2003

Phonological structure in spoken and written language : evidence for a shared representation.

Jane Ashby
University of Massachusetts Amherst

PHONOLOGICAL STRUCTURE IN SPOKEN AND WRITTEN LANGUAGE: EVIDENCE FOR A SHARED REPRESENTATION

A Thesis Presented

by

M. JANE ASHBY

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

February 2003

Psychology

PHONOLOGICAL STRUCTURE IN SPOKEN AND WRITTEN LANGUAGE:

EVIDENCE FOR A SHARED REPRESENTATION

A Thesis Presented

by

M. JANE ASHBY

Approved as to style and content by:

Keith Rayner, Chair

Alexander Pollatsek, Member

John Kingston, Member

Melinda Novak, Department Head
Psychology

ACKNOWLEDGMENTS

I would like to thank Keith Rayner, Sandy Pollatesk, John Kingston and Chuck Clifton for their support, guidance, and insights regarding this thesis. Anne Cook, Sarah Hawrylak and Tami Katzir contributed in other important ways. I would also like to thank my parents for their ongoing encouragement.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

PHONOLOGICAL REPRESENTATIONS IN READING AND SPEECH

Introduction

Over the past twenty years, researchers have gained a good deal of knowledge about the cognitive processes that occur during reading (Rayner, 1998; Adams, 1990). Particularly, developments in eye-movement technology revolutionized reading research by allowing precise data collection while participants read sentences in a natural fashion, i.e. silently and at their own pace. This on-line method records the position of the eye in written text each millisecond, gathering specific information about where a reader is looking at any given time. Findings from eye movement research continue to contribute to our understanding of the interaction of phonological, orthographic, and lexical processes in adults who are proficient readers.

This thesis presents two eye movement experiments that investigate the phonological processes involved in reading. Traditionally, eye movement experiments have examined the role of phonology using homophone and pseudohomophone stimuli within parafoveal preview and fast-priming paradigms (Lesch & Pollatsek, 1998; Pollatsek, Lesch, Morris & Rayner, 1992; Rayner, Sereno, Lesch & Pollatsek, 1995). Recent experiments have contrasted phonological and orthographic processing to describe the time course of each process during word recognition (Lee, Rayner & Pollatsek, 1999). Collectively, these experiments found evidence of pre-lexical phonological processes operating at the letter/phoneme level in reading, irrespective of which experimental paradigm was used. Although this research has established a central role for phonological processes, it has not specified the form of phonological representations, their use or when they are created.

One basic question is whether reading and speech share the same phonological representations. Perfetti, Zhang, and Berent (1992) are among the many reading researchers who contend that the pervasiveness of phonological processes indicates that reading is making use of pre-existent, oral language processes. According to this view, reading is an acquired skill that utilizes the same phonological channels as speech. Informal observation suggests that this might be true. Proficient readers often describe an awareness of the sound of text as they read silently. This "voice-in-the-head" phenomenon is presumed to be the subjective experience of converting print into language, or the conscious awareness of phonological representations. Yet, surprisingly few researchers have attempted cross-disciplinary projects that invoke the phonological principles of spoken language in order to further understand phonological representations in reading (see Birch, Pollatsek, & Kingston(1998) as an exception) . As a result, little is known about the points of overlap between the phonological representations used in reading and in spoken language.

Other basic questions address the nature of phonological representations. Do phonological representations consist solely of phonemes? Several additional conceptions seem plausible. Phonological representations might involve strings of syllables, each with its own internal structure. In turn, the structure of syllables might be flat or, instead, hierarchically composed of several layers.

Many reading researchers conceptualize phonological representations as strings of phonemes, but linguistic evidence offers an alternative description of phonological representations as multi-layered, dimensional structures. Linguistic models of phonology share a core concept: phonological representation consists of a hierarchical structure (Selkirk, 1982; Treiman, Fowler, Gross, Berch & Weatherstone, 1995; Clements & Keyser, 1983). In a chapter reviewing lexical phonology, Frauenfelder and Lahiri (1989) described a multidimensional model from Clements and Keyser (1983) that includes three layers of representation: a prosodic level that indicates the number of syllables in a word; a skeletal level which codes the consonant/vowel pattern; and a melodic (phonetic) level that describes the actual speech sounds.

Word:			CANDY		
Prosodic level		δ			δ
Skeletal level	C	V	C	C	V
Melodic level	[k	ae	n	d	i]

Recently, some researchers have applied this linguistic perspective to study phonological representation during isolated word reading. Berent, Bouissa, and Tuller(2001) and Berent, Shimron and Vaknin(2001) used the hierarchical view as a theoretical base for investigating word recognition in English and Hebrew, respectively. In these papers, Berent and colleagues confined their attention to the basic, skeletal level of the representation, probably because that layer was most relevant to their specific hypotheses. The research presented in this thesis takes a somewhat different approach, focusing on the syllable level of phonological representation.

If reading and speech do share channels of phonological representation, then evidence for hierarchical phonological structure should be found in reading as well as in spoken language. In that case, syllable effects that have been observed in speech perception and production should also appear in reading experiments. To test that assumption, the eye movement experiments presented here draw on methods that have identified a syllabic layer in the phonological structure of speech. These experiments seek evidence of the syllable as a unit of phonological representation in reading and examine whether syllabic structure guides word recognition processes. Although several naming and lexical decision experiments have looked at the role of syllables in isolated word recognition, this is the first attempt to use syllable structure to investigate the nature of phonological representations in the course of natural, silent reading of sentences.

An extensive body of research describes the role of syllables and syllable structure in various aspects of spoken language. The following literature review discusses selected, major findings about the role of syllables in spoken word recognition, visual word recognition, and post-lexical processing.

Background Information

The research on syllable effects in spoken language has yielded disparate findings. Although most syllable effects replicate when tested with methods used in the original experiment, few findings replicate across paradigms. As I discuss in upcoming sections, examples of paradigm-constrained results abound. For example, syllable effects not apparent in monitoring tasks (Cutler, Mehler, Norris, & Segui, 1986) did appear consistently in memory tasks (Bruck, Treiman, & Caravolas, 1995) and in induction experiments (Finney, Protopapas, & Eimas, 1996; Pitt, Smith & Klein, 1998).

One interpretation of these disparate findings is that the role of the syllable in processing English is illusory (Seidenberg, 1987; Cutler et al., 1986). On the other hand, apparently ephemeral syllable effects might reflect the distinct nature of the processes tapped by different paradigms. It is possible, for example, that one paradigm detects effects of syllabic structure while another paradigm detects syllable segmentation processes. In turn, structure effects and segmentation processes might impact distinct aspects of language processing, e.g. phoneme perception or lexical access. The possible connections in this paradigm/effect/level-of-language-processing chain increase exponentially as data are gathered in different languages. It's no wonder that so many possibilities threaten the coherence of theories concerning the syllable's role in phonological representation.

The following sections discuss both significant and null findings of syllable effects in terms of the experimental method used, type of effect, the locus of the effect, and the language context of their observation. Hopefully, this approach will suggest which spoken language processes seem most likely to use syllabic units for what purpose(s) in phonological representation. Once this is established, I review the findings from naming and lexical decision experiments with visually presented stimuli in terms of their congruence with results from spoken language research.

Syllable Effects in Speech Perception

Researchers began investigating the syllable's role in speech perception in various languages largely in response to Mehler et al.'s demonstration of syllable effects in French (Mehler, Dommergues, Frauenfelder & Segui, 1981). In trying to replicate the effects found by Mehler et al. (1981), researchers mostly used the same method, called sequence monitoring.

Sequence monitoring tasks involve the presentation of a visual target (either a CV or CVC syllable), followed by an auditory presentation of the carrier word (BALCON). In the experimental conditions the target is either syllabically congruent (BAL) or incongruent (BA) with the syllabic structure of the carrier word. A control condition used foil sequences (such as SAN) that were not present in the carrier word. Participants hit a yes or no button in response to whether the carrier word included the target sequence of phonemes. Mehler et al. (1981) found that participants were slower to respond "yes" to a matching sequence when that sequence did not constitute a complete syllable in the carrier word. Faster detection of matching targets and carriers when the target did constitute a complete syllable of the carrier word indicated a sensitivity to syllabic units; this is known as a syllable effect.

Demonstrations of syllable effects vary depending on the language being studied, perhaps because languages are governed by different phonological structures. French, for example, is a syllable-timed language where each syllable is articulated without lexical stress in a regular rhythm. English, on the other hand, is a stress-timed language where syllables are articulated differently depending on the stress each receives (Cutler & Norris, 1988). The impact of stress on the realization of the vowel is obvious in homographs such as ‘rebel’ (the person) and ‘rebel’ (the action), where the first ‘e’ is either reduced or full depending on the meaning intended. According to Selkirk (1982), the rhythmic unit in stress-timed languages such as English is the foot, which begins at a stressed syllable and includes one or more of the subsequent unstressed syllables. A few examples of foot structure in spoken words follow:

Word	Number of Feet	Stress Pattern
HAPPY	1	[`happy]
MINNNESOTA	2	[`Minne][`sota]
APALACHICOLA	3	[`Apa][`lachi][`cola]

English and French differ with respect to the prominence of the foot or the syllable as a rhythmic unit as well as in the variation in syllable stress, which occurs only in English. Spanish is a language that incorporates both of these characteristics, since it is at once syllable-timed and shares with English the property of varying lexical stress (Bradley, Sanchez-Casas & Garcia-Albea, 1993). Catalan, like English, is a stress-timed language.

Cross-language experiments. Interest in cross- language comparisons of the syllable’s role arose with an investigation by Cutler et al. (1986) of the role of syllables in French and English. A classic series of experiments conducted in two languages, with native and non-native speakers, found distinct differences in the performance of English and French participants. English speakers did not show any evidence of using syllabic units in a monitoring task, while French speakers used syllabic units in their perception of both English and French words. These results suggest that the relevance of syllabic units in speech perception is primarily influenced by the phonological structure of the speaker's native language.

In a replication of the Cutler et al. (1986) studies, Bradley et al. (1993) compared speakers of Spanish and English on their response latencies in a syllable monitoring task. The Spanish speakers showed sensitivity to syllabic units, replicating the findings of Cutler et al. (1986) with French speakers. The English speakers, however, responded faster when the target and carrier shared more phonemes, irrespective of whether the carrier word shared the syllable structure of the target, which suggests that English speakers do not use syllabic units in speech perception.

In their summary of the literature, Frauenfelder and Kearns (1996) categorized the findings of cross-language sequence monitoring experiments. As discussed above, syllable effects in speech perception were found among speakers of French and Spanish, two languages which share a syllable-timed phonological structure (Cutler et al., 1986; Bradley et al., 1993). Experiments with English and Catalan speakers, which are both stress-timed languages, yielded inconsistent results. Syllable monitoring tasks with English speakers did not offer any evidence for the syllable as a perceptual unit. However, Catalan speakers did show a syllable effect for their perception of words with initial unstressed syllables, but not for words with initial stressed syllables (Sebatian-Galles, Depoux, Segui, & Mehler, 1992). Despite the inconsistent findings, or perhaps because of them, these cross-language experiments raised interest in the study of syllable effects in English.

Speech perception experiments in English. In the mid 1990's, researchers started investigating the syllable's role in speech perception using an attention induction paradigm (Finney et al., 1996; Pitt et al., 1998; Smith & Pitt, 1999). The induction technique operates quite differently than sequence monitoring and, therefore, may tap into a distinct role of the syllable in speech perception. Recall that sequence monitoring tasks measure the time to judge whether a target sequence of phonemes occurs in a stimulus word and, thereby, tap into the use of syllables for segmentation. With the induction paradigm, however, a target corresponds to its carrier only on the basis of a similar (or different) abstract syllable structure. The induction paradigm, then, allows investigation of the effects of syllabic structure on phoneme perception in spoken language.

In induction experiments, a target letter representing a phoneme appears on the screen followed by the auditory presentation of a word. Participants hit a yes or no button to indicate whether the target phoneme is contained in the word. The target phoneme always appears in the third position, and words are classified as either onset or coda words. In onset words, the target phoneme appears in the onset of the second syllable as in "deBris". In the coda words, the phoneme occurs in the coda of the first syllable as in "maGnetic". The lists of presented words contain onset and coda words as well as distractors. Each word is preceded by at least one inductor word that either shares or doesn't share its onset or coda status, eg. in the onset-onset condition "de-Bris" might precede "ne-Glected" or "coG-nition". If faster response times are observed when the structure of the inductor matches that of the target, then syllabic structure has induced attention to the target phoneme.

Finney et al. (1996) attempted to extend to American English the findings from induction experiments in French and Spanish that were pioneered by Pallier, Sebastian-Galles, Felguera, Christophe, and Mehler (1993). The first three of Finney et al.'s induction experiments used words with second-syllable stress. The results of Experiment 1 were consistent with those of Pallier et al. (1993); there was a significant induction effect for phoneme position in a syllable. Experiments 2 and 3 modified the stimuli to test whether the induction effect was the result of attention to the temporal location of the phoneme or the result of anticipation of consonant clusters. All three experiments supported induction of phonemes by syllable position. Experiment 4 attempted to assess whether these syllable induction effects were pre- or post-lexical by using pseudo words that followed the same phonotactic conventions as real words. There was a significant interaction between target and carrier type in these pseudo words, suggesting that induction effects are pre-lexical. Interestingly, the t-test for effects of coda targets on coda carriers was non-significant. This suggests that the onset target-onset carrier condition, e.g. "de-Bris" might precede "ne-Glected, was responsible for the significant induction effects. The induction effect of onsets was also stronger in the Pallier et al.(1993) experiments.

Given the failure of the Cutler et al.(1986) experiments to find evidence for syllable effects in first-syllable stress words, Experiment 5 tested for a syllable induction effect in words with first syllable stress. The data in this experiment extended Cutler's findings by failing to find evidence for syllabic induction of phoneme perception in spoken words with first syllable stress. However, research in visual word recognition, which is discussed in a later section, has demonstrated the salience of syllabic structure in both second-syllable and first-syllable stress words (Ferrand, Segui & Humphreys, 1997).

To summarize, the Finney et al. (1996) experiments demonstrate the relevance of syllabic structure in phoneme perception for native English speakers. Other studies using induction paradigms offer further support for that conclusion (Smith & Pitt, 1999; Pitt et al., 1998). Although these findings may seem inconsistent with the lack of syllable effects in the sequence monitoring task (Cutler et al., 1986), the inconsistency makes sense when one considers the different processes tapped by each method. Sequence monitoring results indicate that speakers of syllable-timed languages, such as French, use syllable segmentation processes while speakers of stress-timed languages do not. Pallier's findings from the first induction experiments indicate another role for the syllable in French: syllable structure primes phoneme perception. The findings from induction experiments in English simply suggest that the syllable has a more limited role in stress-timed languages, which may be restricted to words with initially unstressed syllables. In this sense, the seminal point from the Cutler et al. (1986) experiments still holds: the main factor in defining the role of syllables in speech perception is the phonological structure of the speaker's language -- not the language being heard.

The induction paradigm might be a more effective tool for investigating syllable effects in English because it taps a plausible role for syllabic structure in stress-timed languages -- a role that eludes detection by sequence monitoring tasks which primarily tap syllable segmentation practices. Induction experiments indicate that syllabic structure facilitates the perception of phonemes, even in languages where syllable segmentation processes might not mediate lexical access (Marslen-Wilson, 1978; 1980; 1994). It appears, then, that effects of syllabic structure can exist independently of syllable segmentation processes in speech perception. In that case, the inconsistent findings of syllable segmentation processes in various languages do not contradict evidence for the effects of syllabic structure on phoneme perception gathered from induction experiments. In sum, the experiments discussed above collectively point to a specific, if limited, effect of syllabic structure in English.

Syllable Effects in Visual Word Recognition

This section begins a discussion of experiments that investigate the role of syllables and syllabic structure in reading. First, I describe the data from naming experiments that involve both reading and production processes. Later sections consider data from lexical decision experiments, which tap word recognition processes without involving any observable speech production processes.

Naming experiments. The majority of research on the role of syllables in English involved the naming paradigm, where a word is presented visually and the subject names that word as quickly as possible. The naming experiments discussed in this section examine the effects of syllable units and syllabic structure.

Researchers investigated the syllable's role by contrasting the time to name monosyllabic and polysyllabic words, but the results were inconsistent. Several studies reported longer naming latencies for two syllable words than one syllable words (Klapp, Anderson, & Berrian 1973; Butler & Hains, 1979; Eriksen, Pollack, & Montague, 1970). Other studies found no effect of syllable number on the time to begin naming a word (Forster & Chambers, 1973; Fredricksen & Kroll, 1976).

More recently, Jared and Seidenberg (1990) investigated whether frequency effects could explain the divergent findings in naming latency of multi-syllable words. Their series of experiments attempted to answer that question by manipulating word frequency and number of syllables, among other variables. The experiments failed to find evidence that participants divide words into syllables during isolated word naming. They did report, however, that the number of syllables affected naming latency for low frequency words.

In their final discussion (pp.103), Jared and Seidenberg point out that even though readers may not explicitly syllabify words, syllables may act as perceptual units in word recognition because of their phonological and orthographic properties. Several experiments using a Stroop-type task suggest that syllabic structure does influence the perception of letters. Printzmetal and his colleagues used words which had differently-colored groups of adjacent letters to probe for the effect of syllable boundaries on letter perception. The experimental items were designed such that the boundaries of the color groups did not coincide with the syllable boundaries of the word. When asked to report the color of a letter, participants were more likely to identify letters within a syllable as belonging to a single color group. Conversely, participants were more likely to falsely report that letters on either side of a syllable boundary were of different colors

(Printzmetal, Treiman, & Rho, 1986; Printzmetal & Millis-Wright, 1984; Printzmetal, Hoffman & Vest, 1991).

Other naming experiments found evidence for syllable effects in reading isolated, low frequency words. Tousman and Inhoff (1992) examined the effect of a first or second syllable preview on word recognition. Participants were faster to name low frequency targets that were preceded by a 250 ms, first-syllable preview, as compared to the control condition where a neutral preview (e.g., ---) was available. No benefit was observed for second-syllable previews. Although these results could indicate a syllable effect from previewing the first-syllable, they deserve a cautious interpretation because of the lack of phonologically-matched, control previews. The absence of phonologically-matched controls makes it difficult to distinguish a possible syllable effect from a more general effect of phonological overlap.

Ferrand et al. (1997) conducted an important series of naming experiments in English, in which they used a masked priming paradigm to investigate the role of syllables in word recognition. Their main manipulation was an extension of the original monitoring experiments in speech perception (Mehler et al., 1981; Cutler et al., 1986). The stimuli were pairs of words with clear syllable boundaries which shared the same initial three phonemes taken from the stimuli of Bradley et al. (1993) and Treiman and Danis (1988). Experiments 1 and 5 used target words with a clear CVC pattern in the first syllable or a clear CV pattern in the first syllable, respectively. Words of these two types were preceded by both CVC%%% and CV%%%% primes, so that each subject saw each target type with each type of prime. Participants saw a forward mask, followed the presentation of the prime for 29msec (SAL%%%% or SA%%%%%), followed by a backward mask before the target word (SALVAGE) was displayed. Results from these naming experiments demonstrated shorter latencies when primes constituted the first syllable of the target. Since the CV primes were more effective than the CVC primes in facilitating naming of CV targets in Experiment 5, the syllable effect was not attributed to the degree of phonemic/ orthographic overlap between prime and target.

Surprisingly, when Schiller (2000) attempted to replicate the results from Ferrand et al.'s Experiment 5 he failed to do so. Schiller used the same English materials, design and procedure in his Experiment 1A, but did not find any effects of syllable structure. The reason for this failure to replicate Ferrand et al.(1997) is open to question, however. One serious concern arises from the comparison of mean naming times for targets preceded by neutral primes with the means for those preceded by letter primes. The mean for the neutral prime condition (%%%) was a scant millisecond faster than either the two-letter or three-letter prime conditions. The failure to demonstrate a basic priming effect raises the possibility that some technical problem may have interfered with the data collection. Considering the minimal priming effects overall, it is somewhat interesting that the means for two of the three counterbalanced groups do show a trend towards faster naming times for targets preceded by syllabically congruent, two-letter primes as compared to incongruent, three-letter primes.

In his second failure to replicate Ferrand et al., Schiller used a modified design in which each participant named every target word six times to increase statistical power (Experiment 1B). Despite this increased power, only one of the comparisons of neutral primes versus letter primes reached significance both by items and participants. However, the targets preceded by incongruent three-letter primes were named 4ms faster than those preceded by congruent two-letter primes. Schiller interpreted these results as supporting his theory that it is the number of individual segments in the prime that facilitates naming, not syllabic structure. Yet, his data fail to demonstrate that any significant benefit was derived from a two-letter prime as compared to a non-letter prime. In essence, this data set supports a theory which claims that a three letter prime is better than a two letter prime, but two letters or fewer do not facilitate naming any more than does a prime of irrelevant symbols. If Schiller had presented the means for each block of trials, a clearer picture of the pattern of effects might have appeared. For example, it is quite possible that the pattern of effects might differ if the initial presentation and naming of targets was analyzed separately from subsequent repetitions of each target.

In sum, Schiller's experiments 1A and 1B did not replicate the Ferrand et al. results, nor did they yield a clear pattern of data with which to challenge those results. It could be argued that Schiller obtained stronger results to support the segment theory of word identification in later experiments, but he used very different stimuli from Ferrand et al. in order to do so. For example, Experiment 3 used CV targets with initial syllable stress, although Finney et al.(1996) and Cutler et al.(1986) previously failed to find syllable effects in words with initial syllable stress. Experiment 4 used high frequency words (occurring several hundred times per million) instead of the mid-to-low frequency words used by Ferrand et al. It appears, then, that Schiller's experiments found categories of words that did not show syllable effects, which indicates that syllable structure is not always used in word identification. His experiments do not, however, offer much evidence as to whether or not syllable structure is present in our early phonological representation of a written word.

Lexical decision experiments. These experiments require participants to press a button that indicates whether a string of letters is a real word or not. Because stimuli are displayed visually and responded to manually, this technique is considered to tap isolated word recognition processes specific to reading. Despite the ubiquity of these experiments in reading research, few have investigated the salience of the syllable.

Cutler and Clifton (1984) investigated the use of prosodic information in auditory and visual word recognition. This study offers some of the most reliable results about the impact of syllables on lexical decision times, because the one and two syllable words were matched for frequency, number of letters, and number of phonemes. The experiments failed to find an induction effect for stress pattern (i.e., grouping words by their stress pattern did not facilitate lexical decision times), and Cutler and Clifton concluded that prosody must be encoded after lexical access. More relevant to the present research, their results showed no difference in reaction times to visually presented one and two syllable words.

Ferrand et al.(1997) conducted one lexical decision experiment, in addition to the series of naming experiments described earlier, to examine the priming effects of syllable structure on word recognition. Although the naming experiments demonstrated priming effects, the results from the lexical decision experiment did not. Based on the restriction of syllabic priming effects to word recognition that involved naming, Ferrand et al. concluded that it is the units involved in speech production which are structured syllabically. Their next conclusion was somewhat counter-intuitive. Ferrand et al. claimed that the appearance of syllabic effects at such a brief prime duration indicated that syllable information is gained early in word recognition. Thus, these naming experiments offer evidence both for the early availability of syllabic structure and its impact on production processes.

An important distinction that is too often overlooked can easily account for the temporal disparity between the availability of syllable information and the locus of its effect in word recognition. Perfetti, Zhang, and Berent (1992) emphasized this distinction: the <u>activation</u> of phonological codes vs. phonological <u>mediation</u> of lexical access. Their chapter summarizes data from priming and masking experiments in English and Chinese to present evidence for a universal phonological principle in reading. The robust effects of phonological activation in these experiments offer strong evidence that phonology operates in both alphabetic and logographic writing systems, but at different times.

In their discussion, Perfetti et al. (1992) contend that phonology is activated as early in word recognition as the orthography of a particular writing system will permit. They point out that although some experiments have failed to find phonological mediation of lexical access in more opaque orthographies, such as Hebrew or Chinese, several others have found evidence for phonological activation while reading in these languages. From this evidence they make a persuasive argument that phonological activation occurs during reading in any language, either preceding lexical access as in English (Folk, 1999) or accompanying lexical access as in Chinese (Perfetti et al., 1992). The Ferrand et al. (1997) experiments offer further support for the distinction between activation and mediation since their data suggest both that (a) syllabic structure appears early in the processing of a visually presented word (as indicated by their naming data) and (b) syllable structure does not mediate lexical access (as indicated by their lexical decision data) .

Neither of the lexical decision experiments discussed above found pre-lexical effects for syllable number or syllable structure in visual word recognition in English. This is consistent with findings in spoken language. However, Carreiras and Perea (in press) conducted a series of lexical decision experiments in Spanish that yielded strikingly different results. In Experiment 4, they used the Ferrand et al. (1997) procedure to present syllabically congruent and incongruent primes before CV and CVC targets. The key difference was that the prime was presented for a longer duration in this experiment (116 ms and 160 ms) than it was in Ferrand et al. (29 ms). The Carreiras and Perea data clearly show shorter reaction times when the prime was syllabically congruent to the target, even though no articulatory code was required. They claim that these results suggest a later role for syllables in the internal representation of words. However, it is also possible that using a longer prime duration permitted subvocalization of the prime, and it was that process that gave rise to a syllable congruency effect.

To summarize, then, the naming and lexical decision experiments that found effects of syllable structure in isolated word reading suggest that these effects function post-lexically. A question arises as to how a representation of syllable structure would support reading processes, since normal (silent) reading does not appear to involve the assembly of a production code (Rayner & Balota,1989). Yet, reading comprehension processes do seem to use post-lexical articulatory codes (Slowiaczek & Clifton, 1980). The most obvious post-lexical role for syllable structure would be to retain identified words in the phonological loop of short term memory (for a further discussion of this see Besner, 1987). The next section describes linguistic evidence for the role of syllables in later (post-lexical) processes.

Evidence for Syllabic Units in Post-lexical Processes

Research on the role of syllables in memory rehearsal might offer more relevant evidence for syllable effects in speech and reading, since memory processes are necessary for comprehension in either medium. The following experiments used nonword tasks that depend on rehearsal strategies to different degrees. Altogether, the data indicate a syllable effect in rehearsal tasks that appears independent of lexicality.

Fowler, Treiman, and Gross (1993) conducted a series of experiments (3a-3c, 4 &5) requiring participants to manipulate phonemes in pairs of polysyllabic non-words that were presented visually. Such phoneme manipulation tasks typically involve rehearsal processes to extract the target phoneme(s) from the second stimulus and insert it into the first stimulus, although these participants were not explicitly instructed to use rehearsal. In Experiment 4, this phoneme shift task involved splitting a phoneme(s) located in either the onset or rime of the medial syllable of the second nonword and substituting it for the onset or rime in the medial syllable of the first nonword. For example, when RUPADKIN and YOMEFBUG appeared on the screen four correct spoken responses were possible depending on the experimental condition: rumadkin, rupafkin, rumedkin, or rupefkin. Participants' pronunciation of the 'new' item triggered a voice-key that timed the latency of their response. Results showed faster response times for extracting the consonant in an onset unit than a consonant which is part of a rime unit, indicating that sub-syllabic structure exists in polysyllabic words. Fowler et al. cautioned against the interpretation that words are necessarily segmented into syllables, however. Instead, they claim that these results suggest that syllabic constituents emerge in the course of certain tasks. That idea is consistent with theories that contend that the function of syllable structure resides in the preservation of phonological information in working memory.

Experiments by Sevald, Dell, and Cole (1995) involved explicit, audible rehearsal of the target. Participants repeatedly named a visually-presented nonword for 4 seconds. Experimental conditions compared the production time of a nonword when its first syllable shared the same structure as the previous nonword to production time when it only shared the same sounds with the previous nonword. Results from these experiments showed faster production times when the nonwords shared the same syllable structure, and no advantage for sharing sounds without a common syllable structure.

Both sets of experiments demonstrate the relevance of syllabic structure in tasks that involve the rehearsal of visually presented nonwords. Unfortunately, both also used production processes as a measure of facilitation, making it difficult to know whether it is production or rehearsal, or both, that utilize syllabic structure.

Experiments by Bruck, Treiman, and Caravolas (1995) offer a hint about the role of syllabic structure in memory rehearsal tasks that don't involve naming. Participants listened to pairs of nonwords and indicated whether they contained matching sounds in the first, middle, or last syllable by hitting a "yes" or "no" button. No explicit instructions about rehearsal strategies were given, but an 800 ms SOA certainly permitted the automatic rehearsal processes involved in working memory. Participants consistently identified a match faster when the sounds corresponded to a whole syllable, and this pattern held for all three position conditions. Faster reaction times suggest a role for syllable structure in facilitating phonological rehearsal even when naming is not part of the task.

Bruck et al. (1995) reconciled their finding of a syllable structure effect with the absence of such an effect in previous monitoring tasks by identifying three main differences between their comparison task and the traditional syllable monitoring task. Unlike in the Cutler et al. (1986) experiments, the stimuli had clear syllable boundaries, which avoided the problem of ambisyllabicity that may have obscured the results in Cutler's experiments. Secondly, the comparison task required participants to hold the first word in memory, and syllable effects appear to emerge most strongly in tasks which rely on phonological memory (Treiman et al., 1995). Most obviously, the comparison task used nonwords, so a phonological representation needed to be constructed rather than accessed in the lexicon. The process of constructing a representation might make use of articulatory codes, leading to the pre-lexical involvement of production processes.

Taken together, the data from these three sets of experiments demonstrate effects of syllabic structure in tasks that involve either production processes <u>or</u> explicit rehearsal processes. It is not yet clear, however, whether syllable structure is involved in the phonological representations used during the course of normal reading.

Summary

The previously discussed research offers evidence for syllabic structure in the phonological representations involved in spoken language. Induction experiments have demonstrated syllable effects in speech perception: syllabic structure can influence the perception of phonemes. Experiments involving speech production also have shown syllable effects; matching syllable boundaries in the stimulus and target lead to shorter naming latencies in some, though not all, experiments.

Isolated word recognition experiments that do not enlist speech production processes offered mixed evidence for syllabic structure in readers' phonological representations. Two types of experiments have demonstrated the use of syllabic structure: experiments that engage memory rehearsal processes and experiments that require the assembly of phonological codes. On the other hand, most lexical decision experiments did not find evidence for the use of syllabic structure in lexical access. The one that did find such evidence used primes of more than 100 ms, which may have permitted articulatory encoding of the prime (Carreiras & Perrea, 2002).

The data from speech and visual word recognition experiments indicate that phonological representations specify syllabic structure, even though that structure does not appear to be used for lexical access. What purpose would syllabic structure serve in reading?

The role of articulatory codes in text comprehension might provide a clue to one possibility. If production processes, rehearsal processes, and the assembly of phonological code entail the use of syllabic structure, then it seems likely that syllabic structure guides the generation of articulatory codes. Following this line of thought, the availability of a phonological representation that specifies syllabic structure could help organize the phonological information involved in word recognition as well as preserve this information across saccades in a memory store that could later support reading comprehension (Pollatsek et al., 1992).

CHAPTER 2

DESCRIPTION OF RESEARCH

Rationale

In the two experiments presented here the eye movements of proficient readers were monitored in order to investigate whether the phonological representations used during silent reading have a hierarchical syllabic structure. As an on-line behavioral measure, eye movements are useful in studying the cognitive processes that occur during normal reading of connected text. Eye movement data are a temporally precise (sampled each ms) and spatially accurate (within half a character) measure of reading. Unlike findings from naming and lexical decision experiments that use only isolated words, eye movement experiments have contributed to our understanding of reading as it is experienced by most adults.

For these reasons, eye movement experiments could help describe the structure of phonological representation in reading. Surprisingly, no eye movement experiments have been conducted for this purpose. However, eye movement experiments in object recognition have demonstrated that fixation duration increases dramatically with the number of syllables in an object's name (Pynte, 1974; Noizet & Pynte, 1976).

Recent experiments by Zelinsky and Murphy (2000) compared the naming times for one and three syllable words. In both experiments, participants were trained on the names of the items (either objects or faces) to be presented. For each trial, an array of four items (two with one syllable names, and two with three syllable names) appeared for study, followed by a picture of one item. Participants hit a button to indicate whether that item was part of the array. Data from both experiments show that the three-syllable stimuli, as compared to one-syllable stimuli, were fixated more often and for a longer duration. Zelinsky and Murphy concluded that eye movements are closely coupled with the linguistic processes involved in memory encoding. Their data might also suggest a role for syllables in verbal memory processes. Even though their results are consistent with the rehearsal experiments discussed earlier, it is not known whether the effects of syllable number on object naming also occur in word recognition. The research presented here uses eye movements to investigate effects of syllabic structure during normal reading.

Two eye movement experiments were conducted to seek out evidence for a syllable level in the phonological representations used during reading. Two different display change techniques were used: a fast-priming technique where a brief prime was presented foveally; and a parafoveal preview technique where the prime was presented in parafoveal view. In Experiment 1, the fast-priming technique was employed to examine the use of syllable information in word recognition when the processing of the target was delayed until the eye landed on the word. Experiment 2 used the parafoveal preview technique to examine whether syllable information was utilized when it appeared in parafoveal view, i.e. before the target word was fixated. The use of both fast-priming and parafoveal preview techniques permitted a comparison of the data collected in each case, and such a comparison might further an understanding of the time course along which hierarchical phonological structures develop. That comparison appears in the general discussion, after the results from each experiment have been presented and discussed. The following section describes the preview and fast-priming paradigms.

Description of Display-change Techniques

Parafoveal preview and fast priming paradigms use an eye-contingent display change to control what printed information is available to the reader at a given time. During normal reading, a reader sees the word that is in foveal view (n) and also extracts information about the following word (n+1). A boundary-change technique developed by Rayner (1975) allows the experimenter to manipulate what the reader sees foveally (n) or parafoveally (n+1). In boundary-change experiments, a participant silently reads text displayed on a monitor. When he or she makes a saccade to get to the target word, the eyes move across an invisible boundary and trigger a display change in the target word.

Fast-priming

In the fast priming paradigm (Sereno & Rayner, 1992), the reader is prevented from seeing the upcoming target word (n+1) until it is actually fixated. Before this time, a string of x's or random letters holds the place of the target word. As the eyes move to fixate on the target word, they cross a boundary which triggers the display change. Upon fixation, the string of x's is replaced by a prime which is presented for 18-60 ms before the actual target word appears. Fast priming experiments have manipulated the semantic, orthographic, or phonological characteristics of the prime and measure fixation time on the target as the dependent variable (Lee et al., 1999). The short prime duration suggests that this paradigm taps automatic reading processes that are not consciously controlled by the reader.

Experiment 1 used the fast-priming technique to examine the role of syllable structure in the phonological representations used in early word recognition processes. Because the prime and the target word do not appear until the eyes land in the target region, preview information is completely withheld from the reader. Fixation time measures, therefore, begin at the first moment any information is available from the target word location. The collected data thus describe the earliest phases of processing, some of which would normally occur parafoveally before the eyes landed on the word. For this reason, word recognition processes during fast-priming might deviate somewhat from the processes used when parafoveal information is available. However, fast-priming does offer the closest simulation of the Ferrand et al. and Schiller experiments while allowing presentation of the target in a sentence context.

Parafoveal Preview

These experiments control what information the reader gets from an upcoming word (n+1)before his eyes actually land on it. Initially, an experimental preview appears in the sentence instead of the target word. While fixating on the word(n) before the eventual target, the reader begins parafoveal processing of n+1, which is the experimental preview. As the eyes move from n to n+1, they cross an invisible boundary and trigger the target word to replace the preview. With this paradigm, the reader rarely perceives the display change, which indicates that parafoveal processing is automatic and beyond conscious control.

Parafoveal preview experiments manipulate the characteristics of the preview and/or the relationship of the preview to the target. The preview might share semantic, phonological, or orthographic characteristics with the target depending on the experimental question at hand. Shorter fixation times in the related preview condition show that the preview facilitated recognition of the target and suggest that the shared characteristic contributes to word recognition. Such experiments have already demonstrated that actual letter forms are not encoded parafoveally, but phonological codes and "abstract letter identities" are perceived in the parafovea (Rayner, 1998; Liversedge & Findlay, 2000).

In Experiment 2, the parafoveal preview paradigm was used to investigate the structure of the phonological representations that facilitate word recognition during normal reading. Specifically, this experiment examined whether information about syllabic structure is available before a word is fixated, and whether that information affects the duration of fixations on the target word. Experiment 2 also attempted to extend the findings from naming experiments with isolated words to reading in a natural context and, so, used stimuli from Ferrand et al. (1997).

Pilot Experiments

A pilot fast-priming experiment with 18 participants was conducted to determine the presentation of the prime and its duration. In this study, the target region initially contained a same-length string of random Greek symbols (πϵθΨϕΨ). Once the eyes crossed an invisible boundary immediately before the target region, those symbols were replaced by a 30 ms prime (de%&%&), followed by the target word (device). To minimize the visibility of the display change, the Greek symbols, the prime, and the target all contained the same number of characters –though some were alphabetic and some were not. Two eye movement measures (first fixation time and single fixation time) showed shorter fixation times when the target was preceded by a letter prime (dev%&% or de%&%&) as compared to a non-letter prime (%&%&%&). However, neither measure showed stable effects of either syllable structure or number of letters in the prime. Therefore, two changes were made in the prime presentation used in Experiment 1. First, the prime duration was increased to 40ms based on the findings of Lee, Rayner, and Pollatsek (2001) which indicate that vowels in fast-priming do not contribute significantly to word recognition until primes exceed 30ms. Also, to increase the visibility of the salient, alphabetic information in the prime, the %%% string used by Ferrand et al. was replaced by a series of dashes so that the prime and target were the same length. For example, the three possible primes for device were ------ (neutral), dev--- (syllabically incongruent), and de---- (syllabically congruent).

A pilot parafoveal preview experiment was run with 20 participants. In this study, the target region was initially either an incongruent or a congruent syllable preview followed by a string of random Greek symbols. For example, the two possible previews for device were devθΨϕ (syllabically incongruent) and deΨθΨϕ (syllabically congruent). As the eyes made a saccade across an invisible boundary immediately before the target region, the preview was replaced by the target word. To minimize the visibility of the display change, the preview and the target contained the same number of characters. Two eye movement measures (first fixation and single fixation) failed to show any differences in fixation time that resulted from either the syllabic congruency of the preview or the number of letters in the preview. Therefore, three changes were made in the presentation of the stimuli for Experiment 2, two of which involved the appearance of the preview . To increase the visibility of the salient information in the preview, the salient letters in the preview were separated from the following symbols by a placeholder (_). To decrease the likelihood of detecting the preview when the sentence first appeared on the computer screen, the first Greek symbol after the (_) was followed by a random string of x's and w's. As a result of these two changes, the two possible previews in Experiment 2 looked as follows for vacation: vac_πxwx (syllabically incongruent) and va_πwxwx (syllabically congruent). The third modification involved changing the word occurring directly before the target in each sentence (word n-1). Because every participant read each word twice, once in each preview condition, the targets were embedded in two sentence contexts that were counterbalanced with respect to preview condition. Thus, each target was preceded by two different n–1 words. Since the frequency of n–1 is known to effect the size of the preview benefit (Henderson & Ferreira, 1990), it was likely that the failure to control the word before the target in the pilot study was adding variability to the mean fixation times. Therefore, in Experiment 2 each target word had the same n–1 word in both sentence contexts.

CHAPTER 3

TWO EYE MOVEMENT EXPERIMENTS

Experiment 1

The role of syllable structure in word recognition during silent reading was investigated using the fast priming technique(Sereno & Rayner, 1992). This experiment aimed to extend the findings from Experiments 1 and 5 by Ferrand et al. (1997) beyond the specific context of isolated word naming. Thus, the design was modeled after the Ferrand et al. experiments, such that target words with CV and CVC initial syllables were preceded by syllabically congruent, syllabically incongruent, and control primes. Stimuli were selected from the lists used in Ferrand et al.(1997), and stimuli from Finney et al. (1996) were included as well in order to increase statistical power. The target words in this experiment, however, were embedded in sentences and presentation of the prime was triggered by a saccade into the target region.

Method

Participants. Twenty-seven students at the University of Massachusetts were paid or received experimental credit to participate in the experiment. All were native English speakers with normal vision and all were naive as to the purpose of the experiment.

Apparatus and Procedure. The stimuli were presented on a NEC 4FG monitor through a VGA video board that was controlled by a 486 PC. An A to D converter interfaced the computer with a Fourward Technologies Generation VI Dual Purkinje eyetracker. The monitor displayed text at a 200Hz refresh rate that permitted display changes within 5 ms. The eyetracker monitored movements of the right eye, although viewing was binocular. Letters were formed from a 7 X 8 array of pixels, using the Borland C default font, which is a non-proportional font. Participants sat 61cm away from a computer screen and silently read single line sentences while their head position was stabilized by a bite bar. At this viewing distance, 3.8 letters equaled one degree of visual angle. At the beginning of the experiment, the eye-tracking system was calibrated for the participant. At the start of each trial, a check calibration screen appeared, and participants who showed a discrepancy between where their eye fixated and the location of the calibration squares were re-calibrated before the next trial.

A trial consisted of the following events. The check calibration screen appeared and the experimenter determined that the eye-tracker was correctly calibrated. The participant was instructed to look at the calibration square on the far left of the screen, then the experimenter presented the sentence. Initially a random sequence of Greek symbols held the place of the target word. The participant read the sentence silently and at his/her own pace. Prime presentation was triggered during reading by a saccade into the target region, and the prime appeared for 40 ms after the start of the fixation in the region before being replaced by the actual target word. When the participant finished reading the sentence, he/she clicked a response key to make it disappear. Following a quarter of the sentence trials, a comprehension question appeared on the screen. The participant responded by pressing the response key that corresponded with the position of the correct answer. Then the check calibration screen appeared before the next trial. The experiment was completed in one session of approximately 30 minutes.

Materials . Ninety-six target words were embedded in single line sentences. The stimulus list consisted of 48 words with CV initial syllables and 48 words with CVC initial syllables. The list incorporated the words from Ferrand et al. (1997), which were originally compiled by Treiman and Danis (1988) and Bradley et al. (1993), as well as a selection of words from Finney et al. (1996) . Seven words from the initial stimulus list were eliminated due to their unfamiliarity to our population of readers (mean frequency= 1per million). Of the remaining 89 target words, 43 had CV initial syllables and 46 had CVC initial syllables. On average, these CV initial words occurred 37 times per million, ranging from zero to 210, and the CVC words occurred 24 times per million, ranging from zero to 203 (Francis & Kucera, 1982). Target words ranged in length from 5 to 10 letters with a mean of 7 letters.

Design. Each participant read every target word in one of the six conditions. Experimental condition (see Table 1) was defined by the type of prime (neutral, syllabically incongruent, or syllabically congruent) that preceded a target with either an initial CV or CVC syllable in the 2x3 factorial design. Note that in congruent conditions 3 and 6, the prime is the complete first syllable of the target. In the incongruent conditions 2 and 5, the prime consists of one letter more (in the CV case) or less (in the CVC case) than the first syllable. Conditions 1 and 4 provide an unrelated control prime for comparison with their respective incongruent condition. Conditions 1-3 are modeled on Ferrand et al.'s Experiment 5 and Conditions 4-6 follow their Experiment 1.

All letter primes comprised either the first two or three letters of the target word and a series of dashes, so that the display of the prime and the target were of equal length. The control, non-letter prime contained only a series of dashes equal in length to the target word. Each participant read 89 experimental sentences randomly interspersed with 27 fillers that also included a fast-priming display change.

Data analysis procedures. The purpose of the experiment was to investigate whether syllables were part of the phonological representation that accompanied lexical access. Fixation time on the target was the dependent variable, and the structure of the first syllable of the target (CV or CVC) was treated as a within subjects factor and a between items factor. Prime type was treated as a within factor in both the participant and item analyses. Three measures of fixation time during word recognition were analyzed. *First fixation* is a measure of the mean time spent reading the first time the eye lands on the target word. This includes words processed in a single fixation as well as the first of multiple fixations. Mean *single fixation* times were also examined. Further analyses used *gaze duration* as a measure of the first pass processing time associated with a fixated word (Rayner, 1998). Gaze duration was calculated as the sum of all consecutive fixations on a word, beginning with the first fixation and including additional fixations up until the eye makes a saccade to another word.

Consistent with most eye movement research (Rayner, 1998), predetermined cutoffs were used to trim the data. Fixations on the target word that were under 120ms were eliminated from the analysis since such short fixations do not seem to reflect cognitive processing of the target word (Rayner, 1998; Rayner & Pollatsek, 1987). To eliminate overly long fixations, fixations over 600ms were excluded from the analysis. Approximately 3% of the data were lost due to these cutoffs and track losses. Trials were excluded from the analyses for the following reasons: if no fixations were made on the target word before the eyes moved past it to the right, if the participant blinked while within the target region, if the eye regressed out of the target region, and, most commonly, if the display change occurred before the eyes landed in the target region. After this process, the data for all participants who retained more than 67% of the trials were subjected to analyses of variance (ANOVA) using variability due to participants ($\underline{F}_1$) and items ($\underline{F}_2$).

Results

Planned comparisons of fixation time on target words that were preceded by syllabically incongruent and congruent primes tested whether a prime that included the target's first syllable boundary facilitated word recognition more than a prime that violated the syllable boundary. In the case of CVC targets, I assumed that the CVC prime would facilitate word recognition more than a CV prime, and that the separate contributions of syllabic congruency and number of letters could not be identified in these conditions. Given the difficulty that Schiller (2000) had in replicating Ferrand et al., I expected the data from the CV targets to follow any of three possible patterns. If shorter fixation times were found in the congruent, rather than the incongruent, condition for CV targets, i.e. a prime that contained only the first two letters of the target, it would indicate that syllable information was used during word recognition. This result would be surprising, since the prime in the congruent condition included one fewer letter than the prime in the incongruent condition. Yet such a result would be consistent with the results from Experiment 5 by Ferrand et al. (1997), and it would suggest that the phonological representations used in silent reading have a hierarchical structure. In contrast, finding the shorter fixation times in the incongruent condition for CV targets would fail to extend the Ferrand et al. (1997) findings and suggest that it is the number of shared, initial segments that influences the priming effect, per Schiller (2000). This result would support theories that propose a flat, linear structure for the phonological representations used in reading. The third possible finding would be the appearance of comparable fixation times in the incongruent and congruent conditions for CV targets accompanied by faster fixation times in the congruent than in the incongruent conditions for CVC targets. That pattern of data could reflect both syllable and segment effects, since the cost of having one less letter in the congruent condition was offset by a benefit from syllabic congruency for the CV targets.

First fixation. Table 2 shows the mean first fixation times on the target word in each of the prime conditions for CV and CVC target words. The main effect of prime was significant in the participants and the items analyses, $F_1(2, 52)=16.03$, MSe=640, $p<.0001$, and $F_2(2,174)=18.71$, MSe=937, $p<.0001$. First fixations on targets that were preceded by neutral primes were 23 ms longer on average than fixations on targets preceded by letter primes, which indicates that the fast-priming technique was operating properly. When the analysis was restricted to syllabically incongruent and congruent conditions, the main effect of prime congruency was not significant in either analysis, both F's <1. An interaction of target type and prime congruency did appear significant in both analyses, $F_1(1,26)=5.17$, MSe=412, $p<.05$, and $F_2(1,87)= 6.60$, MSe=760, $p<.015$, such that only CVC targets were read faster when preceded by a congruent prime. Because the test for the interaction of target type and congruency is also the test for a main effect of number of letters in a prime, these results indicate that primes containing more letters provided more facilitation. The main effect of number of letters in the CVC words was confirmed by simple effects tests which were significant, $F_1(1,26)=4.15$, MSe=463, $p<.05$, $F_2(1,45)=5.69$, MSe=845, $p<.05$. The simple effects tests were not significant for CV targets, $F_1(1,26)=1.02$, MSe=453, $p>.3$, $F_2(1,45)=1.48$, MSe=668, $p>.2$.

Single fixation duration. The means for targets that were read in a single fixation appear in Table 2. All participants contributed some single fixations to these means, but all not all items did. Therefore, in the items analyses it was necessary to substitute in the condition mean for any items that had no single fixations, and adjust the degrees of freedom accordingly (-7). The main effect of prime type appeared significant in the participants analyses, $F_1(2,52)=7.91$, MSe=1150, $p<.001$, but not in the items analyses, $F_2(2,167)= 1.61$, MSe=1320, $p>.20$. Single fixations on targets that were preceded by neutral primes were 22 ms longer on average than fixations on targets preceded by letter primes, which indicates that the fast-priming technique was operating properly. When the analysis was restricted to syllabically incongruent and congruent conditions, the main effect of prime congruency was not significant in either analysis, $F_1(1,26)=1.19$, MSe=937, $p>.25$, $F_2<1$.

An interaction between target type and prime congruence (i.e. the effect of number of letters in a prime) once again appeared significant in the items analyses, $F_2(1,80)= 5.07$, MSe=1421, $p<.05$, but did not reach significance in the participants analysis, $F_1(1,26)=1.90$, MSe=937, $p>.15$. Overall, these results were consistent with first fixation measures.

Gaze duration. The gaze duration means appear in Table 2. In contrast to the first fixation and single fixation data, words that received multiple fixations did not have faster first-pass processing times when they were preceded by a letter prime as compared to a prime of unrelated symbols, the main effect of prime type was not significant in either analysis, both Fs <1. A main effect of target type did appear in this measure, however, and was significant in the participants analysis, $F_1(1,26)=9.09$, MSe=1123, $p<.01$, but not in the items analyses, $F_2(1,87)= 1.94$, MSe=6436, $p>.15$. An examination of the gaze duration means suggests the nature of this target type effect. When CV and CVC targets were preceded by a neutral prime they were processed in similar amounts of time (422 ms and 419 ms, respectively). Consistent with the previously reported measures, targets with a CV-initial syllable were processed 13 ms faster on average when preceded by a letter prime than when preceded by a neutral prime. In contrast, targets with a CVC-initial syllable were processed 10 ms slower when preceded by a letter prime, as compared to a neutral prime. This differential priming effect was nearly significant in the participants analysis, $t(26)= 1.97$, $p< .06$, and significant in the items analysis, $t(83)= 2.09$, $p< .05$. Thus, it appears that although letter primes facilitated the processing of CV words, letters had an inhibitory effect on the recognition of CVC words. When the analysis was restricted to syllabically incongruent and congruent conditions, the main effect of prime congruency was not significant in either analysis, both Fs <1. Surprisingly, the interaction between target type and prime congruence was not significant either, both Fs <1.

Discussion

Shorter first fixation times were observed for both CV and CVC syllable-initial target words which were preceded by a letter prime as compared to a prime of irrelevant symbols. This finding is consistent with the Ferrand et al. studies, and not too surprising. The absence of a syllable effect was also predicted from Fernand et al., as they located that effect in the preparation of articulatory codes used in the naming task and no overt articulation was involved the current experiment. The first fixation and single fixation data also indicate, however, that more letters in a prime offered more benefit, since first fixation times were 9ms shorter on average when participants received a three letter prime as compared to a two letter prime. The observation that priming effects corresponded to the number of relevant segments contained in the prime extends the findings of Schiller (2000) to word recognition in the context of silent reading. Interestingly, the effect size in this study was somewhat larger than that reported in most of Schiller's experiments.

It is less clear what conclusions can be drawn from gaze duration, since the pattern of means here differed substantially from that in the first fixation and single fixation data. Particularly, gaze durations were not significantly shortened by the presentation of a letter prime as compared to a non-letter prime. It appears, however, that the priming effect of letters went in different directions, depending on the whether the target had a CV or CVC initial syllable. A nearly significant trend in the means suggested that while letter primes facilitated the reading of CV-initial words, they seemed to inhibit the recognition of CVC-initial words. This trend in the data might indicate that (for CVC-initial words) parts of the word recognition process were slowed by lexical competition effects from priming. If that were the case, then having letters in a prime might offer an early advantage to processing that is offset by lexical competition effects, whereas non-letter primes would not activate any set of words. A comparison of the priming effect for letters found in first fixation and gaze duration measures for CVC-initial words (23 ms and -10 ms, respectively) is consistent with such a description. The question arises, then, as to why only the CVC-initial words appeared to be vulnerable to lexical competition effects. One possibility is that the CVC words in this experiment often shared a syllabic neighborhood with one or more words that occurred more frequently than the target.

In sum, Experiment 1 indicated that participants processed words more quickly when the target word was preceded by a three letter prime than a two letter prime, and no evidence was found for the inclusion of syllable information in the phonological representations used during reading. These results are consistent with the concept of a non-hierarchical phonological representation that includes information about individual phonemes and their sequence. However, there are at least two reasons why the results of this experiment might not accurately reflect the processing of words during natural reading.

The first reason is that the data collected with the fast-priming technique might describe only the earliest parts of the word recognition process, since processing starts from ground zero when the eye enters the target region. In normal reading, however, abstract letter codes and phonological information are processed while the target is in parafoveal view, i.e. processing begins well before the eye lands on the target (Rayner, 1998; Liversedge & Findlay, 2000). Secondly, it seemed remotely possible that the fast-priming technique itself had an effect on the word recognition processes that were observed. Since natural silent reading allows parafoveal processing of upcoming words, it is possible that being denied a parafoveal view of the target changed the demands of the reading task and, in turn, encouraged heavier reliance on some word recognition processes than would be expected in a normal reading situation. Therefore, Experiment 2 sought evidence for syllable structure in word recognition by collecting eye movement data using a parafoveal preview technique that is less disruptive to normal reading processes.

Experiment 2

Experiment 2 was conducted with two main purposes. First, it provided a chance to further test for a syllable level in the phonological representations used during reading. Alternatively, it could replicate the findings in Experiment 1 and, thereby, confirm that it is segment information alone which is used for word identification. The design here basically followed Ferrand et al.(1997), such that target words with CV and CVC initial syllables were preceded by syllabically congruent and incongruent previews. When a sentence appeared on the screen, the target region initially contained either a congruent or incongruent preview, which was replaced by the target word when the eye crossed an invisible boundary immediately before the target word.

Method

Participants. Twenty-eight students at the University of Massachusetts were paid or received experimental credit to participate in the experiment. All were native English speakers with normal vision and naive as to the purpose of the experiment.

Apparatus and Procedure. The apparatus and procedure used in this experiment were the same as described in Experiment 1, with the following exceptions. Data was collected using a Fourward Technologies Generation V Dual Purkinje eyetracker. Instead of a prime, a 2 or 3 letter preview appeared in the target region when a participant began to read each sentence. Presentation of the full target word was triggered during reading by a saccade into the target region.

Materials . Forty-eight target words were each embedded in two single line sentences. The stimulus list consisted of 24 words with CV initial syllables and 24 words with CVC initial syllables. The list mainly included words from Ferrand et al. (1997), which were originally compiled by Treiman and Danis (1988) and Bradley et al. (1993), along with a few words from Finney et al. (1996) to replace the items removed from the analysis in Experiment 1. On average, the CV initial words occurred 47 times per million, ranging from 1 to 210 per million, and the CVC words occurred 28 times per million, ranging from 0 to 203 per million (Francis & Kucera, 1982). Targets words ranged in length from 5 to 10 letters with a mean of 7 letters.

Design. As in Experiment1 by Ferrand et al., each participant read every target word twice, once in the incongruent and once the congruent condition. Preview condition and sentence context were counter-balanced in two stimulus lists, such that 14 participants saw the target preceded by an incongruent preview in sentence context A and then saw the same target preceded by the congruent preview in sentence context B while the other 14 participants saw the inverse. Within a stimulus list, participants were randomly assigned to a counterbalancing condition that determined whether an incongruent or congruent preview preceded the first presentation of the target.

Experimental condition (see Table 3) was defined by the type of preview (a syllabically incongruent prime or a syllabically congruent prime) that preceded either the first or second presentation of a target with either an initial CV or CVC syllable, yielding eight conditions in a 2x2x2 factorial design. Targets were presented in two different sentence contexts, preceded by an incongruent and congruent preview. Two stimulus lists were used, such that the target was read for the first time in Context A by one half of the subjects and read for the first time in Context B by the other half of the subjects. Trials were randomized for each participant and fully counterbalanced across participants. The results presented in this paper were restricted to the first presentation of each target word, for reasons discussed below. Preview conditions 1 and 2 comprised the first presentation of the CV targets and condition 3 and 4 the first presentation of the CVC targets. Odd condition numbers denoted incongruent preview conditions and even numbers the congruent conditions. In congruent condition 2, the preview was the complete first syllable of a CV-initial target (e.g. two letters), while in condition 4 the preview was the complete first syllable of a CVC-initial target (e.g. three letters). In the incongruent conditions, the preview consisted of one letter more in the CV case (three letters) or one letter less in the CVC case (two letters) than the first syllable.

All previews were comprised of either the first two or three letters of the target word followed by a placeholder (_), one Greek character (π), and a random combination of x's and w's which made the preview and the target appear to be of equal length. Each participant read 96 experimental sentences and 32 fillers, all of which included a parafoveal preview display change.

Data analysis procedures. Similar same data analysis procedures were followed as in Experiment 1. Additionally, each participant read every word twice in this experiment and the order of the block and sentence presentation was fully counterbalanced. Upon examination, the data from the second reading of the targets was substantially noisier than the data from the first reading[1]. Therefore, the analyses for Experiment 2 were restricted to the first block of data collected from each participant, in order to avoid introducing noise from possible repetition priming effects. Approximately 2% of the data were lost due to preset cutoffs and track losses. Trials were excluded from the analyses for the following reasons: if no fixations were made on the target word before the eyes moved past it to the right, if the participant blinked while within the target region, if the display change happened before the eyes entered the target region, or if the eye regressed out of the target region. After this process, the data for all participants who retained more than 67% of the trials were subjected to analyses of variance (ANOVA) using variability due to participants (F_1) and items (F_2). In the participants analysis, target type and preview congruency were treated as within factors while list was a between factor. In the items analysis, list and preview were within factors while target type was a between factor.

Results

As in Experiment 1, fixation time on the target word was the dependent variable. Planned comparisons of fixation times on targets which were presented with a syllabically incongruent preview versus a congruent preview tested whether information about the syllable structure of the target was processed parafoveally and whether that information affected word recognition time. The results from Experiment 1 suggested that some letter effects on word recognition would also be found in the parafoveal preview data.

First fixation. Table 4 shows the mean first fixation times on the target word in each of the prime conditions for CV and CVC target words. The main effect of syllable congruency was significant in the participants and the items analyses, $F_1(1, 26)=5.60$, MSe=739, $p<.05$, and $F_2(1,46)=4.06$, MSe=1360, $p<.05$. First fixation time on targets that were preceded by incongruent previews was 13 ms longer on average than time spent on targets preceded by congruent previews, suggesting that information about syllable structure was processed parafoveally and used in word recognition. The interaction of syllable type (CV or CVC) and congruency provided a test for the effect of number of letters in the preview, but that interaction was not significant in either analysis, both Fs<.5.

Single fixation. The means for targets that were read in a single fixation appear in Table 4. Because not all participants and not all items contributed to these means, it was necessary to substitute in the condition mean for any participants or items that had no single fixations, and adjust the degrees of freedom accordingly. The main effect of syllable congruency appeared significant in the participants analysis, $F_1(1,23)=6.22$, MSe=753, $p<.05$, and marginally significant in the items analysis, $F_2(1,41)= 2.56$, MSe=2518, $p<.15$. Single fixations on targets that were preceded by incongruent previews were 13 ms longer on average than fixations on targets preceded by congruent previews. The interaction of syllable type (CV or CVC) and congruency served as a test for the effect of number of letters in the preview, and that interaction was not significant in either analysis, $F_1(1,23)=1.04$, MSe= 644, $p>.30$, and $F_2(1,41)<.5$.

The effect of stimulus list also accounted for a substantial amount of the variance in the items analyses, $F_2(1,41)=19.16$, Mse=1409, $p<.0001$, but not in the participants analysis, $F_1(1,23)=1.19$, MSe=76099, $p>.25$. The strength of the effect was unexpected, but probably irrelevant, to the question at hand. All targets were presented in both sentence contexts with congruent and incongruent previews, and a comparable congruency effect of 11ms appeared in both lists.

Gaze duration. The gaze duration means appear in Table 4. In contrast to the first fixation and single fixation data, the main effect of syllable congruency was not significant in either the participants or the items analyses, $F_1(1, 26)=1.76$, MSe=1177, $p>.15$, and $F_2(1,46)=1.62$, Mse=3154, $p>.20$. However, a look at the means shows a non-significant trend for a congruency effect (9ms), which is consistent with the other eye movement measures. It is likely that the high variability in this measure prevented the congruency effect from reaching significance (as in Pollatsek et al., 1992, Experiment 2). The interaction of syllable type and congruency provided a test for the effect of number of letters in the preview, but that interaction was not significant in either analysis, both Fs<.5.

Discussion

The data collected from measures of first fixation and single fixation time indicate a syllable congruency effect, such that shorter fixation times were observed for targets preceded by syllabically congruent previews as compared to syllabically incongruent previews. This finding offers clear evidence that readers acquired syllable information parafoveally and, therefore, suggests that a syllabic level of phonological representation was activated in the early stages of word recognition. As such, it extends the findings of Ferrand et al. (1997) to demonstrate the presence of syllable structure in the early word recognition processes that occur while reading connected text. The effect of syllable congruency on early processing time persisted in gaze duration, but did not reach significance, such that the eyes remained on the target word an average of 9 ms longer when it was preceded by an incongruent preview. Interestingly, no effects of number of letters in the preview were found.

As in Ferrand et al. (1997), a congruency effect was found for both CV and CVC-initial target words. The appearance of that effect in the CVC-initial targets, which carry stress on the first syllable, might seem unexpected given that Finney et al.(1996) found syllable effects only in words with second-syllable stress. Recall, though, that auditory experiments have failed to demonstrate that pre-lexical coding of stress pattern is used in early lexical access processes (Cutler & Clifton,1984). Since the congruency effect in the current experiment appeared in early measures of word recognition, it is not surprising that no interaction with stress pattern was observed. Irrespective of effect size, the data from CV-initial targets provides the strongest evidence for the representation of syllable information in word recognition. The congruent preview for the CV words had one less letter than the incongruent preview, yet it was the congruent preview that showed the most facilitation of the target.

In sum, the results from Experiment 2 indicate the salience of syllable structure in word recognition. This finding implies that the phonological representations used during silent reading have a hierarchical structure that includes syllable information, and that these representations are constructed quite early in the word recognition process.

CHAPTER 4

THE PHONOLOGICAL REPRESENTATIONS USED IN SILENT READING

Discussion of the Findings from Experiments 1 & 2

These experiments investigated whether syllabically congruent primes facilitate word recognition during silent reading. This question was posed in order to gain evidence that would help clarify some broad issues in reading theory, such as the structure of phonological representations during reading and the similarity of those representations to the ones used for the processing of spoken language. Two views about the nature of phonological representations in silent reading were presented in the introduction. The traditional, linear view contends that phonological representations mirror the structure of the orthography from which they are built, i.e. they consist of strings of phonemes that code the individual speech sounds that the letters represent. The hierarchical view, in contrast, contends that phonological representations are multi-layered descriptions of a word's phonology with various sub-lexical levels that represent syllable as well as segment information. These two views of phonological representation during reading predict different patterns of experimental results. According to the linear view, the data should have indicated segment effects (such that a prime with more segments provided stronger facilitation of the target), but no syllable effects (as when a syllabically congruent prime provides stronger facilitation of the target). The hierarchical view, in contrast, predicts the appearance of syllable effects as well as segment effects. A finding of syllable effects in word recognition would, then, be incompatible with the linear view and lend support to the contention that the phonological representations in reading are very similar to those used in spoken word recognition. Were that the case, then a parsimonious model of reading would suggest that word recognition is routinely achieved through systems used primarily for processing spoken language, as opposed to accessing word meaning directly from orthographic information.

The main finding of interest in these experiments was a syllable effect in word recognition during silent reading of connected text (Experiment 2), which extends the findings of Ferrand et al. (1997). Multi-syllable words were read faster when preceded by a parafoveal preview that shared the initial letters of exactly the first syllable of the target word, as compared to a preview that had one more or one less letter. This result indicates that syllable information is specified in the representations constructed during word recognition and, thus, supports the hierarchical view. However, when congruent and incongruent primes were presented foveally using a fast-priming technique in Experiment 1, no evidence was found for syllable effects. Rather, it appeared that primes with the greater number of segments provided more facilitation. This result extends the findings of Schiller (2000) to word recognition in silent reading and appears to support the traditional, linear view of phonological representation. Hence, the results of the two experiments seem inconsistent.

In order to develop a coherent concept of the nature of the phonological representations used during silent reading, the apparent contradiction between the syllable effect found in Experiment 2 and the segment effect found in Experiment 1 needs to be resolved. Fortunately, these findings can be reconciled quite easily by considering how fast-priming and parafoveal preview techniques yield different reading environments with distinct task demands. With the fast-priming technique, for example, no parafoveal information was available before the target was fixated and no saccade occurred between the presentation of prime and target. The parafoveal preview technique, in contrast, did make parafoveal information about the "prime" available, and a saccade did occur between the presentation of the preview and the target. The following discussion describes how such differences arose from the choice of display-change technique. Understanding the contribution of those differences to the seemingly disparate findings might even help identify some of the ways that phonological representations are used during word recognition.

In the fast-priming experiment (Expt. 1), nonsense characters appeared in the target region while participants read the words that preceded the target in the sentence. Since no relevant parafoveal information was available, the earliest parts of the word recognition process began at the same time as the fixation time measures for the target. In other words, eye movement data were collected from the moment readers began processing the target word, and that coincidence permitted the observation of segment effects. In Experiment 2, however, readers did receive preview information about the target word. Experimental evidence suggests that abstract letter information and phonological information are processed before the eyes land on the target word, at least in reading tasks that permit a parafoveal view of the target (McConkie & Zola, 1979; Rayner, McConkie & Zola, 1980; Hadley & Healey, 1991; Pollatesk et al., 1992). Because preview information was available, the processing of letter features and initial phonemes occurred before the eyes landed in the target region, i.e. *before* fixation time in the target region was measured. In other words, the eye movement data in this second experiment were collected later in the word recognition process and, so, would not be as likely to include early identification processes of the initial letters and phonemes. Therefore, any segment effects that might have occurred in Experiment 2 would be expected to appear while the target was in parafoveal view, i.e. before the onset of fixation time measures for the target word.

Following that line of reasoning, it is the duration of the fixation prior to entering the target region that would be likely to capture the very early parts of the word recognition process. A preliminary analysis of the last fixation before entering the target region did show that the last fixation before a three letter preview averaged 230 ms as compared to an average of 241 ms before a two letter preview, which is suggestive of a segment effect. Tempting though this account may be, the data might instead reflect a far less interesting effect of low-level visual interference. That possible confound in the preview presentation currently prevents a clear interpretation of that data. However, the suggestive evidence for a segment effect on the fixation before the target is consistent with the evidence of early word recognition processes occurring parafoveally and gives some reason to suspect that reliable segment effects would appear in better controlled study.

Thus, at least provisional evidence for segment effects were found in both experiments but at different places in the eye movement record, which suggests that varying the accessibility of the preview changed the reading task in an important way. The choice of a display-change technique, then, defined the reading task and influenced the processes used to perform it. Perhaps a further examination of the distinct reading task demands that accompany each technique can also explain why syllable effects were not observed in Experiment 1.

As a background for that discussion, it might be useful to review the main findings from spoken language experiments, in order to recall which types of tasks consistently yielded syllable effects. Using a variety of paradigms, researchers have found syllable effects when the experimental task involved speech production or storing phonological information in memory, accompanied by the assembly of phonological codes. Conversely, syllable effects appear inconsistently, or not at all, in experiments with tasks that do not require spoken output or memory storage. These findings suggest that syllabic structure guides the generation of articulatory codes which might, in turn, serve as the basis for a range of mental operations that require phonological coding.

Because all data were collected during silent reading, speech production was not a factor in either experiment. However, the type of display-change technique clearly affected the demands that the reading task placed on short-term memory. In Experiment 2, readers began the word identification process parafoveally and, therefore, needed to preserve the information in the preview during a saccade in order to integrate it with the foveally presented target word. Therefore, the phonological information needed to be held in memory during the 20-50 ms required to complete a saccade to the target region. In Experiment 1, however, the prime and target were presented foveally in the same location, so no memory storage was needed. Thus, it seems likely that a syllable effect did not appear in the fast-priming data because the phonological information in the prime did not need to be held in memory during the lexical access process.

The above discussion not only reconciles the findings of Experiment 1 and 2, it also holds implications for when hierarchical phonological representations are constructed and for what purpose. Segment effects, which arise very early in the word recognition process, are consistent with a concept of word recognition that involves the initial letters and phonemes activating a neighborhood of lexical candidates. In that case, a three letter preview would activate a much smaller number of candidates than a two letter preview (see Schiller, 2000), which could shorten the overall time required to activate the full neighborhood before continuing the lexical access process. A syllable level of representation must also be available early in the word recognition process, since it preserves parafoveally-acquired phonological information during the saccade that brings the word into foveal view. Because syllable effects only appeared when it was necessary to hold the parafoveal information in memory, it seems likely that the representation of syllable information stems from the memory storage process. Once a word has been fixated, initial syllable information might also be used to further restrict the number of activated candidates.

Summary and Conclusions

In sum, syllable effects appeared in the word recognition processes used during silent reading, which supports the hierarchical view of phonological representation. This finding adds to a growing number of experiments in several different languages that indicate the presence of hierarchical phonological representations during reading (Carreiras & Perea, in press; Berent et al., 2001; Ferrand, Segui & Grainger, 1996). Given the mounting evidence for the specification of sub-lexical, syllable structure within the representation, and its appearance quite early in the word recognition process, researchers and educators might consider the implications of this information.

For example, although the dual route cascade (DRC) model (Coltheart, Rastle, Perry, Langdon & Zeigler, 2001) is probably the most clearly elaborated model of word recognition at this time, it does not recognize the pre-lexical construction of any phonological representation, nor does it describe how a multi-layered phonological representation might arise. Thus, such word recognition models might be modified to include mechanisms through which syllable effects would arise (given polysyllabic inputs). This step could be taken well in advance of actually modeling the recognition of more complex words.

Likewise, the findings presented here could also benefit various methods of reading instruction. Since several studies have found syllable effects in the silent reading of college students, it appears that these multi-layered phonological representations accompany proficient reading. Given that observation, it may be time to start teaching syllabification strategies, especially in the later elementary grades when Latinate words increasingly appear in content-area reading materials. Such instruction could provide students with effective tools for expanding their vocabulary through reading as well as support their comprehension of content information.

Finally, several conclusions emerge from the results presented here. First, proficient adult readers routinely construct phonological representations while silently reading sentences. Second, these representations are built early in the word recognition process, since syllable effects appear during the first fixation on the target word. Third, these representations are multi-layered, as opposed to linear, and they specify information about word-initial segments and the organization of those segments into syllables. Fourth, these representations are similar to those used in spoken word recognition, both in structure and in content. That similarity strongly suggests that the word recognition processes used in proficient reading are closely tied into, if not routed through, our spoken language systems.

Table 1. Experiment 1: Example Stimuli

	Prime	Target
Condition 1		
cv-control	-------	vagrant
Condition 2		
cv-incongruent	vag----	vagrant
Condition 3		
cv-congruent	va-----	vagrant
Condition 4		
cvc-control	-------	balcony
Condition 5		
cvc-incongruent	ba-----	balcony
Condition 6		
cvc-congruent	bal----	balcony

Table 2. Experiment 1: Measures of Processing Time on the Target Word (ms)

	Neutral Prime	Incongruent Prime	Congruent Prime
First fixation			
CV targets	325	299	304
CVC targets	329	312	300
Single fixation			
CV targets	369	344	346
CVC targets	367	356	342
Gaze duration			
CV targets	422	407	410
CVC targets	419	430	427

Table 3. Experiment 2: Example Stimuli

	Preview	Target
CV-initial Target		
Incongruent Preview (1)	dev_πx	device
Congruent Preview (2)	de_πxw	device
CVC-initial Target		
Incongruent Preview (3)	ba_πxwx	balcony
Congruent Preview (4)	bal_πxw	balcony

Table 4. Experiment 2: Measures of Processing Time on the Target Word (ms)

	CV Targets		CVC Targets	
	Incongruent	Congruent	Incongruent	Congruent
First fixation				
	284	271	287	275
Single fixation				
	300	292	307	289
Gaze duration				
	337	326	342	335

Footnote

No significant differences appeared in any of the four conditions during the second reading of the target words. First fixation means were as follows: CV target (271ms and 276ms for incongruent and congruent primes, respectively); CVC targets (279ms and 281ms for incongruent and congruent primes, respectively).

APPENDIX A

STIMULUS LISTS FOR EXPERIMENT 1

Experiment 1: CV-targets

The military tribunal voted to *demote* the crazy major.

The inmate hoped for a *reversal* of the judge's decision.

The military's new *covert* mission provides weapons to the rebels.

Cassie added more *vanilla* to the pudding mixture.

Alice wanted to spend a *relaxing* day walking on the sandy beach.

Arthur thought about the *dilemma* for the rest of the day.

Sam quickly stirred the *tomato* soup on the stove so that it would not burn.

Ed traveled to Maine each *November* to fish for salmon.

Mary had invented a *device* for drying large amounts of fruit.

Edith bought a silk *sarong* at the market on the tropical island.

Our family enjoyed a *delicious* dinner last night.

Ben desperately tried to *remember* the name of the book he was reading.

Phillip practiced for his *recital* during spring break.

Andrea wanted to *divorce* her husband because he was a drunkard.

John quietly leaked a *report* about the toxic spill to the press.

The inspector hoped to *reveal* the criminal's identity within twenty-four hours.

George quickly grew to *depend* on his daughter's weekly visit.

Robert wanted to *demand* his money back from the store.

The child did not express any *remorse* for his barbarous crime.

Alan obviously hoped to *remain* on the tropical island for one more week.

Mike thoroughly enjoyed his *retirement* in sunny Florida.

Dora was careful to *select* the freshest produce available.

Erin initially tried to *relate* to the traumatic experience of the refugees.

Molly wanted a japanese *pagoda* for her garden in Ohio.

The candidates agreed to *debate* on national television.

The old farmer planted *tobacco* in his field every year.

Linda regularly made a *deposit* at the local bank every Tuesday.

Thomas gradually learned to *regard* his health more since his recovery.

The friendly cousins skiied *together* in the Rockies each winter.

Adam definitely hoped to *secure* a better job within the next year.

The dead squirrel started to *decay* on the hot road.

Maggie picked her mother a *tulip* from the garden.

The symptoms of his *psychosis* were dormant until he turned thirty.

Donna attempted to *record* the rock concert without being observed.

Allison started to plan her *vacation* after she got her first pay check.

Kyle's argument tried to *negate* the evidence presented by the prosecution.

The wine store had *chablis* on sale last week.

The street was littered with *debris* after the parade.

Sandy could feel the *vibration* of the floor when the dancers jumped.

The chorus hired another *soprano* after a week of auditions.

Sam suffered from *depression* for several years after his divorce.

Todd quickly forgave the *regretful* child and gave him a cookie.

Ginger was told to *declare* the value of her new jewelry to the customs officer.

The professor posed *socratic* questions to his puzzled students.

The geese started their *migration* to Canada each spring.

Carolyn improved the *nutrition* of her diet by taking several vitamins.

Jim promised to *refrain* from eating desserts while training for the match.

The goalie lunged to *deflect* the ball and prevent a score.

Experiment 1: CVC-targets

The students sat in the *balcony* on opening night.

Mary got most of her *calcium* from dairy products.

Julia's heart started to *palpitate* from the surprise of seeing her ex-husband.

Bob intended to *salvage* the moldings from the old house.

Sally often sprinkled *talcum* powder in her tennis shoes.

Frank always wore a *helmet* when riding his motorcycle.

Last year, Agnes broke her *pelvis* when she fell in the bathtub.

Beth used an expensive *filter* to purify the water that she drank at work.

Matt enjoyed hiking in the *wilderness* during the summer.

Jennifer swam with a *dolphin* on her vacation.

The airline had to *cancel* the flight to Alaska due to bad weather.

Jasper carried a *lantern* to light his path through the woods.

Candice lost another *sandal* on the bike trail this weekend.

Mark did not bother to *mention* the stock's decline to the prospective buyer.

Cindy chewed on the *pencil* that she used for her math homework.

Dorothy polished the *pendulum* of the old clock to remove the tarnish.

Calvin rewrote the *sentence* more than a dozen times.

Most teens have a *tendency* to wear too much make-up.

Johnathan hoped to *vindicate* the memory of his father.

Adam's illness was caused by an infected *tonsil* in his throat.

Several chronic injuries *hampered* Ed's training for the Olympics.

The car just needed a *simple* adjustment to its brakes.

Sean Connery was the most *masculine* of all the Bond actors.

Leslie bought the *destitute* couple a hot lunch.

Rick reluctantly chose a new *subject* for his science report.

Father Patrick performed the *baptism* of their first child.

Meredith always enjoyed *vodka* drinks in the summer.

Lisa bought another *magnet* for the refrigerator door.

The brilliant painter added *pigment* to intensify the color.

The patrol checked every *sector* for suspicious people.

Julie tried to study *cognitive* processing during jump-rope competitions.

Joey learned how to *segment* sentences in fourth grade.

The flares helped to *signal* the search party after the accident.

Lee wanted to *dictate* a letter to his new secretary.

The ring was a *symbol* of the couple's love for each other.

Scott received a *subsidy* for his rent in the housing project.

Keith glared at the *pompous* man from across the room.

A hungry bear might *tamper* with the new trash container.

The ambassador greeted the *sultan* heartily whenever they met.

The election did not deliver a *mandate* for either candidate.

Liz had felt quite *dismal* after that long night of drinking.

A computer picks the *random* numbers for the state lottery.

The governor closed the *mental* hospital in order to save money.

Cathy gently washed the *poplin* before making the pillows for the couch.

The secretary was *seldom* seen in the office before noon.

Tom's latest movie got *splendid* reviews from the local critics.

Brett eagerly paid the *ransom* that the kidnappers demanded.

George decided to give Mary a *pendant* for her birthday.

APPENDIX B

STIMULUS LISTS FOR EXPERIMENT 2

List A: Block 1, CV-targets

The prisoner hoped for a quick *reversal* of the judge's decision.

Cassie tried adding more *vanilla* to the pudding mixture.

Alice hoped to spend a few *relaxing* days walking on a sandy beach.

Arthur thought about his economic *dilemma* for the rest of the day.

Mary was designing a clever *device* for drying large amounts of fruit.

Susan learned to make really *delicious* desserts in her cooking class.

Ben desperately wanted to *remember* the name of the book he was reading.

Phillip practiced for his piano *recital* during spring break.

Andrea told a lawyer that she wanted to *divorce* her husband.

Jonathan finally submitted his *report* to the environmental journal.

George quickly grew to *depend* on his daughter's weekly visit.

Older children tend to *select* the most advertised toys.

The teenager did not appear to feel *remorse* for his barbarous crime.

Alan obviously hoped he would be chosen to *remain* on the island.

Mike thoroughly enjoyed his *retirement* in sunny Florida.

The beach was filled with smelly *debris* left by the storm.

The candidates eventually agreed to *debate* on national television.

Linda regularly made a small *deposit* at the local bank every Tuesday.

Thomas gradually learned to *regard* his health more since his recovery.

The friendly cousins played *together* every week in the summer.

Adam trained for a year in order to *secure* a better job.

The dead squirrel started to *decay* on the hot road.

Many pioneers died during their *migration* to the west coast.

Allison started to plan a spring *vacation* in Bermuda.

List A: Block 1, CVC-targets

The students sat in the top *balcony* on opening night.

Sally often sprinkled some *talcum* powder in her tennis shoes.

Frank always wore his *helmet* when riding a motorcycle.

Beth purified her water with a good *filter* to make it taste better.

The doctor failed to improve the *mental* health of his patients.

Jennifer swam in the ocean with a *dolphin* last year.

The airline needed to *cancel* the flight to Alaska due to bad weather.

Jasper carried an old *lantern* to light his path through the woods.

Candice lost her blue *sandal* on the bike trail this weekend.

The puppy happily chewed the *pencil* that Cindy used for her math homework.

Calvin quickly rewrote the long *sentence* a dozen times.

Most teenagers have a strange *tendency* to wear too much make-up.

Adam's fever was caused by a bad *tonsil* infection.

A serious car crash *hampered* Ed's training for the Olympics.

The car only needed a *simple* adjustment to its brakes.

Leslie often bought the *destitute* couple a hot lunch.

Rick reluctantly chose a new *subject* for his science report.

Brian and Meredith always drank *vodka* in the summer.

Lisa shopped for a little *magnet* for the refrigerator door.

The brilliant painter added dark *pigment* to intensify the color.

Julie wanted to study *cognitive* processing during jump-rope competitions.

Joey learned several ways to *segment* words into syllables.

George lit the flares to send a *signal* to the next camp.

Keith could easily hear the *pompous* man from across the room.

List B: Block 1, CV-targets

The surprisingly quick *reversal* of the senator's position was unfortunate.

Sheila decided to add more *vanilla* to the cookie recipe.

Alexander enjoyed a few *relaxing* hours in the pool.

The last political *dilemma* was resolved after several hours of debate.

Nathan bought a handy *device* to sharpen the kitchen knives.

Connie prepared a very *delicious* brunch for the newlyweds.

Sebastian made several attempts to *remember* his locker combination.

Abigail liked the piano *recital* that was performed by the children.

Martin was shocked by the sudden *divorce* of his parents.

The bank president gave his *report* at the last meeting.

Jack did not want to *depend* on his parents for spending money.

Dora was unusually careful to *select* the freshest produce.

The criminal did not show *remorse* at the trial.

The young couple chose to *remain* on the boat during the hurricane.

Doug started to plan for *retirement* more than ten years ago.

The street was littered with *debris* from the parade.

The Economics Club planned a *debate* about the tax reform proposal.

The company's last big *deposit* did not show up in Ed's account.

All boaters should *regard* the regulations posted on the dock.

The college students sang *together* at the candle-light vigil.

The soldiers worked all day to *secure* the new territory.

Ted noticed the slow *decay* of the old tree stump.

The geese started their *migration* to Canada each spring.

Sophie hoped to spend her winter *vacation* on a tropical island.

List B: Block 1, CVC-targets

The theater's original front *balcony* had crushed velvet seats.

Melissa carefully patted some *talcum* powder on the baby's legs.

Sally refused to wear her *helmet* when cycling in the country.

The thin walls did not seem to *filter* out the noise from the neighbors.

The governor had to close the *mental* hospital in order to save money.

Christopher patiently trained the *dolphin* to jump and roll for fish snacks.

Ellen called her travel agent to *cancel* the trip.

Jim carried the old *lantern* inside the tent.

Molly put the pretty pink *sandal* on the little girl's foot.

Laura brought a new *pencil* to school every day.

Andrew revised the long *sentence* to make it less ambiguous.

Grandparents have a common *tendency* to spoil their grandchildren.

Emily was born with only one *tonsil* in her throat.

Lisa's craving for candy *hampered* her ability to stay on a diet.

Vegetarian dishes are often *simple* to prepare and delicious to eat.

The volunteers taught a *destitute* family how to grow their own food.

Max thought for a while about the *subject* of his paper.

Most cheap brands of *vodka* taste quite similar.

The strength of the large *magnet* makes it unsafe for young children.

Boiling water helps the dark *pigment* to dissolve quickly in the dye bath.

Samantha applied to study *cognitive* problem-solving in monkeys.

The bicycle tour along the coast was the best *segment* of our trip.

The town council voted for a new *signal* to be installed next year.

The college students disliked the *pompous* teacher who didn't seem that smart.

REFERENCES

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print.* Cambridge: MIT Press.

Besner, D. (1987). Phonology, lexical access in reading, and articulatory suppression: A critical review. *Quarterly Journal of Experimental Psychology, 39A*, 467-478.

Berent, I. & Perfetti, C.A. (1995). A rose is a REEZ: The two cycles model of phonology assembly in reading English. *Psychological Review, 102*, 146-184.

Berent, I., Bouissa, R. & Tuller, B. (2001). The effect of shared structure and content on reading nonwords: Evidence for a CV skeleton. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 4, 1042-1057.

Berent, I., Shimron, J. & Vaknin, V. (2001). Phonological constraints on reading: Evidence from the obligatory contour principle. *Journal of Memory and Language, 44*, 644-665.

Birch, S., Pollatsek, A., & Kingston, J. (1998). The nature of sound codes accessed by visual language. *Journal of Memory & Language, 38*, 70-93.

Bradley, D. C., Sanchez-Casas, R. M., & Garcia-Albea, J. E. (1993). The status of the syllable in perception of Spanish and English. *Language and Cognitive Processes, 8*, 197-233.

Bruck, M., Treiman, R., & Caravolas, M. (1995). Role of the syllable in the processing of spoken English: Evidence from a nonword comparison task. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 469-479.

Butler, B., & Hains, S. (1979). Individual differences in word recognition latency. *Memory and Cognition, 7*, 68-76.

Carreiras, M., & Perea, M. (2002). Masked priming effects with syllabic neighbors in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 5, 1228-1242.

Clements, G. N., & Keyser, S. J. (1983). *CV Phonology*. Cambridge, Massachusetts: MIT Press.

Coltheart, M., Rastle, K., Perry, C., Langdon, R. & Zeigler, J. (2001). DRC: A dual route cascade model of visual word recognition and reading aloud. *Psychological Review, 108*, 1, 204-256.

Corina, D. P. (1992). Syllable priming and lexical representations: Evidence from experiments and simulations. Paper presented at the 14th Annual Conference of the Cognitive Science Society.

Cutler, A., & Clifton, C., Jr. (1984). The use of prosodic information in word recognition. In H. Bouma & D. G. Bouwhnis (Eds.), *Attention and Performance X* (pp. 183-196). Hillsdale, N.J.: Erlbaum.

Cutler, A., Mehler, J., Norris, D., & Segui, J. (1986). The syllable's differing role in the segmentation of French and English. *Journal of Memory and Language, 25*, 385-400.

Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance, 14*(1), 113-121.

Eriksen, C. W., Pollock, M. D., & Montague, W. E. (1970). Implicit speech? Mechanisms in perceptual encoding. *Journal of Experimental Psychology, 84*, 502-507.

Ferrand, F., Segui, J., & Humphreys, G. W. (1997). The syllable's role in word naming. *Memory and Cognition, 25*(4), 458-470.

Ferrand, F., Segui, J. & Grainger, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language, 35*, 708-723.

Finney, S., Protopapas, A., & Eimas, P. D. (1996). Attentional allocation to syllables in American English. *Journal of Memory and Language, 35*, 893-909.

Folk, J. R. (1999). Phonological codes are used to access the lexicon during silent reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(4), 892-906.

Forster, K. I., & Chambers, S. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*, 627-635.

Fowler, C. A., Treiman, R., & Gross, J. (1993). The structure of English syllables and polysyllables. *Journal of Memory and Language, 32*, 115-140.

Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton Mifflin.

Frauenfelder, U. H., & Kearns, R. K. (1996). Sequence Monitoring. *Language and Cognitive Processes, 11*(6), 665-673.

Frauenfelder, U. H., & Lahiri, A. (1989). Understanding words and word recognition: Can phonology help? In W. Marslen-Wilson (Ed.), *Lexical Representation and Process.* Cambridge, Massachusetts: MIT Press.

Frederiksen, J. R., & Kroll, J. F. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception and Performance, 2*, 361-379.

Hadley, J.A. & Healey, A. F. (1991). When are reading units larger than the letter? A refinement of the unitization reading model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 1062-1073.

Hammond, M.(1999). *The Phonology of English.* Oxford University Press: New York.

Henderson, J. M., Dixon, P., Petersen, A., Twilley, L. C., & Ferreira, F. (1995). Evidence for the use of phonological representations during transsaccadic word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 21*(1), 82-97.

Henderson, J.M. & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 417-429.

Jared, D., & Seidenberg, M. S. (1990). Naming multisyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 16*(1), 92-105.

Kirk, C. (2001). Parsing preferences in the absence of phonotactic or allophonic cues to syllabification. Unpublished doctoral dissertation.

Klapp, S. T., Anderson, W. G., & Berrian, R. W. (1973). Implicit speech in reading, reconsidered. *Journal of Experimental Psychology, 100*, 368-374.

Lee, H., Rayner, K., & Pollatsek, A. (1999). The time course of phonological, semantic, and orthographic coding in reading: Evidence from the fast-priming technique. *Psychonomic Bulletin & Review, 6*(4), 624-634.

Lee, H., Rayner, K., & Pollatsek, A. (2001). The relative contribution of consonants and vowels to word recognition during silent reading. *Journal of Memory and Language, 44*, 189-205

Lesch, M., & Pollatsek, A. (1998). Evidence for the use of assembled phonology in accessing the meaning of printed words. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 24(3), 573-592.*

Liberman, A. M. (1992). The relation of speech to reading and writing. In R. F. a. L. Katz (Ed.), *Orthography, Phonology, Morphology, and Meaning* (Vol. 94, pp. 167-178). Amsterdam: Elsevier.

Liversedge, S. P., & Findlay, J. M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Sciences, 4*(1), 6-13.

Marslen-Wilson, W., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. *Cognition, 8*(1), 1-71.

Marslen-Wilson, W., & Warren, P. (1994). Levels of perceptual representation and process in lexical access: Words, phonemes, and features. *Psychological Review, 101*(4), 653-675.

Marslen-Wilson, W., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology, 10*(1), 113-129.

Mehler, J., Dommergues, J. Y., Frauenfelder, U., & Segui, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior, 20*, 298-305.

Noizet, G., & Pynte, J.(1976). Implicit labeling and readiness for pronunciation during the perceptual process. *Perception, 5*, 217-223.

Pallier, C., Sebastian-Galles, N., Felguera, T., Christophe, A., & Mehler, J. (1993). Attentional allocation within the syllabic structure of spoken words. *Journal of Memory & Language, 32*(3), 373-389.

Perfetti, C., Zhang, S., Berent, I. (1992). Reading in English and Chinese: Evidence for a "universal" phonological principle. In R. F. a. L. Katz (Ed.), *Orthography, Phonology, Morphology, and Meaning* (Vol. 94, pp. 227-248). Amsterdam: Elsevier.

Pitt, M. A., Smith, K. L., & Klein, J. M. (1998). Syllabic effects in word processing: Evidence from the structural induction paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 24*(6), 1596-1611.

Pollatsek, A., Lesch, M., Morris, R. K., & Rayner, R. (1992). Phonological codes are used in Integrating Information across saccades in word identification and reading. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 18*(1), 148-162.

Pollatsek, A., & Rayner, K. (1992). What is integrated across fixations? In K.Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp.166-191). New York: Springer-Verlag.

Prinzmetal, W., Hoffman, H., & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 17*(4), 902-923.

Prinzmetal, W., & Keysar, B. Functional theory of illusory conjunctions and neon colors. *Journal of Experimental Psychology: General, 118*(2), 165-190.

Prinzmetal, W., & Millis-Wright, M. (1984). Cognitive and linguistic factors affect visual feature integration. *Cognitive Psychology, 16*, 305-340.

Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461-475.

Pynte, J. (1974). Readiness for pronunciation during the reading process. *Perception & Psychophysics, 16*, 110-112.

Rayner, K., Sereno, S., Lesch, M., & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science, 6*(1),26-32.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 65-81.

Rayner, K., McConkie, G.W. & Zola, D.(1980). Integrating information across eye movements. *Cognitive Psychology, 12,* 206-226.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*, 372-422.

Rayner, K., & Balota, D. A. (1989). Parafoveal preview effects and lexical access during eye fixations in reading. In W. Marslen-Wilson (Ed.), *Lexical Representation and Process*. Cambridge, Massachusetts: MIT Press.

Schiller, N.O. (2000). Single word production in English: The role of subsyllabic units during phonological encoding. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 26*(2), 512-528.

Sebastian-Galles, N., Dupoux, E., Segui, J., & Mehler, J. (1992). Contrasting syllabic effects in Catalan and Spanish. *Journal of Memory & Language, 31*(1), 18-32.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and Performance XII: The psychology of reading* . Hillsdale, New Jersey: Erlbaum.

Selkirk, E. O. (1982). The syllable. In H. van der Hulst & N. Smith (Eds.), *The structure of phonological representations.* Dordrecht: Foris.

Sereno, S. C., & Rayner, K. (1992). Fast priming during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 18*(1), 173-184.

Sevald, C. A., Dell, G. S., & Cole, J. S. (1995). Syllable structure in speech production: Are syllables chunks or schemas? *Journal of Memory and Language, 34*, 807-820.

Slowiaczek, M. L., & Clifton, C. (1980). Subvocalization and reading for meaning. *Journal of Verbal Learning and Verbal Behavior, 19*, 573-582.

Smith, K. L., & Pitt, M. A. (1999). Phonological and morphological influences in the syllabification of spoken words. *Journal of Memory and Language, 41*, 199-222.

Tousman, S., & Inhoff, A. (1992). Phonology in multi-syllabic word recognition. *Journal of Psycholinguistic Research, 21*, 525-544.

Treiman, R., & Danis, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language, 29*, 66-85.

Treiman, R., Fowler, C. A., Gross, J., Berch, D., & Weatherston, S. (1995). Syllable structure of word structure? Evidence for onset and rime units with disyllabic and trisyllabic stimuli. *Journal of Memory and Language, 34*, 132-155.

Zelinsky, G. J., & Murphy, G. L. (2000). Synchronizing visual and language processing: An effect of object name length on eye movements. *Psychological Science, 11*(2), 125-131.