15.33% to 7.09% (see Figure 14). The results of the analysis of the error data with these outliers removed (see Table 46) showed that all of the significant effects observed in Table 45 remained significant. Despite the removal of these nonwords from the analysis, the percent error for this delayed naming task appears to be strongly influenced by number of syllables. Discussion of the role of number of syllables for lexical access and output is discussed further in the General Discussion.

Insert Figure 14 about here

Online vs residual production effects

The corrected response latencies are presented in Table 47. As shown in Table 48, the analysis of the corrected data replicated the findings from the noncorrected data. The magnitude of the length effect in the corrected data was similar to the noncorrected data (222 vs 239 ms, respectively). The magnitude of the stimulus format effect in the corrected data was also similar to that with the uncorrected data (144 vs 145 ms, respectively). Furthermore, the interaction between length and stimulus format remained significant after the correction for delayed naming. It is concluded that the results observed in the online naming task can be interpreted without any confounding post-lexical processes.

Table 46

ANOVA by Subjects and Items for Delayed Naming Errors with Outliers Removed:Experiment 4

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	8.31 ^{***}	4	5.57 ^{***}
MSE	116	(22.63)	186	(32.90)
Stimulus Format	1	28.62 ^{***}	1	37.33 ^{***}
MSE	29	(16.48)	186	(21.76)
Length x Stimulus Format	4	7.61 ^{***}	4	7.23 ^{***}
MSE	116	(19.06)	186	(21.76)

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 47

Online Naming Latencies Corrected for Delayed Naming Latencies: Experiments 4

<u>Length</u>	<u>Lower-Case</u>	<u>Case-Altered</u>
three	212	271
four	252	352
five	286	379
six	321	578
seven	375	585

Table 48

ANOVA by Subjects and Items for Corrected Naming Latencies: Experiment 4

<u>Subject</u>			<u>Item</u>	
<u>Source</u>	<u>df</u>	<u>F</u>	<u>df</u>	<u>F</u>
Length	4	58.78***	4	54.96***
MSE	116	(10361.64)	195	(11942.22)
Stimulus Format	1	60.21***	1	114.05***
MSE	29	(25756.07)	195	(12990.36)
Length x Stimulus Format	4	21.16***	4	11.66***
MSE	116	(5111.72)	195	(12990.36)

* $p < .05$ ** $p < .01$ *** $p < .001$

Summary

As with the results from Experiment 3, the results of Experiment 4 are consistent with Norris' (1994) multiple-levels model. Again, length was shown to affect processing at sublexical levels of processing. This was demonstrated by the interaction between length and stimulus format: As predicted, length effects on nonword naming were larger in the case-altered than the lower-case presentation condition. This interaction supports the assumption that the effects of length are directly related to the number of orthographic units that must be mapped onto phonology.

The delayed naming task revealed that both length and stimulus format (error data only) influenced nonword processing during output. Unlike the online naming portion of this experiment, number of syllables may be a better predictor of length effects during output than number of letters. Regarding the error data, the effect of syllables was demonstrated to be confined to the case-altered stimuli. This finding indicates that case alternation may disrupt the output process(es) involved in preparing a vocalization involving syllabic breaks in nonwords.

GENERAL DISCUSSION

The present research examined length effects in word and nonword naming. An online naming paradigm was used to discern whether length influences processing during encoding and/or lexical access. According to additive factors logic (Sternberg, 1969), if length influences encoding, then length should interact with stimulus quality because stimulus quality is believed to affect the rate at which information is encoded (Becker & Killion, 1977; Besner & Chapnik-Smith, 1992; Meyer et al, 1975; Stanners et al., 1975). If length influences lexical access, then length should interact

which any level contributes to generating a pronunciation depends upon the characteristics of the stimuli. For example, letter strings which are difficult to process (i.e., low-frequency words, case-altered words, and nonwords) receive a greater contribution from sublexical units of analysis than larger multi-letter units (i.e., lexical-level units). More common, high-frequency words receive relatively more contribution from the lexical level.

The length effects observed in the present research are consistent with the view that increasing the processing difficulty of a word requires the word recognition system to rely more on sublexical than lexical-level information. According to Frederiksen (1980, 1981, Frederiksen et al., 1985), long words do not provide enough information about multi-letter units within the letter string. On this view, length effects reflect the fact that for long letter strings the word recognition system must identify and integrate numerous small units. This account of length effects on naming latencies fits well with the processing assumptions of the multiple-levels perspective (Herdman et al., in press, Norris, 1994).

In accord with the assumptions of Frederiksen (1980, 1981, Frederiksen et al., 1985) and the multiple-levels perspective (Herdman et al., in press, Norris, 1994), increasing word length has an effect on lexical access that is similar to the effects of decreasing word frequency and presenting words in case-altered format: For longer words, the word recognition system is forced to rely more on sublexical than lexical information than for shorter words. That the sublexical levels do not contribute greatly to the processing of short words is reflected in the assumption that short words are processed rapidly as a single, visually addressable representation via the lexical

level. That long words require more time to process than short words is consistent with the view that long words are processed via sublexical information.

The multiple-levels account is also supported in the interactions between length and frequency and length and stimulus format that were found in the present research. On the assumption that length influences sublexical levels of processing, the effects of length interacted with frequency because the contribution of sublexical mappings are greater for low- than for high-frequency words. Stimulus format and length interacted because presenting letter strings in case-altered format increases the reliance on the sublexical levels.

Additional support for the multiple-levels account comes from the finding that length has a greater effect on naming nonwords than words (Mason, 1978; Weekes, 1997). The effects of length in the present research were more than twice as large for nonword naming (Experiments 2 and 4) than for word naming (Experiments 1 and 3). In the multiple-levels framework, phonological coding of nonwords relies exclusively on sublexical levels of processing. On this view, the effects of length are greater for nonwords than for words because, for words, the lexical level diminishes the relative contribution of sublexical input.

Figure 15 supports the notion that the results of the present research reflect the contribution of various levels of processing. Specifically, changes in the effect of length from short high-frequency words presented in lower-case format to long nonwords presented in case-altered format reflect the contribution of various levels of information required to process letter strings which vary in difficulty of processing. It can be argued that lexical-level information dominates the processing of the short high-frequency words presented in lower-case format, whereas various levels of

sublexical information dominate the processing of increasingly difficult letter strings with single-letter representations providing the greatest contribution for the long nonwords presented in case-altered format. Thus, for a model of visual word recognition to account for these findings, it appears that the model must consist of various OPCs to account for a variety of online naming responses (see Frederiksen, 1980, 1981, Frederiksen et al., 1985; Sternberg, 1969). That the multiple-levels model contains six levels of processing units that range from whole-word to individual letter units provides a viable way to account for the length effects observed in the present research.

Insert Figure 15 about here

In the present study, length effects have been interpreted as reflecting the number of letters that comprise a word or nonword. Despite this, the multiple regression analyses from Experiments 2, 3, and 4, showed that number of syllables accounted for significant proportions of variance in the response latencies in online naming. Figures 4, 7, and 11 show that response latencies are longer for two than single syllables letter strings. In its present form, the multiple levels model cannot account this effect of number of syllables because the model does not contain a sublexical level for syllables. That the model does not contain a syllable level is due to an attribute of the corpus of words that the model was trained on for simulations. That is, the model was trained with monosyllabic words. Thus, there was no need to include a level for syllabic processing in the model. However, the original formulation of the multiple-levels model (Shallice et al., 1983), the model contains a

level for processing syllables. In order to account for the effects of number of syllables in online naming, this syllable level of processing needs to be reinstated as a part of the model's sublexical levels. Thus, in its original form, the multiple-levels model can account for the effects of number of syllables observed in the present study.

At this time, the multiple-levels (Herdman et al., in press; Norris, 1994) model has not been implemented to simulate the effects of length on naming. Consequently, a complete evaluation of the model's ability to simulate length effects cannot be made until an appropriate simulation is attempted. At a conceptual level, given the discussion of length effects thus far, a 'lengthy' leap of faith is probably not required to assert that the multiple-levels perspective will be able to simulate length effects on naming performance. However, making the necessary adjustments to the parameters of this model may turn out to be a nontrivial challenge. Not only will the model need to simulate the effects of length on word and nonword naming, but these changes will also have to maintain the effects of word frequency, regularity, case-alternation, and the interactions between length and frequency, length and case alternation, and as would be predicted on the basis of additive factors logic, an interaction between length and regularity.

Length and Other Models of Word Recognition

The Dual-Route model

Dual-route theorists assume that processing occurs along two independent routes: A visually addressable lexical route and a rule-based sublexical/assembly route. By simply assuming that the assembly route is sensitive to the number of sublexical elements (e.g., graphemes) that must be processed, dual-route theorists can

account for length effects in word and nonword naming: Long letter strings have many sublexical elements which slows naming. Furthermore, because the assembly route is assumed to play a greater role in processing low- than high-frequency words, a dual-route approach provides a straightforward account of the finding that length interacts with frequency. The interaction between stimulus format and length can also be addressed using the assumption that presenting letter strings in case-altered format increases reliance on, length-sensitive, processes in the assembly route. Finally, the finding that length interacts with lexicality fits with the notion that the reliance on the assembly route is greater for nonwords than for words.

Although the dual-route approach can account for the aforementioned effects of length, this approach cannot provide a complete account of the present results. In particular, and as discussed by Herdman et al. (in press), a dual-route approach cannot be used to explain the three-way interaction that has been found between stimulus format, frequency, and regularity. As discussed above, if case alternation slows processing more along the lexical than the assembly route (Besner, 1990), then the effects of case alternation should be greater for low-frequency irregular words than for low-frequency regular words. As shown by Herdman et al., however, case alternation slows naming of low-frequency irregular and regular words equally. The alternative assumption that case alternation slows processing more along the assembly than the lexical route has also been rejected: This assumption leads to the erroneous prediction that case-altered presentation should facilitate naming of low-frequency irregular words by diminishing the contribution of the incorrect assembled phonology to the naming of an irregular word.

cannot account for length effects, the interaction between length and lexicality, and by default, the interaction between length and lexicality.

Another problem for PDP theorists (Plaut et al., 1996; Seidenberg & McClelland, 1989) is that this approach cannot account for the effects of case alternation on naming latencies. As discussed in the Introduction, the orthographic input layer of the PDP model provides an abstract representation of letter strings. Because this input layer makes use of abstract letter representations, presenting letter strings in lower-case versus case-altered format cannot effect processing in the input layer. Consequently, case-alternation must influence processing prior to the lexical network and therefore, PDP theorists cannot account for the interactions between case alternation and length observed in the present study.

In sum, a PDP approach (Plaut et al., 1996; Seidenberg & McClelland, 1989) cannot account for the effect of length and case alternation on word and nonword naming. Thus, a PDP approach is unable to provide an account for the observed interactions between length and frequency, length and case alternation, and length and lexicality.

Length and Output

In the present research, the primary purpose of including a delayed naming task was to control for effects in online naming that arise during output because of possible extraneous interactions between stimuli and the apparatus. However, the delayed naming data also provided an opportunity to speculate about how length may influence response output. In the delayed naming tasks of Experiments 2, 3, and 4, length effects in delayed naming were found almost exclusively within the error data.

Only in Experiment 4 was length observed to influence delayed naming latencies. The results from the delayed naming tasks are shown in Table 49.

In Experiment 1, length did not influence delayed naming latencies or errors for word stimuli. This suggests that length does not influence response output to words. The error data from the delayed naming condition of Experiment 2 suggested, however, that length influences the output of nonword stimuli: More errors in delayed naming to long than to short words. However, the findings from this delayed naming task must be interpreted with caution because of a potential problem with the delayed naming procedure. In particular, the effect of length in delayed naming may be an artifact of incomplete processing during encoding because an insufficient amount of presentation time was used.

In Experiment 3, length was observed to influence percent error in the delayed naming task. This suggests that length influences response output with word stimuli. In addition, because length was observed to interact with word frequency, and both length and word frequency were observed to be additive with stimulus format (these findings are based on the error data analysis with outliers removed), this pattern of results suggests that length and word frequency influence a common level of response output that is different from the level of response output that stimulus format influences. Within the context of the findings of Balota and Chumbley (1985), both length and word frequency may influence an early level of response output. Balota and Chumbley showed that word frequency has a greater influence on the earlier rather than later levels of output by demonstrating a diminishing effect of frequency with increases in delay interval. In the present research, because number of letters

was observed to interact with frequency, we can infer that number of letters influences the same early processes as word frequency. Further research is required to determine which level of response output stimulus format influences when words are being processed.

In Experiment 4, length was shown to influence both percent error and naming latencies (main effect only) associated with nonword naming. Interestingly, the data from Experiment 4 suggests that the length effects were related to number of syllables rather than to number of letters. According to some researchers, syllables do not affect an early component of output that may be involved in the derivation of phonemic content, but instead, influence the last component of output: vocalization (Sevold et al., 1997; Frederiksen, 1980, Sternberg, et al., 1978). It is hypothesized that the motoric component of output is in some way sensitive to the number of sounds required for each syllable and stress assignment. The sensitivity of this motoric component to multi-syllabic letter strings has the effect of adding a constant amount of time to the overall response time for the pronunciation of that letter string. Interestingly, stimulus format and number of syllables had interactive effects with the error data in Experiment 4. This finding suggests that number of syllables and stimulus format may influence a common stage of response output when nonwords are being processed.

To summarize, the findings from Experiment 3 suggest that length (defined as number of letters) and word frequency influence the processing of words at an early level of response output. In Experiment 4, length (as defined as number of syllables) and stimulus format appear to influence the processing of nonwords at a later level of response output: vocalization.

General Conclusions

The present study has shown that length, as defined by number of letters, influences lexical access. It was suggested that length influences this stage of processing by mediating the size of the perceptual unit of analysis used to process letter strings. Furthermore, the magnitude of length effects on naming was demonstrated to interact with word frequency, case alternation, and lexicality. These findings and conclusions are consistent with a multiple-levels model (Herdman et al., in press; Norris, 1994) of visual word recognition.

Future research into the effects of length on word and nonword naming should focus on the perceptual units of analysis used to process letter strings. The present study did not explicitly investigate this avenue of research. However, the present findings do provide support for theories of word recognition in which the visual word recognition system is viewed as a multi-level framework corresponding to various sizes of perceptual units of analysis. Future research should provide more detailed information about the types of sublexical information that the word processing system can utilize. A fruitful starting point for this research would be to examine the relationship between length effects and individual differences in naming performance. Because researchers (Butler & Hains, 1979; Lichacz & Herdman, 1995; Marr & Kamil, 1981; Mason, 1978; Mason et al., 1981; Spielberger & Denny, 1963; Waters et al., 1984) have shown that the naming latencies of skilled readers are less influenced by orthographic variables than are less-skilled readers, this suggests that skilled readers make greater use of lexical-level information than less-skilled readers. Consequently, length effects in word and nonword naming should be attenuated for skilled readers in comparison to less-skilled readers. Furthermore, the present study

also provided some evidence that length, as defined by number of letters and number of syllables, may influence the response output stage of the word recognition system. Although these findings are not directly applicable to current perspectives on how orthographic and phonological variables influence processing during lexical access, these findings could be a catalyst for future research aimed at deriving a better understanding of response output.

Notes

1. This traditional account stands in contrast to adherents of a parallel processing account of lexical processing (Plaut et al., 1996; Seidenberg & McClelland, 1989). According to Plaut et al., naming tasks cannot involve any form of sequential processing because sequential processing is a slow process that "may be satisfactory in many domains but not in word reading" (p. 65). Unfortunately, parallel processing theorists have not addressed the issue of length effects in their models.
2. Researchers have employed additive factors logic across a wide range of interests to model the cognitive system. For example, in addition to using additive factors logic to examine lexical processing (Becker & Killion, 1977; Besner & Chapnik Smith, 1992; Herdman et al., in press; Meyer et al., 1975; Stanners et al., 1975; Terry et al., 1976), researchers have used additive factors logic to examine the effects of narcosis on divers (Fowler, Mitchell, Bhatia, & Porlier, 1989), the effects of closed-head injuries on information processing (Schmitter-Edgecombe et al., 1992), the effects of global precedence in visual pattern recognition (Hughes et al., 1984), the effects of chronic illness on mental health (Erdal & Zautra, 1995), the effects of aging on information processing (Strayer, Wickens, & Braune, 1987), the locus of effects of selective attention in children (Enns & Cameron, 1987), and the effects of intersensory facilitation on reaction time (Schmidt, Gielen, & Van den Heuvel, 1984). In sum, additive factors logic has been an important research tool across an array of cognitive research interests.
3. There is the possibility that length does influence a pre-lexical stage of processing which is not influenced by stimulus quality (e.g., a substage). Because there has been

no explicit research on the substages of pre-lexical processing this possibility cannot be easily dismissed.

4. Orthographic neighbourhood size was indexed by Coltheart's N (Coltheart, Davelaar, Jonasson, & Besner, 1977).
5. Number of phonemes was not included in the analysis because although number of phonemes is correlated with number of letters, it has been demonstrated that number of letters is a better predictor of naming latencies than number of phonemes (see Weekes, 1997; Whaley, 1978).
6. Illumination intensity was measured using a Tektronix J6503 photometer. The illumination intensities that were used in the present experiments were selected based on the results of a pilot study in which participants named words until a significant difference in naming latencies was observed between levels of illumination.
7. The confidence intervals for Figure 1 and the rest of the figures in the present research represent the 95% confidence intervals as defined by Loftus and Masson (1994).
8. Although in its current form the PDP model (Plaut et al., 1996; Siedenberg & McClelland, 1989) cannot account for length effects, it would be possible modify parameter weights such that the network becomes sensitive to word/nonword length. However, making the necessary adjustments to the parameters may turn out to be a nontrivial challenge because the network will still have to be able to simulate the effects of frequency, regularity, and lexicality, that it is able to do presently.

Appendix 1

Word Stimuli used in Experiments 1 and 3

<u>Three-letter words</u>									
<u>Word</u>		<u>K&F Frequency</u>		<u>Bigram Freq</u>		<u>Neighbourhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low	High	Low
got	gut	482	1	11.0	149.0	19	15	1	1
day	bog	197	1	6.5	12.0	20	21	1	1
big	jot	360	1	21.0	94.5	17	17	1	1
job	rip	238	1	35.0	2.0	15	15	1	1
bad	bib	142	2	97.0	12.5	22	12	1	1
gun	gig	118	1	18.0	8.5	12	12	1	1
art	ire	208	1	78.0	70.0	8	5	1	1
law	lob	299	1	10.0	16.5	19	17	1	1
men	nay	763	2	32.0	71.5	13	17	1	1
yet	ale	419	1	58.0	58.0	14	14	1	1
far	fad	427	2	30.0	101.0	19	22	2	2
set	sap	414	1	73.0	23.0	20	22	2	2
sat	hex	150	2	29.0	52.0	26	8	2	2
tax	pun	196	1	4.0	21.0	15	16	2	2
car	cud	274	1	68.5	3.5	19	10	2	2
ten	hem	165	4	22.5	50.5	17	10	2	2
six	sip	220	2	12.0	9.5	13	20	2	2

top	tan	204	9	35.0	72.5	20	22	2	2
say	soy	504	1	93.5	14.0	29	19	2	2
pay	coy	<u>172</u>	<u>4</u>	<u>76.5</u>	<u>11.5</u>	<u>26</u>	<u>18</u>	2	2
Mean		297.6	1.7	40.5	42.6	18.2	16		

Four-letter words

<u>Word</u>		<u>K&F Frequency</u>		<u>Bigram Freq</u>		<u>Neighbourhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low	High	Low
next	numb	394	4	17.6	2.6	5	1	1	1
line	loin	298	1	86.3	38.0	20	6	1	1
girl	gout	220	2	19.6	54.0	5	7	1	1
dark	dole	185	1	44.3	49.5	11	20	1	1
word	noun	274	1	66.0	36.0	12	2	1	1
less	lice	438	2	35.0	59.6	11	12	1	1
blue	romp	143	1	13.0	55.3	5	5	1	1
need	bide	360	1	87.6	30.0	9	15	1	1
miss	jade	258	1	22.3	33.3	9	8	1	1
main	mash	119	1	88.6	79.6	11	15	1	1
form	fret	370	1	60.0	57.6	12	3	2	2
turn	tuck	233	2	17.6	51.6	6	11	2	2
true	toad	231	4	15.6	39.6	1	6	2	2
part	plod	504	1	46.0	26.0	16	6	2	2
hope	harp	178	1	30.0	89.0	15	9	2	2

The locus of length effects 120

case	cask	362	1	71.6	61.6	18	7	2	2
side	suck	380	5	38.6	64.6	11	14	2	2
sent	pram	145	1	41.6	4.6	14	5	2	2
high	hiss	497	2	29.6	23.0	2	6	2	2
find	flog	<u>299</u>	<u>1</u>	<u>75.3</u>	<u>9.0</u>	<u>12</u>	<u>8</u>	2	2
Mean		294.4	1.7	45.3	43.2	10.3	8.3		

Five-letter words

<u>Word</u>		<u>K&F Frequency</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low	High	Low
built	lurch	103	3	41.3	36.5	3	2	1	1
board	retch	240	1	39.3	39.0	3	4	1	1
brown	vault	176	2	37.0	39.3	7	2	1	1
black	bloke	203	1	40.5	29.3	6	1	1	1
large	groan	361	1	35.0	37.3	2	3	1	1
group	roach	390	2	54.5	54.5	2	3	1	1
wrote	glean	181	1	35.3	35.5	2	2	1	1
north	noose	206	3	47.5	57.5	2	4	1	1
range	drake	160	2	25.7	22.7	2	3	1	1
leave	loath	205	3	56.0	31.0	3	1	1	1
front	float	221	3	47.5	27.5	2	3	2	2
place	pluck	571	2	52.5	24.0	4	3	2	2
sense	stunt	311	1	48.5	63.3	3	4	2	2

still	thump	782	3	78.7	78.0	8	3	2	2
field	flirt	274	1	59.7	19.3	3	1	2	2
since	stink	628	3	39.7	85.3	3	8	2	2
short	shrug	212	2	50.5	25.7	8	1	2	2
point	poach	395	1	70.5	56.5	3	7	2	2
class	crass	207	2	44.7	37.5	8	8	2	2
small	chunk	<u>542</u>	<u>2</u>	<u>30.7</u>	<u>34.3</u>	<u>5</u>	<u>3</u>	2	2
Mean		318.4	1.9	46.7	41.7	3.9	3.3		

Six-letter words

<u>Word</u>		<u>K&F Frequency</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low	High	Low
enough	beware	430	3	37.2	50.0	0	0	1	1
around	allure	561	1	56.0	30.8	2	1	1	1
number	nether	472	1	58.2	63.8	4	2	1	1
better	beckon	414	1	103.6	44.8	12	1	1	1
action	beaver	291	3	27.4	88.2	0	7	1	1
moment	mellow	246	1	29.0	25.2	2	4	1	1
reason	rafter	241	4	43.4	67.0	1	4	1	1
matter	mumble	308	1	94.8	38.2	11	6	1	1
mother	mingle	216	2	68.6	43.0	2	5	1	1
volume	vortex	135	1	12.6	33.0	1	2	1	1
toward	supine	386	1	18.6	38.0	1	1	2	2

police	propel	155	4	24.6	28.2	2	2	2	2
public	pickle	438	1	14.0	31.8	0	4	2	2
system	sadist	416	1	30.0	51.4	0	1	2	2
common	carrot	223	1	23.4	24.6	0	1	2	2
figure	fiddle	209	2	31.8	38.0	1	6	2	2
simple	sallow	161	1	45.6	33.0	6	6	2	2
couple	cavern	122	1	55.2	26.0	0	1	2	2
father	faucet	183	1	78.0	22.0	5	1	2	2
single	spider	<u>172</u>	<u>2</u>	<u>44.2</u>	<u>67.2</u>	<u>5</u>	<u>2</u>	2	2
Mean		288.9	1.6	44.8	42.2	2.7	2.8		

Seven-letter words

<u>Word</u>		<u>K&F Frequency</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low	High	Low
because	disgust	883	1	47.6	20.3	0	0	1	1
between	despise	730	1	37.6	26.3	0	1	1	1
million	bastion	204	2	41.0	40.8	5	0	1	1
written	butcher	154	8	34.2	47.5	0	1	1	1
neither	brothel	141	1	60.0	43.8	0	1	1	1
western	lobster	137	1	40.0	37.3	0	1	1	1
justice	bluster	114	1	34.6	38.3	0	6	1	1
nothing	recluse	412	2	120.6	35.5	1	0	1	1
measure	deathly	91	6	37.2	41.6	0	0	1	1

greater	glimmer	188	1	43.5	33.8	3	3	1	1
control	compile	223	1	21.0	27.3	0	0	2	2
provide	preside	216	2	28.5	24.0	0	0	2	2
program	crusher	394	1	27.2	40.8	0	2	2	2
country	fission	324	5	33.0	33.0	0	1	2	2
college	checker	267	1	27.3	36.8	0	0	2	2
special	heathen	250	2	21.2	49.6	1	1	2	2
further	feather	218	6	53.5	62.3	1	3	2	2
problem	prosper	313	3	35.2	41.6	0	0	2	2
section	platter	189	2	50.5	47.6	2	6	2	2
picture	plunder	<u>162</u>	<u>2</u>	<u>30.2</u>	<u>31.3</u>	<u>0</u>	<u>3</u>	2	2
Mean		280.5	2.5	41.2	37.8	0.6	1.5		

Note. High = High-frequency words, Low = Low-frequency words

The numbers 1 and 2 in the Onset column refer to voiced and unvoiced onsets, respectively.

tis	tay	92.2	74.0	10	22	2	2
ket	sen	49.5	42.0	18	18	2	2
cug	poy	<u>4.0</u>	<u>11.0</u>	<u>17</u>	<u>15</u>	2	2
Mean		38.9	45.5	13.7	14.7		

Four-letter nonwords

<u>Word</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low
lext	lumb	19.3	5.6	6	5	1	1
gine	goin	58.0	28.0	16	7	1	1
wark	vout	53.0	35.6	17	7	1	1
jeal	jeem	52.0	88.3	12	6	1	1
mide	roun	36.0	49.3	19	7	1	1
bess	bice	59.0	20.6	13	12	1	1
zirl	gomp	9.3	58.6	1	4	1	1
yest	yide	97.0	27.3	10	9	1	1
bife	bick	19.0	32.6	11	14	1	1
yain	yash	49.7	37.6	10	10	1	1
torm	tret	67.6	20.3	12	5	2	2
kurn	kuck	15.3	49.3	4	10	2	2
prue	poad	8.3	24.3	1	7	2	2
sirm	slod	21.3	22.0	2	11	2	2
fope	farp	27.6	42.3	10	9	2	2

tace	hask	68.0	97.0	14	12	2	2
kide	fack	35.6	53.3	11	10	2	2
hent	fram	54.3	55.0	16	10	2	2
figh	fiss	42.3	35.6	5	15	2	2
pind	plog	<u>56.0</u>	<u>11.0</u>	<u>15</u>	<u>9</u>	2	2
Mean		42.4	39.6	10.3	8.9		

Five-letter nonwords

<u>Word</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low
ninge	zirth	21.3	42.0	4	4	1	1
darge	yetch	28.7	45.3	6	4	1	1
doice	dault	72.0	41.0	2	4	1	1
glack	gloke	39.7	28.5	6	3	1	1
zorce	rymph	41.0	1.5	1	2	1	1
noard	voach	37.5	52.0	3	5	1	1
breen	blean	57.0	36.3	3	5	1	1
borth	boose	49.3	59.3	7	6	1	1
geath	grake	54.3	26.7	3	9	1	1
meave	moath	53.5	37.3	3	4	1	1
pront	ploat	48.3	28.7	4	4	2	2
flace	fluck	51.3	22.7	6	7	2	2
herve	slunt	20.7	33.0	5	6	2	2

slace	shump	48.0	18.0	8	4	2	2
slear	slirt	27.3	16.0	6	3	2	2
shart	shonk	50.5	60.0	11	4	2	2
taith	thrug	50.5	60.0	1	2	2	2
hoint	hoach	77.5	63.5	3	4	2	2
plass	prass	40.7	37.3	6	8	2	2
krive	thunk	<u>26.5</u>	<u>99.7</u>	<u>1</u>	<u>4</u>	2	2
Mean		44.7	41.7	4.5	4.6		

Six-letter nonwords

<u>Word</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low
unough	deware	37.2	33.2	1	1	1	1
agound	allore	39.2	40.2	2	1	1	1
bumber	bether	58.4	84.6	7	7	1	1
retter	deckon	95.6	28.0	12	2	1	1
ection	reaver	20.4	80.2	1	6	1	1
mament	rellow	27.0	37.8	2	4	1	1
dather	refter	70.4	86.6	7	2	1	1
motter	momble	87.6	43.2	10	1	1	1
mather	langer	75.8	64.4	8	8	1	1
lolume	lortex	18.6	39.0	1	2	1	1
towerd	sumine	18.0	48.8	2	1	2	2

polace	protel	18.4	37.2	3	1	2	2
peblic	hickle	17.2	32.6	1	6	2	2
sestem	cadist	43.0	24.0	2	1	2	2
hannot	fanter	18.2	83.0	1	7	2	2
sigure	sellow	32.6	32.0	1	5	2	2
semple	foddle	50.4	38.6	3	6	2	2
fouple	slaxen	50.8	17.0	1	1	2	2
hather	farcet	74.8	28.2	7	1	2	2
hingle	seffix	<u>41.2</u>	<u>20.8</u>	<u>5</u>	<u>1</u>	2	2
Mean		44.7	44.9	3.8	3.2		

Seven-letter nonwords

<u>Word</u>		<u>Bigram Freq</u>		<u>Neighborhood</u>		<u>Onset</u>	
High	Low	High	Low	High	Low	High	Low
betause	bellon	41.0	34.6	1	1	1	1
betteen	beclare	45.6	33.7	1	1	1	1
mellion	glister	43.2	38.5	2	3	1	1
wratten	mastion	33.2	44.3	1	1	1	1
beither	bettler	61.3	55.2	1	1	1	1
bestern	glutter	44.0	38.0	1	4	1	1
jurtice	rempest	29.8	33.2	1	1	1	1
gorning	meather	130.0	66.0	1	4	1	1
beasure	bection	44.3	57.5	2	2	1	1

breater	loisten	44.0	25.5	2	1	1	1
kerself	conteen	23.2	37.0	1	2	2	2
protide	clatoon	44.3	27.6	1	1	2	2
prigram	plander	22.3	38.6	1	3	2	2
hountry	shammer	26.0	34.6	1	2	2	2
correge	thamber	32.3	40.0	1	1	2	2
spudent	corture	20.2	41.5	1	2	2	2
surther	standal	58.5	32.2	1	1	2	2
prablem	chicker	27.2	33.8	1	3	2	2
seation	hission	54.0	33.8	2	2	2	2
hicture	conpose	<u>32.8</u>	<u>26.5</u>	<u>1</u>	<u>1</u>	2	2
Mean		42.8	38.6	1.2	1.8		

Note. High = Nonwords derived from high-frequency words, Low = Nonwords derived from low-frequency words.

The numbers 1 and 2 in the Onset column refer to voiced and unvoiced onsets, respectively.

Appendix 3

Outliers from the Online and Delayed Naming Tasks of Experiment 3

<u>Stimuli</u>	<u>(Online) %Error</u>	<u>(Delay) % Error</u>
1. nEtHeR (nether)	53.33	6.67
2. mUmBlE (mumble)	33.33	6.67
3. mInGlE (mingle)	26.67	13.33
4. pIcKlE (pickle)	33.33	13.33
5. fIdDlE (fiddle)	26.67	6.67
6. sAlLoW (sallow)	<u>46.67</u>	<u>13.33</u>
	Mean = 36.67	Mean = 10.00

* the word nEtHeR was pronounced as 'neither'

Appendix 4

Outliers from the Online and Delayed Naming Tasks of Experiment 4

<u>Nonwords</u>	<u>(Online) %Error</u>	<u>(Delay) %Error</u>
1. sEmPIE (semple)	73.33	26.67
2. fOuPIE (fouple)	93.33	53.33
3. hInGlE (hingle)	80.00	33.33
4. aLIOrE (allore)	46.67	40.00
5. rElLow (reallow)	40.00	46.67
6. mOmBIe (momble)	93.33	53.33
7. hIcKIe (hickle)	80.00	80.00
8. fOdDIe (foddle)	66.67	46.67
9. sIgUrE (sigure)	<u>40.00</u>	<u>20.00</u>
	Mean = 68.15	Mean = 44.44

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Figure 1: Online Word Naming Latencies In Experiment 1
(Subject Data)

Figure 2: Online Word Naming Latencies in Experiment 1 (Item Data)

Figure 3: Stimulus Quality x Word Frequency Interaction for Percent Error in Online Naming in Experiment 1.

Figure 4: Online Nonword Naming Latencies in Experiment 2

Figure 5: Delayed Nonword Naming Errors in Experiment 2.

Figure 6. Main Effect of Length for Online Word Naming in Experiment 3.

Figure 7. Online Word Naming Latencies in Experiment 3.
(Subject Data)

Figure 8. Online Word Naming Latencies in Experiment 3.
(Item Data)

Figure 9: Online Word Naming Errors in Experiment 3.

Figure 10: Delayed Word Naming Errors in Experiment 3.

Figure 11: Online Nonword Naming Latencies in Experiment 4.

Figure 12: Online Nonword Naming Errors in Experiment 4.

Figure 14: Delayed Nonword Naming Errors in Experiment 4

Figure 15: Magnitude of Length Effects across Experiments 3 and 4

IMAGE EVALUATION TEST TARGET (QA-3)

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