

An Investigation of Pre-Motor Encoding for
Production of High and Low Frequency Words

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Abstract

An Investigation of Pre-Motor Encoding
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Theories of spoken language production propose that the formulation of an utterance entails processing at a number of functionally distinct stages. The stages of processing that include the generation or retrieval of an abstract phonologic representation (i.e., *lexeme*), and motor programming, and that occur prior to motor execution are collectively referred to as pre-motor encoding.

The *dual route* model for pre-motor encoding proposes that processing within these stages proceeds by means of two distinct routes: an indirect route, through which the phonologic representation of a word is created by means of the assembly of sublexical units, and a direct route, in which the phonologic representation of a word is retrieved as a whole unit, precluding the need for sublexical assembly.

According to the dual route model, the route through which a word is processed depends upon the frequency with which the word is used. Thus the dual route model accounts for the word frequency effect, the robust finding that high frequency words are responded to faster than low frequency words, by ascribing fundamentally different mechanisms for the pre-motor encoding of high frequency versus low frequency words. A central tenet of the dual route model, then, is the assumption that the word frequency effect arises during the stages of pre-motor encoding – the lexeme-as-locus hypothesis.

Experiment 1 tested the lexeme-as-locus hypothesis using the cross-modal picture-word interference paradigm, an online method of investigating response preparation. It was hypothesized that greater phonologic interference effects would be obtained for low frequency words than for high frequency words.

Counter to the prediction, however, greater interference effects were obtained for high frequency words. This unexpected result led to the formulation of a new hypothesis relative to the dual route model, the *interference-induced assembly* hypothesis.

Experiment 2 tested this hypothesis using a variation of the cross-modal picture-word interference paradigm, which involved reading words rather than naming pictures. Null results were obtained. However, trends in the data provide some support for both the dual route and the interference-induced assembly hypotheses. These trends and their implications for further investigation of the interference-induced assembly hypothesis are discussed.

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DEDICATION

To my mother, Miriam; it is only because of her unwavering love, support and encouragement that I have been able to achieve this goal. And to my husband, James, whose love, support and constant encouragement has enabled me to persevere and to see this project through to fruition.

CHAPTER 1: INTRODUCTION

In spoken language production, the stages of processing that involve phonologic processing and motor programming, but occur prior to motor execution, are collectively referred to as pre-motor encoding. There are two models of pre-motor encoding that create contrasting accounts concerning the nature of processing occurring during pre-motor encoding. According to the *obligatory assembly hypothesis* (Rogers & Spencer, 2001), pre-motor encoding proceeds via a singular route: utterance plans are generated anew with each production attempt by means of the assembly of sublexical units (i.e., syllables, phonemes, distinctive features). In contrast, the *dual route model* maintains that pre-motor encoding proceeds via two routes: a direct route, through which phonologic representations and motor plans are retrieved as whole word units, and an indirect route, through which phonologic representations and motor plans are generated by means of the assembly of sublexical units as described above (Varley & Whiteside, 2001). According to the dual route model, the route by which pre-motor encoding is achieved depends primarily upon the frequency of occurrence of the word being produced.

Experiment 1 was designed to test one of the central tenets of the dual route model, that the word frequency effect (i.e., the finding that more frequently used words are responded to faster than less frequently used words) arises during the stages of pre-motor encoding. According to the dual route model, the pre-motor encoding of high frequency and low frequency words proceeds along fundamentally different routes. High frequency words are modeled as being processed by means of the direct route whereas low frequency words are processed by means of the indirect, assembly route. In Experiment 1, the effects of phonologic interference on high frequency and low frequency words were investigated to test predictions regarding the locus of the word frequency effect. Experiment 2 was designed to ascertain whether the route of processing is shifted for high frequency words under conditions of phonologic interference. The central question motivating these experiments concerns the role of word frequency in modeling the processing that occurs during pre-motor encoding.

In the chapters that follow, the theoretical foundations of both the obligatory assembly and dual route and theories will be reviewed. Chapter 2 presents a review of stage models of lexicalization and the evidence to support them. Chapters 3 and 4 will review the proposed sublexical units of pre-motor encoding, and the processes of sublexical assembly. In Chapter 5, the obligatory

assembly and dual route models and the evidence relevant to each will be discussed. Chapter 6 will review the word frequency effect and the evidence that addresses the hypothesis that the word frequency effect arises during the stages of pre-motor encoding. Subsequent chapters will outline Experiments 1 and 2, and the relevance of the results to models of pre-motor encoding.

CHAPTER 2: STAGES OF LEXICALIZATION

Theories of spoken language production propose that the formulation of an utterance entails processing at a number of functionally distinct stages (e.g., Dell, 1986; Garrett, 1980; Kempen & Huijbers, 1983; Levelt, 1989). These stages begin with the conceptualization of an idea and proceed to *grammatical encoding*, the stage wherein the semantic and syntactic information is specified in an abstract representation referred to as a *lemma*. The next stage has been labeled *phonologic encoding*, and is the stage wherein the word form and syllable stress is specified. The next stage, *phonetic encoding*, involves the incorporation of contextually dependent phonetic features such as aspiration. During the next stage, *motor programming*, a motor plan is generated and programmed. These stages then culminate with the execution of that motor plan. The stages of processing that include the processing of phonologic information and motor programming and occur prior to motor execution are collectively referred to as *pre-motor* encoding. Figure 2.1 is a schematic of these stages.

There are a number of assumptions upon which theories of spoken language production, and the research that fuel them, is based. These include the notions that:

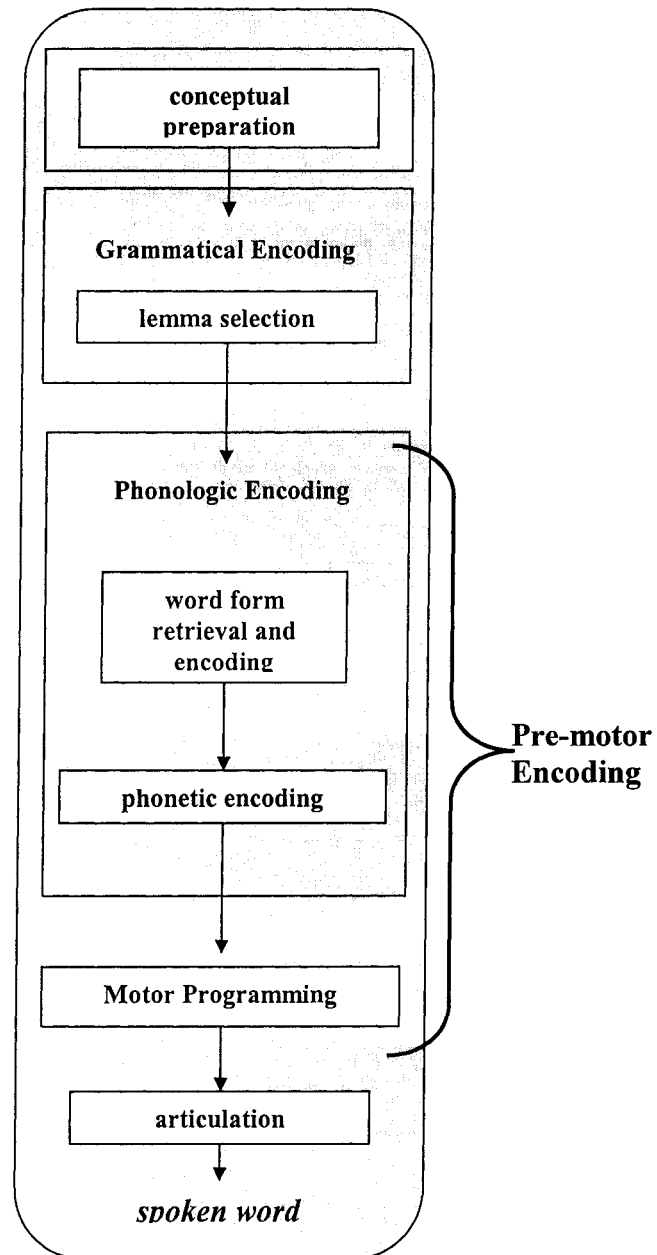


Figure 2.1. Processes of Spoken Language Production. Adapted from Indefrey & Levelt (2000).

- (1) Speech requires planning, and that this planning occurs at separate levels with regard to the processing of word meaning as opposed of the processing of word form (e.g., Butterworth, 1989; Garrett, 1980; Kempen & Huijbers, 1983);
- (2) Information is level specific, and the units of processing vary from stage to stage (Levelt, 1989);
- (3) The retrieval of word forms involves the assembly of sublexical units rather than the retrieval of whole word units (e.g., Meyer, 1992; Rogers & Spencer, 2001; Shattuck-Hufnagel, 1987);
- (4) Spoken language production relies on processing buffers in which word frames are constructed and sublexical units are assembled (e.g., Dell, 1986; Rogers & Storkel, 1998; Shattuck-Hufnagel, 1986).

The program of research discussed in this document focuses on the stages of phonologic encoding through motor programming, and is aimed at identifying methods and variables through which these stages may be examined. The stages of pre-motor encoding are putative areas of disruption in a number of motor speech disorders such as apraxia of speech, stuttering, and possibly hypokinetic and ataxic dysarthria. After nearly five decades of speech, language, and

psycholinguistic research, however, there is a dearth of information regarding the precise mechanisms that underlie these stages. Research centered on the focused investigation of these stages has the potential to not only inform theories of normal and disordered spoken language production, but also to influence the development of clinically effective intervention strategies.

Stages and the Time Course of Lexicalization

Nearly all theories of spoken language production agree on the notion that phonologic and semantic information is processed in functionally distinct stages (e.g., Bock, 1996; Dell, 1986; Dell, Chang, & Griffin, 1999; Dell & Reich, 1981; Fromkin, 1971; Garrett, 1980, 1988; Jescheniak & Schriefers, 1998; Kempen & Huijbers, 1983; Levelt, 1989, 1992, 1999; Levelt, Roelofs, & Meyer, 1999b; Levelt et al., 1991; MacKay, 1972; Meyer, 1990, 1991, 1992, 1996, 2000; Roelofs, 1992, 1997, 2000; Rogers, Belleville, Jones-Redmond, & Beretvas, 1999; Rogers, Jones-Redmond, & Alarcon, 1999; Shattuck-Hufnagel, 1979; van Turenout, Hagoort, & Brown, 1997, 1998, 1999).¹ Theories diverge,

¹ An exception is Caramazza and Miozzo ((Caramazza, 1997; Caramazza & Miozzo, 1997; Miozzo & Caramazza, 1997)) who argue against the lemma/lexeme distinction based on the modality specific patterns of errors observed in neuropsychological studies. They note that grammatical class deficits may be modality specific, that semantic substitution errors made in response to the same object may differ depending on the response modality, and that in the tip-of-the-tongue phenomenon, the availability of syntactic and phonologic information are not correlated. Based on these patterns, they propose a theory of spoken language production that is

however, on their accounts of the nature of the processing relationships between each stage. Discrete serial models maintain that processing at each stage takes place one at a time, with no overlap, and without the influence of information processed at other stages (e.g., Fromkin, 1971; Garrett, 1975; Levelt, 1989). Interactive-activation models, in contrast, maintain that processing at varying stages overlaps in time and that feedback mechanisms allow for the bi-directional flow of information between stages (i.e., that activation can proceed from lower levels, like phonologic encoding, back to higher levels, like grammatical encoding, e.g., Dell, 1986, 1988; MacKay, 1987).

Although the degree of interactivity among the stages of lexicalization is still a matter of debate, the stages of semantic and phonologic encoding have been modeled in terms of their general temporal characteristics based on both speech error and experimental evidence: the onset of semantic processing precedes the onset of phonologic processing (e.g., Levelt, Praamstra, Meyer, Helenius, & Salmelin, 1998; Levelt et al., 1991; Rogers, Belleville et al., 1999; Rogers, Jones-Redmond et al., 1999; Schmitt, Munte, & Kutas, 2000; Schmitt, Schiltz, Zaake, Kutas, & Munte, 2001; Schriefers, Meyer, & Levelt, 1990; van Turennout et al., 1997, 1999). This chapter will review some of the evidence

not based on between independent specification of semantic/syntactic and phonologic information.

that supports stage models of lexicalization and their general temporal characteristics.

Evidence from Speech Errors

Speech error research, along with the related “tip-of-the-tongue” phenomenon, highlights the striking difference between those processes related to meaning, and those related to form, and support the notion that lexicalization involves the encoding of two distinct types of information: semantic and phonologic.

Analyses of the patterns of speech errors that occur in the spontaneous speech of neurologically intact individuals have shown that such errors are naturally divided into two groups: those characterized by meaning similarities and those characterized by sound or form similarities (e.g., Fay & Cutler, 1977; Fromkin, 1971; Garrett, 1980; MacKay, 1970). Meaning-based errors, such as substituting *lion* for *tiger*, show a meaning similarity between the intended words and the intruding word. Sound-based errors, such as substituting *bayonet* for *bassinnet*, in contrast, show similarities in word forms, or sounds, in the absence of any similarities in meaning.

The strongest evidence for distinct stages of lexicalization in the speech error literature, however, comes from the patterns of the distribution of errors. Word exchange errors and sound exchange errors present contrasting profiles. In word exchanges, (e.g., *dinner is being served at wine*, when *wine is being served at dinner* was intended, Fromkin, 1971) exchanging words belong to the same syntactic category and do not bear any phonologic similarity. In addition, such exchanges are known to be insensitive to phrasal boundaries – words transpose across phrases (Garrett, 1975). In contrast, sound exchanges (e.g., *nerve of a vergeous breakdown*, when *verge of a nervous breakdown* was intended, Fromkin, 1971) rarely involve words from the same syntactic category, and typically arise from words that occur within the same phrase (Garrett, 1975). These varied patterns of word and sound exchanges suggest that word exchanges arise when planning spans multiple phrases (e.g., sentence length), but that sound exchanges arise when planning is focused on smaller spans (e.g., within phrases).

Data from the well-documented “tip-of-the-tongue” (TOT) phenomenon (Brown & McNeill, 1966) lend further support to stage models. When in the TOT state, individuals are often able to report some phonological characteristics, such as number of syllables, or beginning segments, of the word they are attempting to retrieve. Data reported by Brown and McNeill (1966) show that while in an

experimentally induced TOT state, 60-70% of the time, participants were able to correctly identify the first phoneme or consonant cluster, as well as the number of syllables of the word in question.

The TOT phenomenon highlights the fact that full access to semantic information does not necessarily include full access to phonologic information, underscoring the notion that there are different stages at which these different types of information are processed, or encoded. Furthermore, the TOT suggests that there is a distinct difference in the type of information that is available at a particular point in time.

These two types of information have been conceptualized as two different abstract representational units, the *lemma* and the *lexeme*, (Kempen & Huijbers, 1983) each of which corresponds to two different stages of lexical processing – semantic encoding and phonologic encoding. Within stage models of lexical retrieval, then, meaning-based errors, such as meaning-based word exchanges, are modeled as arising during the stage of lemma processing. In contrast, those errors in form or sound patterns arise during the stages of lexeme processing, or pre-motor encoding, during which time phonologic information is specified.

Speech errors analyses also have important, albeit limited, relevance to the question of the time course of lexicalization. Initial conceptualizations of the temporal properties of semantic and phonologic processing stages stemmed from the analysis of two types of word exchanges. In one case, the intruding word in such exchanges bears meaning similarities, but does not share phonologic characteristics. In the second case, the intruder shares phonologic characteristics, an error often referred to as *malapropism* (Fay & Cutler, 1977; Vitevich, 1997). That meaning based errors without phonologic similarities occur in some, but not all cases suggest an asynchrony in the specification of semantic and phonologic information. This error pattern suggests that meaning based errors occur *before* phonologic information has been encoded, supporting the notion that semantic encoding precedes the specification of phonologic information during phonologic encoding.

Evidence from Interference Studies

Beyond speech error analyses, however, reaction time studies have provided additional insight into the functional separation and temporal properties of semantic and phonologic processing stages. Schriefers, Meyer and Levelt (1990), for example, investigated the time course of semantic and phonologic activation using picture-word interference, a reaction time paradigm. Within the

cross-modal picture-word interference paradigm, participants name pictures as quickly as possible while ignoring an interfering stimulus (IS) that is presented in the auditory modality at different time intervals relative to the presentation of the picture. By varying the time interval between the presentation of the picture stimulus and the presentation of the IS, the stimulus onset asynchrony (SOA), processing can be affected by the IS at specific points during the naming process. Presentation of the IS prior to picture presentation is represented by negative values, hence an SOA of -300 ms indicates that the IS was presented *300 ms before* the picture was presented. Positive SOAs represent IS presentation *after* the target. Schriefers et al. (1990) included the SOAs of -150 ms, 0 ms, and $+150$ ms. This manipulation allows for the specific investigation of the time course of processing.

Four experimental conditions were included in which the type of relationship between the target word and the IS was manipulated. In a *semantic* condition, the target words and IS were semantically related to each other (e.g., cat – dog). In a *phonological* condition, targets and IS shared phonologic characteristics (e.g., fog – dog). In an *unrelated* condition, targets and IS were not related in either form or meaning (e.g., book – dog). In a *blanco* condition, no auditory IS was presented, however, the typed word “blanco” was superimposed on the

picture stimulus. In a *silence* condition, no auditory IS or typed word was presented in conjunction with the picture stimulus.

Within this paradigm, it is assumed that specific semantic effects can be obtained when the interfering stimulus is presented slightly before or while the lemma of a picture name is being activated. Likewise, it is assumed that specific phonologic effects can be obtained when the interfering stimulus is presented slightly before or during the activation of a lexeme of a picture name.²

Trials were presented in a blocked design. Response times in the interference experimental conditions were compared to response times in silence and unrelated conditions to estimate the effects of type of IS on picture naming latencies. Results showed that at the SOA –150 ms, the presentation of unrelated, phonologic, and semantic IS led to significant interference relative to the *silence* condition. However, the mean reaction time was significantly longer in the *semantic* condition than in the *unrelated* condition; the *unrelated* and *phonological* conditions did not differ from each other. At –150 ms, the specific interference was observed only for semantically related IS. It was inferred that semantic, and not phonologic information is being processed at this early SOA.

² See Chapter 7 for an in-depth theoretical discussion of the mechanisms underlying this domain-specific effect.

These results support the notion that semantic information is processed prior to phonologic information.

At the 0 ms SOA, once again significant interference was observed for unrelated, phonologic, and semantic IS, relative to the *silence* condition. However, the mean reaction time for the *phonologic* condition was significantly shorter than the mean in the *unrelated* condition, reflecting a specific facilitation effect of phonologically related IS relative to unrelated ones that had not been observed at the earlier SOA. However, unlike the results obtained at the –150 ms SOA, at the 0 ms SOA, the *unrelated* and *semantic* conditions did not differ significantly from each other. This same general pattern held for the SOA +150 ms. Facilitation in the *phonologic* condition continued to be observed relative to the *unrelated*, *semantic*, and *blanco* conditions, and, again, at this later SOA, the *unrelated* and *semantic* conditions did not differ significantly from each other. Thus the specific semantic interference effects observed at the early SOA was no longer present at later SOAs, however, specific phonologic effects that were not observed at the early SOA were observed at later SOAs.

In a partial replication of the Schriefers et al. (1990) study, Rogers, Belleville Jones-Redmond and Beretvas (1999) used the cross-modal picture word interference to investigate the differential effects of semantic and phonologic

interfering stimuli at five SOAs: -300 ms, -150 ms, 0 ms, +150 ms, and +300 ms in a mixed design in which the SOAs were distributed throughout each run. In an additional similar experiment, Rogers, Belleville et al. (1999) included +700 ms, as well. Results obtained from neurologically intact individuals for both studies revealed an asynchronous onset of interference effects in the semantic IS condition relative to the phonologic IS condition. The onset of interference effects, defined as the earliest SOA at which response times were significantly slower than the silence control condition, for the semantic IS condition preceded the onset of interference for the phonologic condition. These findings held true for both high frequency and low frequency words. In addition, results from Rogers, Jones-Redmond and Alarcon (1999) obtained from individuals with aphasia revealed the same temporal patterns of activation. These findings, obtained through the use of cross-modal picture word interference, offer strong evidence that the onset of semantic processing precedes the onset of phonologic processing.

In summary, studies using the cross-modal picture-word interference paradigm have found that response time is a function of the type of interfering stimulus and the SOA. In a semantic IS condition, at early SOAs (e.g., - 300 ms), faster response times have been recorded relative to baseline, which is indicative of facilitation. Facilitation by the semantically related stimulus at these early SOAs

can be attributed to the creation of an expectancy for the target that is to come, which allows for the conscious use of strategies (i.e., controlled processing, Posner & Snyder, 1975; Shiffrin & Schneider, 1977), as well as to the automatic spread of activation (e.g., Dell, 1986; Dell et al., 1999; Levelt, 1989).

At later SOAs, however, the semantic IS effects shift from facilitation to interference, and this same progression is evident for phonologic IS effects (Rogers, Jones-Redmond et al., 1999; Schriefers et al., 1990). Interference results when the IS activates a concept other than the target. It is hypothesized that such interference effects reflect a competition within a processing domain. Figure 2.2 shows a schematic of interference functions in semantic and phonologic IS conditions based on data obtained using cross-modal picture-word interference. A comparison of these interference functions shows that the onset of interference effects in the semantic IS condition *precedes* the onset of interference effects in the phonologic IS condition.

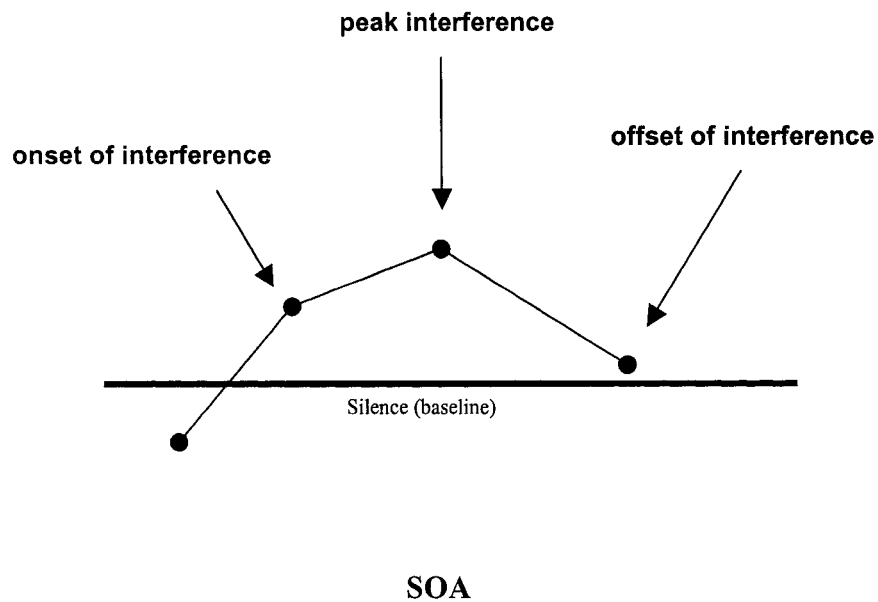


Figure 2.2. Parameters of activation. Y- axis represents SOLs. Onset of interference is defined as the first SOA at which SOLs in the interference condition are significantly longer than SOLs in the silence (baseline) condition. Peak interference is defined as the SOA of greatest amount of significant interference. Offset of interference is the first SOA thereafter at which interference is no longer significant.

Evidence from Dual Naming-Lexical Decision

Levelt et al. (1991) used a dual naming-lexical decision task to trace the time course of semantic and phonologic activation. Participants named a series of pictures. Critical trials for target pictures embedded within that series were followed by an acoustic test probe on which the lexical decision was made. The test probes included four types of words: semantically related, phonologically related, identical to the target word and unrelated to the target word. The acoustic test probe occurred at one of three SOAs: 1) short, in which the acoustic probe was presented shortly after the presentation of the picture stimulus; 2) long, in which the acoustic probe was presented shortly before the naming response was initiated, or 3) medium, in which the acoustic probe was presented somewhere in between those two extremes.

The analysis involved determining whether semantic, phonologic and identical acoustic probes show lexical decision effects that were different from the unrelated probes for the same pictures at different SOAs. For the short SOA condition, lexical decisions were significantly slower for the semantic, phonologic and identical probes relative to the unrelated probes. There were, however, no significant differences between the semantic, phonologic, and identical probe conditions. For the medium SOA condition, only the phonologic

probe latencies were significantly slower than the unrelated probe latencies. Again, there were no differences between the semantic, phonologic, and identical probe conditions. For the longer SOA condition, the phonologic probe latencies were significantly slower than the unrelated probe latencies, and identical probe latencies were significantly faster than the unrelated probe latencies. Significant semantic effects were found only at the short SOAs and significant phonologic effects were found at long SOAs. These results further corroborate the temporal characteristics of semantic and phonologic processing: semantic processing precedes phonologic processing.

Evidence from Electromagnetic Techniques

The temporal relationship between semantic and phonologic processing has also been investigated using electromagnetic techniques, which offer extremely precise millisecond-to-millisecond temporal resolution (Chertkow & Murtha, 1997; Demonet & Thierry, 2001; Indefrey & Levelt, 2000; Kantowitz, 1974; Savoy, 2001; Ungerleider, 1995). Levelt et al. (1998), for example, used magnetoencephalography (MEG) to relate a psycholinguistic model of language processing to the dynamics of cortical activation during picture naming. A dipole source analysis was used to relate peak activity of distinct cortical areas to the time windows of specific stage activation obtained by means of previous

reaction time experiments. The authors identified four time windows: 1) *visual processing and accessing the lexical concept*: 0 – 150 ms; 2) *lemma selection*: 150 – 275 ms; 3) *phonological encoding*: 275 – 400 ms; and 4) *phonetic and articulatory processing*: 400 – 600 ms. Magnetic field source cluster patterns showed distinct differences across these four time windows. Dipole sources identified in the lemma selection time window clustered in the right hemisphere at the parietal cortex, along the posterior end of the superior temporal sulcus. Dipole sources identified in the phonologic encoding time window clustered in the left hemisphere, close to the posterior third of the superior temporal gyrus and the temporo-parietal junction, in agreement with the site of Wernicke's area. These differential patterns in magnetic fields during picture naming support the notion of distinct processing stages and provide further evidence for the temporal relationships.

Van Turennout et al. (1997) introduced the registration of event-related brain potentials (ERPs) to the study of the time course of semantic and phonologic encoding in speech production. Lateralized readiness potentials (LRPs), slow, negative-going potentials that start to develop sometime before the execution of a voluntary hand movement and reach their maximum just after the onset of movement, have been used to assess aspects of human information processing, and have established that an LRP can develop in the absence of an overt

response on the basis of partial information (e.g., Coles, 1989; De Jong, Weierda, Mulder, & Mulder, 1988). Thus LRPs can be used to detect the relative moments in time at which semantic and phonologic information influence the preparation of a response. If a response is related to a combined semantic and phonological stimulus evaluation, response preparation will first be based solely on the semantic information (a partial evaluation), followed by the response preparation based on both the semantic and phonologic information (van Turennout et al., 1997).

To differentiate the distinct influences of semantic and phonologic information, a two-choice go/no-go reaction time paradigm was used, in which, on critical trials, participants performed two tasks. For the primary task, participants were asked to name a picture as quickly as possible. At 150 ms after picture onset, however, on critical trials (50% of the trials), a frame appeared around the picture as a cue to perform an additional task *before* naming the picture. For the secondary task, participants were asked to classify the picture along both a semantic and phonologic dimension and give the appropriate response. The semantic classification consisted of an animate/inanimate categorization task, designed to tap into the stage of semantic activation. The phonologic classification task consisted of a word-final phoneme decision, designed to tap into the stage of phonologic encoding.

Response type for the classification task was determined by the outcome of the semantic and phonologic classification. In Experiment 1, the type of phonologic classification determined whether a response should be executed. For example, a button-push response was required if the picture name ended with the phoneme /n/, but had to be withheld if the picture name ended with the phoneme /s/. If a response was required, the side used for the response was determined by the type of semantic categorization. For example, when the target picture represented an animal, a right-hand response had to be made. In the case of an object, however, a left-hand response had to be made.

The critical test for tapping into the time course of semantic and phonologic processing in Experiment 1 involved the presence or absence of an LRP on no-go trials in which the target word did not end with the phoneme that was being monitored, thus requiring that a response be withheld. If semantic information is processed earlier than phonologic information, response preparation is first based on semantic information, and phonologic information will affect response preparation at a later point in time. Since both go and no-go trials involved the semantic processing associated with the semantic categorization task, the onset of an LRP was expected to develop on both go and no-go trials at about the same latency.

In Experiment 2, the task instructions were reversed. The result of the semantic analysis determined the go/no-go decision, and the phonologic analysis determined the response hand. In this case, the critical test involved the presence or absence of an LRP for go trials. If semantic information is processed prior to phonologic information, the go/no-go decision could be made before information about the response hand becomes available. Thus the presence of an LRP was predicted only for go trials.

The results for Experiments 1 and 2 conformed to the predictions. In Experiment 1, an LRP was observed for both go and no-go trials, indicating that the cued response hand for the semantic categorization task was activated even when the phonological evaluation cued that no response be made. The onset latency for the LRPs for go and no-go trials was about the same, indicating that the preparation of a response began in the same time frame for both types of trials. In Experiment 2, in which the result of the semantic analysis, rather than the result of the phonologic analysis determined the go/no-go decision, significant development of the LRP was observed only for go trials, which required the use of both semantic and phonologic information in determining the appropriate response type. The absence of a significant LRP on no-go trials indicates that phonologic information did not influence response preparation; on no-go trials,

the decision to withhold the response could be made on the basis of the semantic categorization alone, which would preclude the activation of a response hand.

A similar study was conducted by Schmitt, Munte and Kutas (2000), who used a vowel versus consonant categorization rather than phoneme monitoring task.

Schmitt et al. also utilized the N200 event-related potential, a measure of response inhibition (Jodo & Kaymama, 1992). Both LRP and N200 results replicated the van Turennout, et al. (1997) findings. Additional studies by van Turennout et al. (1998) and Schmitt et al. (2001) that considered the time course of lexical processing also place phonologic processing at a later stage relative to the processing of conceptual and syntactic information. Thus electromagnetic techniques have provided another strong line of evidence to support the notion that the onset of semantic processing precedes that of phonologic processing.

Discreteness or Interactivity in Lexicalization?

While there is a consensus among theories of spoken language production that phonologic and semantic information are processed in different stages, the nature of activation spreading between associated lemmas and lexemes remains unclear. A key question concerns whether multiple phonological word forms are activated for the production of a single word (phonologic coactivation).

According to the strict, discrete stage processing models proposed by Levelt and colleagues (e.g., Levelt, 1989; Levelt et al., 1999b; Roelofs & Meyer, 1998), only selected lemmas will activate their corresponding phonological information because there is no feedback between the lemma and word form levels. In an alternative view, proponents of interactive activation theories (e.g., Dell et al., 1999; O'Seaghdha, Dell, Peterson, & Juliano, 1992; O'Seaghdha & Marin, 1997) hypothesize that the phonologic content of related words is automatically activated along with the corresponding semantic representations because of feedforward and feedback activation spreading in a densely connected lexical network.

Evidence from Speech Errors

One line of support for feedback and interactive mechanisms is often derived from the tendency for sound errors to result in real words, referred to as the *lexical bias effect*, (Baars, Motley, & MacKay, 1975; Dell & Reich, 1981). The reasoning stands that if lexical access proceeds in two serial, independent stages, errors involving the stage of phonologic processing should not lead to real words more than is expected by chance (Dell & Reich, 1981). A second line of support for such mechanisms derives from the statistical overrepresentation of “mixed errors” which have been identified in speech error corpora comprised of both

naturally occurring and experimentally induced errors (Dell & Reich, 1981; Martin, Gagnon, Schwartz, Dell, & Saffran, 1996; Martin, Weisberg, & Saffran, 1989). These consist of semantic errors that are also phonologically related to the target, such as in the example, “read-write” and “lobster-oyster” (Garrett, 1988). Analyses of these mixed errors reveal that they occur more frequently than to be expected by chance (Dell & Reich, 1981). Both of these lines of evidence together suggest that semantic and phonological information interact during lexicalization. Interactive models account for these errors by means of feedforward and feedback mechanisms which allow both semantic and phonologic information to influence processing at other stages (Dell et al., 1999; O'Seaghdha et al., 1992; O'Seaghdha & Marin, 1997).

There are, however, alternative explanations of the lexical bias effect and the existence of mixed errors that do not necessitate the inclusion of feedback mechanisms. Levelt and colleagues (Levelt, 1989; Levelt et al., 1999b; Levelt et al., 1991), maintain that the lexical bias effect can be accounted for within a discrete-stage framework through the inclusion of a self-monitoring component which is presumed to block out non-word errors (Baars et al., 1975). Although the lexical bias effect is classically considered an automatic phenomenon, Baars, Motley and MacKay (1975), in an error-elicitation study, showed that it is not a necessary effect. No lexical bias effect was observed in errors produced by

participants when all the targets and filler items in the experiment were nonwords. The lexical bias effect only appeared when some real words were included as filler items. Baars et al. accounted for this contrast using a self-monitoring mechanism; speakers monitor their internal speech for errors just before articulating when the task involves some real words. When the experimental task deals exclusively with nonwords, speakers do not monitor the lexical status of their output. Such results support the notion that speakers are able to prevent the overt production of internally prepared items when they violate lexical or other constraints.

Mixed errors can also be accommodated within a discrete-stage framework. The *word-form encoding by activation and verification* model (WEAVER, and the full model, WEAVER++, which includes lemma selection), as developed by Roelofs (e.g., Levelt, Roelofs, & Meyer, 1999a; Levelt et al., 1999b; Roelofs, 1992, 1997, 2000), is a computational model reflecting the basic assumptions of the discrete, feedforward stage model. Computer simulations of lemma and word-form activation during picture naming using WEAVER++ have yielded predictions that agree with reaction time data (e.g. Levelt et al., 1999b; Roelofs, 2000). In its native state, WEAVER++ makes no errors (Levelt et al., 1999b). However, modifications to the system parameters can be made to allow for the production of errors. For example, by means of the parameter “binding,” a

mechanism binds selected segments to the word-form node to which they belong. In phonologic encoding, then, only the segments that are linked to a particular word-form will be selected and syllabified. If such a parameter is modified to allow other segments to be selected, output errors can occur. When such modifications to WEAVER++ are included, WEAVER++ error predictions closely match those of naturally occurring speech errors, including the statistically overrepresentation of mixed errors (Levelt et al., 1999b). Thus, Levelt and colleagues argue that the existence of both the lexical bias effect and mixed errors do not oblige the inclusion of feedback mechanisms during lexicalization.

Evidence from Reaction Time Studies

Support for a discrete, strictly feedforward model has been derived from data obtained using behavioral online methodology that do not support an interactive view. For example, Schriefers, Meyer, and Levelt (1990) used the cross-modal picture-word interference paradigm to investigate the time course of semantic and phonologic encoding. A discrete stage model predicts no interference of phonologic information at early SOAs because information is fed forward to the phonologic level only after a single lemma has been selected. They found that semantically related interfering stimuli created specific semantic effects only

when they were presented at the early –150 ms SOA and not when there were presented at the later 0 ms and +150 ms SOAs. However, phonologically related interfering stimuli showed a differing pattern in that specific phonologic effects were not obtained at the earliest –150 ms SOA, but rather only at the later 0 ms and +150 ms SOAs. These results supported the predictions of a discrete stage model, suggesting that semantic encoding proceeds without the influence of phonologic information, contrary to the multiple activation predicted by interactive processes occurring within a dense, interconnected network. Similar results were obtained by Levelt et al. (1991). No priming effects were measured for targets that were phonologically related to the categorical associates of the picture's name. Such findings lead the authors to conclude that only the word form of the selected lemma will be activated during pre-motor encoding.

This view is challenged, however, by O'Seaghdha and Marin (1997), who found evidence to support feedback effects within the lexical network, using a mediated semantic phonological priming paradigm. Semantic-phonologic triples were created in which the middle word constituted the potential semantic-phonological mediator. For example, in the triple *pen-ink-inch*, the word *pen* is semantically related to the mediator, *ink*, which is phonologically related to *inch*. Results showed that such feedback effects were demonstrable; *pen* facilitates *inch*, not directly, but by means of the semantic relationship between *pen* and

ink. The authors conclude that it appears to be a real, but admittedly slender, effect.

More robust support for feedback mechanisms emerged from a priming study conducted by Peterson and Savoy (1998, Experiments 1A and 1B). This study was designed to examine the temporal relationship between selection and encoding processes of semantic and phonologic information, focusing on whether they are organized as temporally discrete stages or whether they overlap in time. The experimental design employed the use of near-synonyms, two words that are used to refer to the same object. In English, for example, the words *couch* and *sofa* are near synonyms. Synonym pairs with an asymmetry in the frequency of possible names were chosen. The name that is most frequently used to name a picture is referred to as the dominant name, while the less frequent name is the secondary name. In the case of *sofa* and *couch*, *couch* is the dominant name. Name dominance was verified in a pilot study in which dominant names were used 84% of the time to name pictures while the secondary name was used only 16% of the time.

Serial and interactive models differ in their predictions regarding the time course of phonologic activation of dominant names, such as *couch*, versus the phonologic activation of secondary names, such as *sofa*. According to serial

models, only selected lemmas will activate their corresponding phonological information. Since lemmas associated with dominant names are most likely to be selected during picture naming, serial stage models predict phonologic activation should only occur for the word form of that dominant name. If stages overlap, however, as predicted by interactive models, then the phonologic content of all words related to the target lemma is automatically activated because of feedforward and feedback mechanisms in the lexical network. Thus, within an interactive framework, upon picture presentation, regardless of whether participants produce the dominant or secondary name, phonologic activation, should occur for the word forms of both names.

To test these predictions, word targets were selected that were phonologically related to the either dominant name of the picture or to the secondary name of the picture. For the example of the couch-sofa near synonym pair, the target phonologically related to the dominant name, “couch” would be the word *count*, whereas the target phonologically related to the secondary name, “sofa” would be the word *soda*. For non-critical trials, subjects were asked to name the picture primes as they appeared on a computer screen. On critical trials, however, the phonologically related target words were presented simultaneously with their picture primes. On such critical trials, participants were asked to name the target word rather than produce the picture name.

The experimental design also addressed the opposing predictions of serial and interactive model with regard to the temporal characteristics of phonologic activation by including different picture-target SOAs of 50, 150, 200, 300, 400 and 600 ms. Both serial and interactive models predict that no phonologic priming effects should be observed at the earliest SOA (e.g., 50 ms), and that by the latest SOA (600 ms), given that the dominant word will be produced by most of the participants most of the time, priming effects should occur only for dominant-related targets. Interactive models generate additional prediction. Since according to such models the word forms of *all* words related to the target lemma are automatically activated prior to the selection of a single target lemma, interactive models predict that robust priming effects for the secondary-related targets may be found at earlier SOAs (e.g., 200 and 400 ms) if these SOAs precede the explicit selection of the lemma of the dominant name.

For the -100, 100 ms, 300 ms and 400 ms. SOAs, results showed that phonologic priming effects for both dominant- and secondary-related targets were essentially equal and substantial. Only at the 600 ms SOA did the phonologic priming effect of the secondary-related targets disappear. These results demonstrated that the phonological codes for both dominant and secondary picture names were initially active with the presentation of a single

picture; *soda*, which is phonologically related to the secondary name, *sofa*, primed the word *couch*, thus supporting the notion of phonologic coactivation. Contrary to the predictions of serial models, results showed that word forms of both names are phonologically active, not just the preferred name. Furthermore, the predictions of interactive models regarding the time course of phonologic coactivation were also supported; both word forms are activated at earlier SOAs, but, after the single target lemma is selected, only the word form of the dominant name is active. Similar findings obtained by Jescheniak and Schriefers (1998) using the cross-modal picture-word interference paradigm also support phonological coactivation for near-synonyms.

In response to these findings, however, proponents of discrete stage models argue that near-synonyms may present a special case for a particular class of semantic alternatives. They propose that in such cases of extreme semantic overlap, the lemmas of both synonyms are selected due to equal levels of activation, an account that can explain the occurrence of mixed errors, or blends, as well (Levelt et al., 1999a; Roelofs, 1992). If near-synonyms can result in simultaneous lemma activation and phonologic coactivation, however, then it follows that this same principle would apply to a lesser degree to cases in which lemmas share some degree of overlap, producing low levels of phonologic

priming (Saffran, 1999). This is precisely the view advocated by O'Seaghdha and Marin (1997).

Evidence from Neuropsychology

Further support for interactivity between the conceptual/syntactic and phonological/articulatory domain, and against a strictly discrete stage model can be found in neuropsychological studies. For example, Lambon Ralph, Sage and Roberts (Lambon Ralph, Sage, & Roberts, 2000) describe a subject, GM, who exhibits classic anomia (i.e., impaired naming in the absence of semantic or phonological impairment). When presented with a *semantically* related prime, which presumably increases the activation of a set of words semantically related to the target, GM displayed a reduced ability to name the target. This inhibitory effect suggests that the observed deficit arises primarily from an inability to select a single lexical item from amongst various semantically related competitors. Despite this unresolved semantic competition, however, GM demonstrated partial activation of word form information (such as the metrical structure of the target word), suggesting that phonologic word form access is not dependent on the full selection of a target lemma, but can proceed before selection is complete. Of further relevance to the present discussion as well is the finding that for GM, the critical type of cue required to alleviate the

semantically based competition at the lemma level was a *phonemic* cue. This suggests that partial phonologic information can produce feedback to the lemma level thus indirectly reinforcing the activation of a target lemma.

CHAPTER 3: SUBLEXICAL UNITS OF PRE-MOTOR ENCODING

That words are not always retrieved as wholes is supported by the existence of speech errors and the tip-of-the-tongue phenomenon (Brown & McNeill, 1966; Fowler, Treiman, & Gross, 1993; Fromkin, 1971; Levelt, 1989; MacKay, 1970, 1972; Meyer, 1992, 2000; Shattuck-Hufnagel, 1983, 1986, 1987, 1992; Treiman, 1986).

There are a number of constraints on sound errors involving the movement of phonemes that provide support to the notion that lexicalization involves the assembly of sublexical units. For example, patterns suggest a *syllable position constraint* in that onsets tend to exchange with onsets, nuclei with nuclei, and codas with codas, rather than exchanging across syllable position (e.g., MacKay, 1970; Schiller, 2000; Shattuck-Hufnagel, 1979) and most errors leave the rime intact, involving only onsets (MacKay, 1970). Furthermore, there is a tendency for exchange errors to involve phonemes that are phonemically similar rather than phonemically dissimilar (Meyer, 1992, 2000; Shattuck-Hufnagel, 1987), and exchanging phonemes typically differ by just one or two features (e.g., MacKay, 1970; Shattuck-Hufnagel, 1983). Consonants in word onsets have also been shown to interact more with each other than with consonants that are word-

internal. Similarly, vowels, in general, exhibit a very strong tendency to interact with each other rather than with consonants (Meyer, 2000).

If words are not retrieved as whole words, then it remains to be determined what units are being assembled. These sublexical units have been hypothesized to be syllables and syllable schemas (e.g., Collins & Ellis, 1992; Dell, 1986; Ferrand & Segui, 1998; Meijer, 1996; Sevald, Dell, & Cole, 1995; Sullivan & Riffel, 1999), onset and rimes (e.g., Collins & Ellis, 1992; Garrett, 1975; MacKay, 1970; Shattuck-Hufnagel, 1986, 1987, 1992; Sullivan & Riffel, 1999), phonemes (e.g., Dell, 1986; MacKay, 1970; Nadeau, 2001; Nooteboom, 1969; Roelofs, 1999; Shattuck-Hufnagel, 1979), and distinctive features (e.g., MacKay, 1970; Meyer & Gordon, 1985; Rogers & Storkel, 1998).

The answer to the question of units is not obvious. Levelt (1989) describes the approach as a “search for the Holy Grail,” alluding to the presumably misguided search for a *single* unit of speech production (p. 23); it is more likely that multiple units are actively manipulated during spoken language production. Addressing the issue of whether words can be retrieved as whole units, or whether some degree of sublexical assembly is typical or obligatory is central to gaining a complete understanding of pre-motor encoding. This section will examine potential candidates for the units involved in pre-motor processing.

Syllables

The Syllable in Linguistic Theory

In linguistic theory, the syllable is at the core of the phonological representation (Katamba, 1993). The phonemes within the syllable can be viewed as being grouped into three components: the onset, the nucleus and the coda. Of these, only the nucleus, which constitutes the sonority peak of the syllable, is a requisite constituent of all syllables. The onset is the single phoneme or phoneme cluster that may precede the nucleus, and the coda is the single phoneme or phoneme cluster that may follow it (e.g., Fowler et al., 1993; Treiman, 1988). In the word *sprint*, for example, the onset is /spr/, the nucleus is /ɪ/, and the coda is /nt/.

In considering a three constituent composition of the syllable, two major theories have been advanced regarding the internal structure, or relationships among these elements. In the *flat structure* view, there is no differential link between either the nucleus and the onset or the nucleus and the coda. The nucleus does not belong to any other unit within the syllable but is autonomous. In the *hierarchical structure* view, syllable is modeled as reflecting a hierarchical grouping between two of its three constituent elements. This

grouping can occur in one of two ways. With a *rime structure* hierarchy, the nucleus and the coda are joined at a higher level, reflecting a closer link between these two constituents, and creating a more autonomous onset. Within a *body structure* hierarchy, the onset and nucleus are linked to form a body (Fowler et al., 1993).

Of these views, the bulk of the evidence appears to support the onset/rime structure as having psychological salience. Treiman (1988) summarizes this evidence, citing that the rime plays a key role in the assignment of stress in English, that in speech errors, vowels followed by consonants (i.e., rimes) are more likely to behave as units than are initial consonants and vowels, and that errors in short-term memory have been shown to follow patterns similar patterns. Each constituent then connects to a slot on the *skeletal tier*, which is conceptualized as a place-holder representing the quantitative aspects of phonemes; features specify their quality (i.e., place and manner of articulation, Sevald et al., 1995). Thus Figure 3.1 presents a model of the syllable based on the onset/rime distinction, and the skeletal tier.

A “syllable paradox” is created by the conflicting evidence on the status of the syllable and its constituents in language encoding (Dell, 1986). Evidence from speech errors with respect to the functional role of the syllable is rather

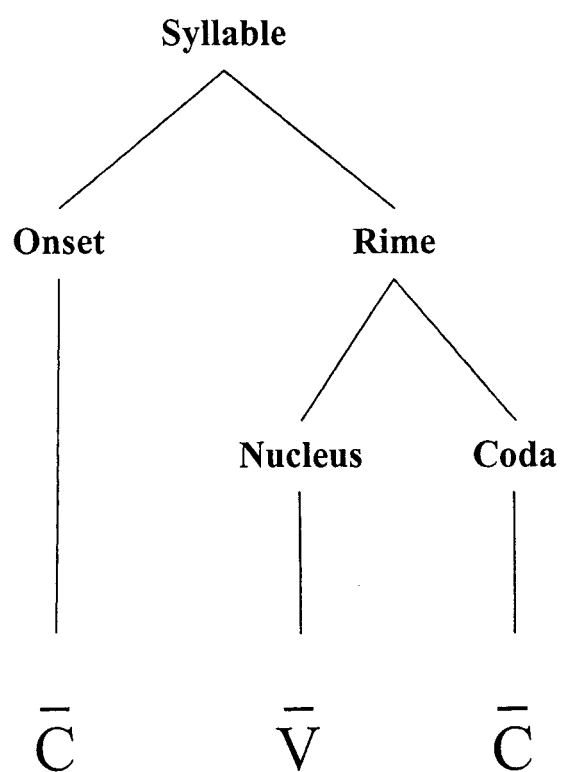


Figure 3.1. A model of hierarchical syllable structure with skeletal tier.
From Sevald, Dell & Cole (1995).

inconclusive. For example, speech errors appear to reflect a *syllable position constraint*, in which onsets tend to exchange with onsets, nuclei with nuclei, and codas with codas (e.g., MacKay, 1970; Schiller, 2000; Shattuck-Hufnagel, 1979) but most errors leave the rime intact, involving only onsets (MacKay, 1970).

Some examples (from Fromkin, 1971):

space food → *face spood* (onset exchange)

clip peak → *cleap pik* (nuclei exchange)

gone to seed → *god to seen* (coda exchange)

This error pattern suggests that syllables consist of frames that are labeled according to constituent position – onset, nucleus and coda, and thus that the syllable itself, due to the influence of its constituents, has a representation and a functional role in speech production planning.

There are, however, alternative explanations for these effects that do not include the syllable as a unified functional representation. Since the vast majority (more than 80%) of such errors involve word onsets, the syllable position constraint may, in fact, be explained in terms of word structure – a *word-onset constraint*, or in terms of the general tendency of segments to interact with segments that are phonemically similar rather than phonemically dissimilar segments (Meyer,

1992, 2000; Shattuck-Hufnagel, 1987). Consonants in word onsets are particularly error-prone, and have been shown to interact more with each other than with consonants that are word-internal. Furthermore, vowels, in general exhibit a very strong tendency to interact with each other rather than with consonants (Meyer, 2000), which would explain the findings regarding nucleus exchanges. The finding that whole syllables are highly unlikely to participate in speech errors (e.g., Meyer, 1996; Nadeau, 2001; Sevald et al., 1995) provides counterevidence to the notion that the syllable is a singular unit that is independently selected and manipulated during production.

While there is some evidence obtained through the use of offline methods to support a functional, albeit potentially limited, role of the syllable in language production, very little evidence has been obtained to support the existence of syllable-sized units (Schiller, 2000). In one online investigation, however, Ferrand, Segui, and Grainger (1996) found evidence to support a *syllable priming effect* in French, and were the first to report the replication of these results for British English (Ferrand, Segui, & Humphreys, 1997). They found that targets such *sarong* were named faster when they were preceded by primes that shared exactly the first syllable of the target but not when preceded by primes that shared more than the first syllable (i.e., that shared the first three phonemes). Findings suggesting that syllables can be primed would present

compelling evidence that they are functional units in speech production and that there are corresponding syllable-sized representations within the mental lexicon.

Additional support for the functional role of the syllable was obtained by Levelt and Wheeldon (1994) who conducted a series of four experiments designed to test the hypothesis that speakers have access to a *mental syllabary*, a repository of syllable-sized representation detailed enough to guide articulation.³ They hypothesized that if speakers must access a mental store of syllabic gestural scores, syllable frequency will affect access in a manner analogous to the effects of word frequency in accessing the mental lexicon, i.e., response latencies to low frequency syllables should be longer than response latencies to high frequency syllables. Results indicated that naming durations of high frequency syllables were consistently shorter than naming durations for low frequency syllables without influence from the frequency of their constituent phonemes.

Investigations by Schiller (1998, 2000), however, using the masked priming paradigm, failed to replicate this syllable priming effect in Dutch or English. In masked priming, a forward pattern mask consisting of hash marks or other symbols (i.e., #####) is presented first, followed by a prime. After presentation of the prime, a backward pattern mask is presented (i.e., #####). The target

³ See the section, “A Mental Syllabary” in Chapter 5 for a more detailed discussion.

word then appears and remains until a response is given. Schiller (1998) found that phonologically related primes in Dutch facilitated the naming of the targets, but, unlike Ferrand, et al. (1996, 1997), found no systematic relationship between the syllabic structure of prime and target.

Further, in a replication of the Ferrand et al. (1997) study of English, Schiller (2000) also failed to find a syllable priming effect using the masked priming paradigm. In Experiment 1, monomorphemic English nouns of CV, CVC, or CV[C] structure were preceded by visually masked primes in CV, CVC and neutral conditions. While main effects of priming condition were obtained - naming latencies for target words were fastest when targets were preceded by a CVC prime, slower when preceded by a CV prime, and slowest when preceded by a neutral prime - there was no support for a syllable priming effect. This same experiment was replicated in Experiment 2, using a picture-naming task to test whether the syllable priming effects obtained in previous studies using word naming could be partially attributed to the visual overlap between prime and target. Results for Experiment 2 were similar to those of Experiment 1. Both experiments demonstrated that amount of segmental overlap influences speed of production, but fail to support the notion that the syllable plays a functional role in the early stages of phonologic encoding in English. The syllable as a unit may play a more functional role at later stages of pre-motor encoding, as is suggested

by Levelt and colleagues (Levelt, 1989; Levelt et al., 1999b; Levelt & Wheeldon, 1994).

Metrical Representations: Syllables as Schemas or Chunks?

Another issue that is central to the consideration of the status of the syllable involves the nature of the metrical representation of words, and the implications such a representation has regarding the processing mechanisms of pre-motor encoding. During pre-motor encoding, a variety of information relevant to the particular word-form must be encoded. This includes the number of syllables, the location of stress, and the actual phonemes of the word. While processing mechanisms will be addressed in the section that follows, the representation of the syllable is relevant to the present discussion regarding units of representation.

Inherent in this issue of syllable priming, however, is the question of what *type* of representation is being primed. The *chunk* view (Figure 3.2) characterizes syllables as independent units that are pre-specified with phonological content. The *schema* view (Figure 3.3), in contrast, characterizes syllables as abstract and unspecified representations of the structure of the syllable that is independent of phonologic content, and is based on the assumption that

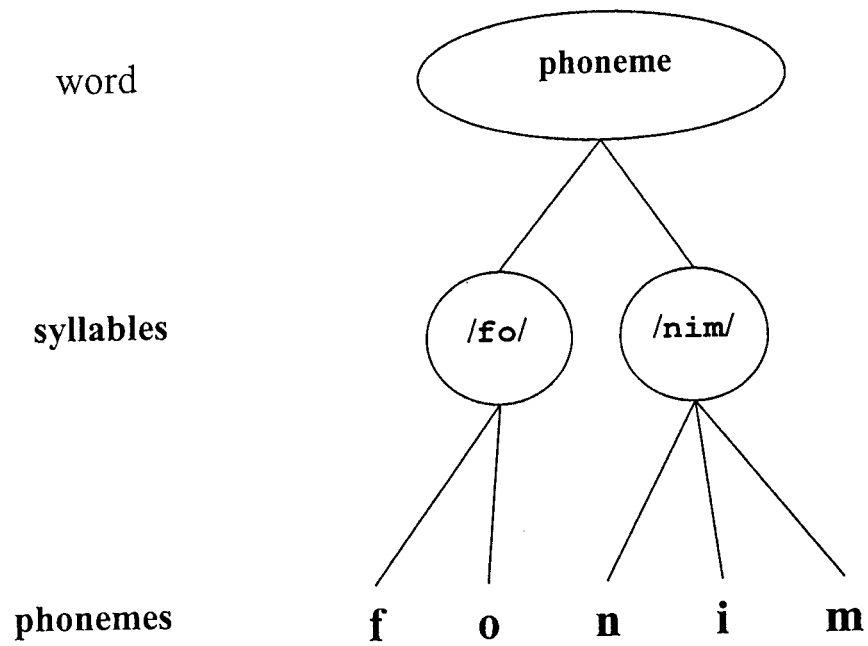


Figure 3.2. The chunk view of the syllable. Adapted from Sevald, Dell & Cole (1998)

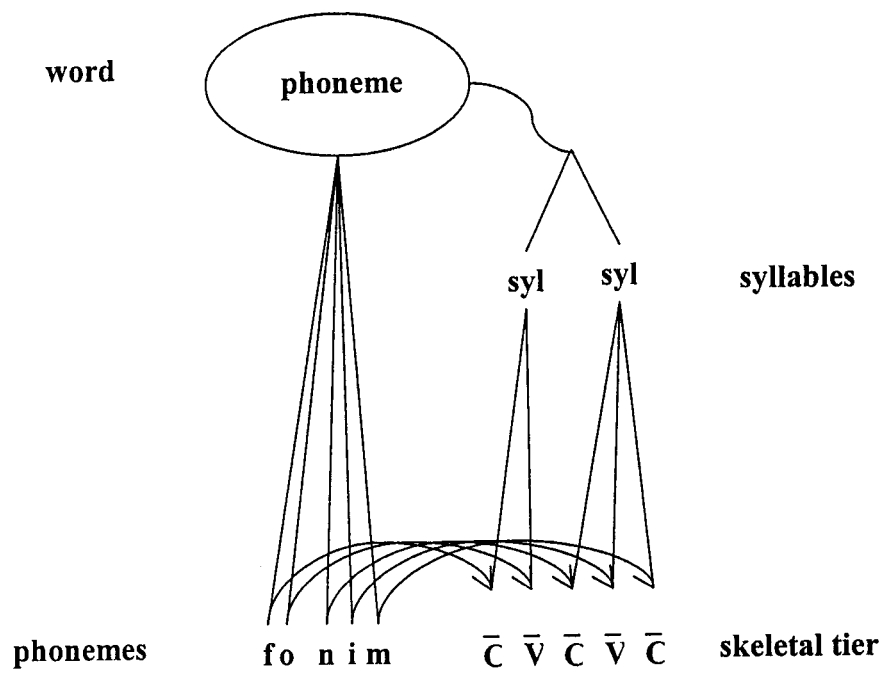


Figure 3.3 The schema view of the syllable. Adapted from Sevald, Dell & Cole (1998).

phonemes and other sublexical units are *types*, rather than *tokens*, (i.e., they are part of a pool that is shared by all words, Meyer, 1991). In this view, syllables are frames that must be filled with the appropriate phonological content (Ferrand & Segui, 1998; Meijer, 1996; Schiller, 2000; Sevald et al., 1995). The relationships between syllables would thus be conceived of differently depending on the representational approach. Considering the examples *cat* and *dog*, in the chunk view, these monosyllabic words would be different chunks, sharing no relationship. In the schema view, however, they represent different *syllables*, but share the same frame structure at the level of the skeletal tier (Sevald et al., 1995). This conceptualization differs from the onset/rime position tentatively suggested by speech errors in that constraints are not based on a two or three-way constituent structure, but rather on a CV or consonant and vowel position structure in which frame positions are specified with respect to the type of phoneme that may fill it. There have been several recent investigations that have addressed these joint questions regarding the status of the syllable as a functional unit and the structure of such a representation.

Romani, in Experiment 1 of an unpublished doctoral dissertation (1992, as discussed in Meijer, 1996 and Ferrand & Segui, 1998) found some evidence to support the functional relevance of the schema view of the syllable in an investigation of the effect of shared (skeletal tier) structure on naming a word.

An interference paradigm was used in which subjects prepared to repeat auditorily presented nonwords, but in a minority of cases would be asked to read a word aloud.

The relationship between the nonwords prime and the word target was manipulated. Results showed that reading latencies were faster when the prime and the target overlapped in both structure and content (lexical features) than when there was no overlap in stress and structure. A second experiment, however, failed to replicate these findings, raising the possibility, as Ferrand and Segui (1998) point out, that the use of the reading paradigm may have influenced the results of these experiments.

Studies using other paradigms have, however, produced support for the schema view. For example, Meijer (1996, Experiment 1) used a translation naming task in which subjects, when presented with visually presented words in English, translated them aloud into Dutch as quickly as possible. Four conditions were used that manipulated the relationship between the syllable constituents in the English and Dutch words:

Double similarity → shared onset and shared CV structure

Onset similarity → shared onset, different CV structure

Structure similarity → different onset, shared CV structure

Dissimilarity → neither shared onset nor shared CV structure

Results showed that shared CV structure led to facilitation but different CV structures did not. There was a significant main effect of structure: naming was on average 23 ms faster when the target and the prime shared the CV structure. There was, however, no significant main effect of onset, nor was there a significant structure by onset interaction. This structural facilitation effect was found regardless of whether onsets were shared.

Sevold, Dell and Cole (1995) found similar results in three experiments in which speakers repeated pairs of phonological strings as quickly as possible during a 4 second period. Speech rate was measured. Results showed that speech rates were faster when both the structure and content of words and nonwords were shared relative to when structure was *not* shared, but most or all of the phonemic content was shared.

Within a phonological priming paradigm, Collins & Ellis (1992) and Sullivan & Riffel (1999) investigated the influence of syllable position during phonologic encoding. Both studies manipulated the relationship between target and prime. Collis and Ellis (1992) used three priming conditions. In the *same-position*

condition, at least two phonemes were shared by the target and prime in the same syllabic position. In the *different-position* condition, at least two phonemes were shared, but at least one of them was in a difference syllable position. In the *unrelated* condition, the prime and picture name did not share any phonemes. The participants' task was to repeat an auditory prime twice. After the second repetition, a target picture was presented, and participants named this as quickly as possible. Results showed that target words were named faster when the primes shared targets in the same syllable position. There was no significant facilitation observed when targets and primes shared phonemes that were in difference syllable positions.

Sullivan and Riffel (1999) used three prime conditions: identical primes and targets, primes and targets with shared onsets, and primes and targets that shared rimes. Primes and targets were both elicited by line drawings. Participants named prime pictures that appeared either 650 ms or 100 ms before target pictures. Analyses revealed significant inhibitory effects for both onset-related and rime-related primes. Furthermore, a location x prime type interaction was observed across subjects, showing that the magnitude of inhibition was reliably larger for the onset-related than the rime-related targets. These results support a syllable architecture in which phonemes and structural frames are independent as in the schema view. Additionally, the differential effects of shared-onset and

shared-rime primes on naming latencies obtained in the latter study also highlight the functional importance of the onset and rime.

Data from the tip-of-the-tongue phenomenon also supports the independence of syllabic structure and phonological content since it suggests that speakers have access to structural properties of words, such as number of syllables, in the absence of knowing the specific sounds (e.g., Brown & McNeill, 1966). Speech error evidence also provides support for this independence. In Stemberger's (1990) analysis of phonological errors involving consonant clusters, it was found that errors that create clusters are more likely when there is a cluster in nearby syllables, suggesting that the frame of one syllable tends to be reduplicated in another syllable. If aspects of the frame can move across words, such findings offer strong support for the reality of an abstract structure at the level of the skeletal tier (Sevald et al., 1995). Thus there appears to be a convergence of evidence from sound error and TOT analyses and a variety of behavioral data, to support a schema-type representation of the syllable in which frames are retrieved independently of their phonological content. Thus syllables do not appear to be stored as representational units constraining specific phoneme combinations, but rather as templates that specify the metrical representation of words as they relate to the component phonemes (consonants and vowels) of the word.

Nearly all theories agree on the independence of metrical representations and the segments that fill them. However, support for the existence of functional representations for onsets and rimes is found in evidence of double dissociations in the speech error literature (e.g., Garrett, 1975; MacKay, 1970; Shattuck-Hufnagel, 1986, 1987, 1992), as well as evidence from priming studies (e.g., Sullivan & Riffel, 1999). This evidence suggest that these sub-syllabic units are also independently manipulated to some extent during pre-motor encoding and that phonemes may be marked for their position within a syllable. The notion that segments are marked for word position is compatible with both the chunk and schema views of the syllable.

Is Syllabification Part of the Metrical Representation?

A question that has recently been receiving more attention involves whether or not syllable-position information is included as part of the metrical representation. The speech error patterns summarized by the syllable position constraint, suggests that phonemes are indeed coded for syllable and/or word position. That such effects do not unequivocally support syllable position itself as functionally important has already been discussed.

As an alternative to this approach, Levelt and colleagues (e.g., Levelt, 1992; Levelt et al., 1999b; Levelt & Wheeldon, 1994) propose that syllable-specific information is not stored as part of the metrical representation, but rather that syllabification is created “on-the-fly” by means of a mechanism that creates new metrical frames for what they term *phonological words*, which contrast with *lexical words* in that their metrical properties are determined by taking the phonologic environment into consideration. Frames for phonological words often involve multiple lexical words, and reflect the metrical characteristics of such lexical words *in context*. Thus, syllabification, in their view, involves the blending of the stored metrical frames of the constituent lexical words, and the creation of phonological words, whose metrical properties reflect environmental influences.

To build the crux of the argument, they point out that when generating connected speech, speakers do not concatenate the canonical forms of words, but rather create rhythmic, pronounceable metrical structure. In fact, they assert that a word’s syllabification in connected speech rarely follows its canonical form, but instead may transcend both the canonical syllable of the word itself, and word boundaries. For example, the word *escort* is divided as “e-scor” in its canonical form, but in connected speech, as in the phrase *He’ll escort us*, syllabification becomes “e-scor-tus,” thus transcending a word boundary. If a

word's syllables were fully specified within the metrical representation, they argue, then this would be reflected in errors of syllabification, such as the production of "de-mand-it" for "de-man-dit." As such errors have not been reported in connected speech, the authors interpret such absence as support for a syllabification mechanism that operates after word forms have been assembled and placed in a phonologic context.

Phonemes

The mere fact that syllable constituents take part in movement errors suggests that units smaller than the syllable are actively manipulated during the processes of production. Thus, motivation for the identification of phonemes as units of production stems primarily from the speech error literature. It has been estimated that 70 to 90% of phonological slips-of-the-tongue concern a single segment. This includes the movement, deletion, substitution, or addition of a single phoneme (Dell, 1986). Some examples (from Dell, 1986):

<i>spill beer</i> → <i>speer bill</i>	(exchange)
<i>reading list</i> → <i>leading list</i>	(anticipation)
<i>black boxes</i> → <i>back bloxes</i>	(shift)

Nooteboom's (1969) analysis of sound errors in Dutch, a typical sample, identified 89% single segment errors, 7% consonant cluster errors, and just 4% for the remainder. Furthermore, the segmental environment has been shown to influence the potential for speech errors. For example, *similarity effects* in speech errors indicate that repeated phonemes tend to induce the misorderings of surrounding phonemes (MacKay, 1970). Such patterns in speech errors suggest that phonemes are units that have an explicit representation and are actively manipulated during the planning and generation of an utterance (Nadeau, 2001; Roelofs, 1999; Shattuck-Hufnagel, 1979). However, there is some evidence to suggest that units smaller than the phoneme also play a role in production.

Phonetic Features

Within linguistic theory, phonemes are described in terms of an internal structure made up of systematic relationships between phonetic features. These features provide a theoretical framework through which phonological processes, such as assimilation, can be described (Katamba, 1993). There is some evidence to support the role of distinctive features in the planning processes of production. For example, in most phonological substitution errors, the error and target differ in just one or two features (e.g., MacKay, 1970; Shattuck-Hufnagel, 1983).

Additional support comes from studies of anticipatory coarticulation in which phonetic features of speech segments in an utterance are sometimes articulated ahead of other features associated with segments upstream (Meyer & Gordon, 1985). Examples such as the anticipatory coarticulation of nasality in the /i/ vowel during production of the utterance “free Ontario” suggests that phonetic features play an independent role in processes of word form encoding, phonetic encoding and/or motor programming. However, it has been argued that such coarticulation effects may be more appropriately attributed to biomechanical constraints imposed by the articulatory mechanisms than to pre-motor stages of processing (Rogers & Storkel, 1998).

The status of features is further clouded by the finding that in the speech error literature, purely feature-based errors are rare. It is estimated that less than 5% of all sound errors can be characterized as such (Fromkin, 1971; MacKay, 1970; Meyer, 2000). Furthermore, they are difficult to identify, since, in many cases, phonetic feature errors could also be attributed to phoneme selection errors.

Consider the following examples, taken from Nadeau (2001):

/bat/ → /pat/ (deletion of voice,
or /p/ for /b/ substitution)

/not/ → /dot/ (deletion of nasality,
or /d/ for /n/ substitution)

/fat/ → /pat/ (deletion of continuance,
or /p/ for /f/ substitution)

Some rare cases have been identified, however, that point to distinctive feature selection errors (Fromkin, 1971; Shattuck-Hufnagel, 1979).

clear blue sky → glear blue sky (exchange of voice feature)

Cedars of Lebanon → Cedars of Lemadon (movement of nasality
feature)

Such findings create a “feature paradox” (Dell, 1996) due to the conflicting evidence on the importance of features as encoding units. Their low frequency of occurrence appears to signify a limited role as unit (Shattuck-Hufnagel, 1979), and suggests that they are not the processing units that are selected independently and combined (Meyer, 1990), but rather than they are combined, or “chunked” into segments, a position is supported by experimental evidence (Roelofs, 1999). However, as evidenced by patterns observed in speech errors and anticipatory coarticulation, features do appear to play an important role in constraining phoneme slips in both normal and disordered production, thus

underscoring their relevance in the planning process. Since perceptual biases associated with speech error collection techniques may compromise the reliability of frequency counts of speech error types, a convergence of evidence from a variety of experimental paradigms, rather than from speech errors analyses alone, should form the foundation for theories of spoken language production (Frisch & Wright, 2002; Mowrey & MacKay, 1990).

Rogers & Storkel (1998) experimentally investigated the role of phonetic features in speech production by means of a form-based priming technique in which participants read aloud visually presented prime-stimulus pairs of monosyllabic words. Word pairs differed in the number of features shared by the initial consonants and the type of feature shared. There were five featural similarity conditions, two conditions in which two features were shared (*shared voicing and manner* and *shared place and manner*), two conditions in which one feature was shared (*shared voicing only* and *shared manner only*) and one control condition in which no features were shared. The authors predicted that if features are independently selected during the processes of pre-motor encoding, then the mechanisms of post-selection inhibition should render the just-cleared feature nodes temporarily unavailable, creating a processing delay that will increase response times in shared feature conditions relative to the control condition. Results indicated that the conditions *shared voicing and manner* and

shared manner consistently yielded response latencies that were significantly longer than those of the control condition. Such experimental results, taken together with speech error data, suggest that not only phonemes, but also the distinctive features that specify phonemes, are actively manipulated to some extent as independent units during pre-motor encoding.

CHAPTER 4: SUBLEXICAL ASSEMBLY DURING PRE-MOTOR ENCODING

In the process of lexicalization, semantic information is activated prior to phonologic information (e.g., Levelt et al., 1998; Levelt et al., 1991; Rogers, Belleville et al., 1999; Rogers, Jones-Redmond et al., 1999; Schmitt et al., 2000; Schmitt et al., 2001; Schriefers et al., 1990; van Turenout et al., 1997, 1999). Once the meaning information is activated, processing at the pre-motor level must entail the generation of the appropriate form of the word that is to be spoken. This begins with metrical encoding, the activation and retrieval of the lexical word form from the mental lexicon, with its appropriate syllabic and segmental information.

Phonetic encoding and motor programming represent the final levels of pre-motor encoding. These stages presumably operate on the output of the phonologic or word form encoding system, and involve the translation of representations from the realm of the abstract to the context-dependent surface structures of connected speech by means of the programming and execution of motor commands. During these processes a number of units that are independently selected have been identified: syllables and syllable schemas (e.g., Collins & Ellis, 1992; Dell, 1986; Ferrand & Segui, 1998; Meijer, 1996;

Sevald et al., 1995; Sullivan & Riffel, 1999), onset and rimes (e.g., Collins & Ellis, 1992; Garrett, 1975; MacKay, 1970; Shattuck-Hufnagel, 1986, 1987, 1992; Sullivan & Riffel, 1999), phonemes (e.g., Dell, 1986; MacKay, 1970; Nadeau, 2001; Nooteboom, 1969; Roelofs, 1999; Shattuck-Hufnagel, 1979), and distinctive features (e.g., MacKay, 1970; Meyer & Gordon, 1985; Rogers & Storkel, 1998).

The Role of the Phonologic Buffer

Speech error and other evidence suggest that, to some extent, sublexical units are assembled for production. A *phonologic output buffer* has been posited that acts as temporary storage for such units during the assembly processes (Caplan, 1992; Dell, 1986; Levelt, 1989; Rogers & Storkel, 1998, 1999; Sevald & Dell, 1994; Shattuck-Hufnagel, 1986). A number of characteristics are ascribed to the phonologic output buffer (Cowan & Barron, 1987).

- (1) It is hypothesized that a word or sound cannot be spoken until it has entered the buffer;
- (2) There may be cases in which an unwanted item enters the buffer automatically, as seen in Stroop-like tasks;

- (3) In conditions of response competition then, it is assumed that there is a selection mechanism following the buffer, and this mechanism allows the subject to trace the origin of each item (i.e., whether a prepared item was generated by means of the primary task, or whether it was an unwanted item that has mistakenly entered the buffer) and to decide which item is the intended item;
- (4) The selection mechanism sometimes creates errors, and the speed of selection can be interfered with. Items that are not selected clear the buffer. This could be by means of decay, active clearing, or replacement by new item.

Support for the hypothesized phonologic buffer is found in the length effect. It has been observed that response times to the naming of pictures representing bi-syllabic targets are longer than naming latencies for monosyllabic target words (e.g., Klapp, Anderson, & Berrian, 1973). This finding suggests that initiation of articulation does not begin until the second syllable of a bi-syllabic word is encoded, and that the encoded phonologic form of the first syllable is maintained in the phonologic buffer until the encoding of the second syllable is complete, and the word can be articulated. Results obtained by Levelt & Wheeldon (1994) support this hypothesis. In Experiment 2, the frequency of occurrence of the second syllable of bi-syllabic words was manipulated. If

articulation for bi-syllabic words begins with the completion of the programming for the *initial* syllable, no effects of second syllable frequency should be observed. If, however, the initiation of articulation is constrained by the motor programming of the second syllable, second syllable frequency effects would be expected. A 12 ms second syllable frequency effect was observed for the bi-syllabic target words. These results thus support both the notion that articulation does not begin until the second syllable has been programmed, and the notion of a phonologic buffer, in that the encoded phonologic form of the first syllable must be maintained before it is articulated, while the remainder of the word is being encoded.

Rogers and Storkel (1998) provide additional empirical support for the existence of the phonologic buffer and for the mechanisms involved in loading, clearing and reprogramming the buffer. They examined the effects of shared features on reaction times based on the *phonologic similarity effect*, the robust finding that similar sound structure among words interferes with processing. Participants were asked to quickly produce word pairs that differed in the number of features shared by the initial consonants and the type of feature shared. Significant interference effects were obtained when articulatory features were shared. In particular, shared manner was the most influential factor associated with the observed interference effects. Changing the place of articulation feature yielded

no systematic effects on reaction times, and the maintenance of place of articulation while manipulating other features did not result in facilitation of production. The absence of facilitative effects when place of articulation was held constant strongly suggests that programming processes do not proceed by means of an editing mechanism that “removes” articulatory features and phonologic information associated with the prior plan that are not relevant to the current plan, replacing them with only the information that is needed. Rather, these findings suggest that information is quickly cleared from the buffer and that the buffer is “reprogrammed” with the new plan (Rogers & Storkel, 1998, see also Meyer & Gordon, 1985).

This hypothesized buffer, then is modeled as playing an integral role in pre-motor encoding, allowing a temporary workspace in which forms can be assembled and/or maintained during the processes of metrical encoding, phonetic encoding and motor programming before the initiation of articulation.

Metrical Encoding

Once the appropriate word form has been activated, both the phonological segments of the word, and the metrical properties of the word must be retrieved.

Despite the lack of a general consensus regarding the nature of the representation of syllable structure (metrical frames), nearly all theories of phonological encoding distinguish between segmental and metrical form, and a complete understanding pre-motor processing necessarily entails a description of the mechanisms underlying segment retrieval, as well as segment-to-frame association. This process can be viewed as the integration of the segmental and syllable representations essential to language production, which, in-and-of-themselves, embody different aspects of word form.

The Nature of Phoneme Activation and Segment-to-Frame Association

Several studies have addressed the issue of the nature of the mechanisms behind the serial ordering of syllables and segments. Collins and Ellis (1992) approached the issue in a phonologic priming study in which subjects repeated an auditorily presented prime and then named a target picture. A principle experimental question was how phonologic priming effects are influenced by the position of shared phonemes. A serial account of activation, in which segments are activated and associated positions within the frame in the order they are to be retrieved, would predict a greater effect of the phonological relationship when prime-target pairs share the same early phonemes (i.e., onset + nucleus) than when the pairs share the same later ones (nucleus + coda), since early segments

would be activated prior to later ones. In contrast, a parallel account of activation, in which the segments of a word are activated and associated in parallel, without regard to their serial position, would predict similar effects of the phonological relationship, regardless of the position of the phonemes shared by the prime and target. Results conformed to the latter prediction; primes sharing onset + nucleus afforded no processing differences when compared to primes sharing nucleus + coda. The authors concluded that the activation of the phonemes of the targets by means of the production of a prime would affect selection of targets sharing both early and late-occurring phonemes equally only if selection occurred in parallel.

The Collins and Ellis (1992) findings, however, are in stark contrast to the bulk of the evidence obtained through investigations of the nature of segment activation. For example, Sullivan and Riffel (1999), using a picture-naming paradigm, found support for sequential left-to-right processes. Participants were instructed to name picture pairs in which the first picture represented the prime, and the second represented the target. On critical trials, primes and targets were onset-related or rime-related. Prime effects were reliably larger for onset-related than for rime-related targets. Similar results involving early location-specific effects were obtained in a variety of other studies that employed a variety of different paradigms, suggesting that the finding is robust (Levelt & Wheeldon,

1994; Meyer, 1991; Meyer & Schriefers, 1991b; Santiago, MacKay, Palma, & Rho, 2000; Sevald & Dell, 1994).

An interesting related issue, however, is presented by additional findings involving effects specific to shared-rime only conditions. In addition to the findings reported above, which support sequential processes, Sullivan and Riffel (1999), also found shared-rime effects, and similar shared-rime effects were also obtained in other, independent priming studies (Lupker & Williams, 1989; McEvoy, 1988). Such a combination of onset-related and rime-related results may be more consistent with a two-stage sequential processing model (Dell, 1988; Levelt & Wheeldon, 1994; Meyer, 1990, 1991; Shattuck-Hufnagel & Klatt, 1979). According to a two-stage model, there is an initial parallel spread of activation to all words sharing the same phonemes. Selected phonemes are then associated to frames in a left-to-right sequential manner. Both stages produce competition for selection, but the second stage significantly increases this competition for onset-related targets, due to their early location, and consequently early frame association (Sullivan & Riffel, 1999). Further support for a two-stage model comes from the existence of exchange errors across words. (e.g., baked a cake → caked a bake). While such errors have been interpreted as providing support for the independence of segments and frames, they also suggest that the phonemes of a word are initially selected as a set and

are only subsequently associated with frames. In the case of such errors, when a segment is mis-selected for a word, it does not appear again in its correct slot, but rather that slot is filled with the still-available word-initial phoneme that should have been selected for the first word (Meyer, 2000; Rogers & Storkel, 1998).

The Time Course of Activation, and the Implications of the Phonotactic Constraint and Phonetic Accommodation

Findings that support the left-to-right sequential association speak to the time course of segment-to-frame association in that they indicate that initial segments are assigned prior to segments that occur later in the word. However, a theory of pre-motor encoding must account not only for data that suggests a sequential integration of segments and metrical frames, but must also account for constraints within which these processes operate.

For example, speech error analyses indicate that when errors occur, the results rarely create sequences that are phonologically “illegal” for the given target language, a phenomenon referred to as a *phonotactic constraint* (e.g., Fromkin, 1971). The existence of phonotactic constraints on misordered sequences strongly suggests that rules governing the acceptable sequencing of phonemes operate at the level of segment-to-frame association, or that there is some

mechanism that would only allow phonologically “legal” sequences to be uttered, such as self-monitoring. An increasing number of phonologists propose that the syllable is the basis for determining the pattern of acceptable sequences, and suggest that the language specific constraints on the segmental make-up of syllable onsets are fundamental (Wolfram & Johnson, 1982).

Adherence to phonotactic constraints also suggests that segmental errors, such as exchanges, occur at the level of segment-to-frame association, during the time period in which association rules apply. A slip ostensibly occurs when the wrong constituent is assigned to a frame (e.g., Dell, 1986; Garrett, 1975; Shattuck-Hufnagel, 1979; Stemberger, 1985), yet phonotactic rules are still applied, thus imposing positional constraints on the mis-selected segment.

An additional constraint involves the phonetic characteristics of erroneous utterances. Even when segments are misordered during segment-to-frame association, utterances are *phonetically* well formed, reflecting a phonetic accommodation of even erroneous segments to the segmental environment. (Fromkin, 1971; Garrett, 1980) and others have commented on cases like those of the following in which the plural morpheme accommodates to the voicing characteristics of the preceding phoneme (from Garrett, 1980):

- (1) It certainly run outs (/s/) fast. (intended: runs (/z/) out fast);
- (2) Even the best team losts (/s/). (intended: teams (/z/) lost);

Such cases suggest that the locus of such errors corresponds to a processing level that occurs *prior* to the creation of phonetic representations and the programming of motor sequences. Thus there is strong support from speech error analyses that the mechanisms of segment-to-frame association are distinct from and occur prior to processes of phonetic encoding and motor programming.

Phonetic Encoding, and Motor Programming

The ultimate output of the phonologic system is the actual phonetic realization of the phonologic representation. The phonetic well-formedness of speech errors, along with the implications regarding the locus of such errors, supports the notion that mechanisms of phonetic encoding operate independently of other processes of word form encoding. This information does not appear to be an integral part of the abstract phonologic representation, but rather is determined by the context in which the item is spoken, and is incorporated into the representation at a later point in time (Levelt & Wheeldon, 1994; Wolfram & Johnson, 1982). Speech production necessitates the ability to improvise action in a variety of circumstances, and this suggests that the planning processes that

precede articulation proceed independently of the need to consider the details of motor execution (Shaffer, 1992). Motor programming, then, is conceptualized as the translation of the abstract representation into a motor plan that specifies the coordination of the articulators for speech.

The mechanisms that drive these processes, however, are elusive, and many theories of pre-motor encoding, in fact, are not specific in addressing them. Although much of the data that has been discussed thusfar, particularly data obtained by means of behavioral online methodology, has been interpreted to reflect events occurring at isolated stages of processing, it remains extremely difficult to determine whether outcomes reflect processing during phonologic encoding, phonetic encoding, and/or motor programming.

The role of Phonetic Features Revisited

As discussed earlier, some support for the independent role of phonetic features in pre-motor processing has come from both anticipatory coarticulation (Meyer & Gordon, 1985), and speech error analyses, like, for example, the finding that phonemes with shared features are more likely to exchange (e.g., MacKay, 1970).

As phonetic features can be understood as playing a role in the specification of articulatory goals (conceptualized as specifications of place and manner of articulation and voicing characterization), several studies have investigated the potential integral role of phonetic features in the translation of abstract representations into a motor plan that specifies the coordination of the articulators for speech. For example, both Meyer and Gordon (1985) and Rogers and Storkel (1998) examined the effects of shared features on reaction times based on the *phonologic similarity effect* (PSE). The PSE refers to the finding that similar sound structure among words interferes with processing as measured by slower reaction times, reduced working memory span and increased error rates. The PSE has been demonstrated even in the absence of an overt verbal response, which suggests that this robust effect arises during the stages of pre-motor encoding rather than during articulation. As discussed in the preceding chapter, Rogers and Storkel (1998) predicted that if features are independently selected during the processes of pre-motor encoding, then the mechanisms of post-selection inhibition should render the just-selected feature nodes temporarily unavailable, creating a processing delay that will increase response times in shared feature conditions relative to the control condition. Results indicated that the conditions *shared voicing and manner* and *shared manner* consistently yielded response latencies that were significantly longer than those

of the control condition. The Rogers and Storkel results corroborated findings obtained by Meyer and Gordon (1985) in that significant interference effects were obtained when articulatory features were shared. The Rogers and Storkel findings further qualified the role of features in that shared manner was found to be the most influential factor associated with the observed interference effects.

Findings from both studies also have implications regarding the potential contributory role of articulatory and/or biomechanical factors. Neither study found a processing advantage or facilitation when place of articulation was held constant. If the observed interference effects could be attributed to inherent biomechanical limitations in the rapid articulation of utterances, then facilitative effects would be predicted when no changes in the positioning of articulators for production were necessary (i.e., when place of articulation was held constant). The absence of facilitative effects when place of articulation was held constant, however, strongly suggests that biomechanical factors alone cannot account for interference effects.

With regard to processing mechanisms, this absence of facilitation also suggests that programming and reprogramming processes do not proceed by means of an editing mechanism within the phonologic buffer. If plans were simply edited, and irrelevant articulatory features and phonologic information associated with

the prior plan were simply removed and replaced with the information that is needed, facilitative effects would be observed when features were shared. Findings from both Rogers and Storkel (1998) and Meyer and Gordon (1985) were inconsistent with this account. Rather, findings suggest that information is cleared from the buffer and that the buffer is “reprogrammed” with the new plan.

This account also provides a theoretical framework for the phonologic interference effect, which can be explained by means of post-selection *lateral inhibition* mechanisms within the lexical network. Sublexical units at various levels are selected for assembly as a result of their nodes reaching their corresponding thresholds of activation. Once the frames are filled and the representation is transmitted to the next processing stage, the previously selected nodes are quickly suppressed by means of *post-selection inhibition* to avoid being immediately reselected in the reprogramming of the phonologic buffer. If the reprogramming involves accessing features or other sublexical units that are shared with the previous program, a *refractory period* related to post-selection inhibition which temporarily renders the nodes unavailable creates a processing delay (Rogers & Storkel, 1998, see also Meyer & Gordon, 1985).

CHAPTER 5: IS SUBLEXICAL PHONOLOGIC ASSEMBLY OBLIGATORY?

Data obtained by means of speech error analyses, interference studies and electromagnetic techniques together form a strong foundation for a theory of spoken language production in which semantic and phonologic information are processed at functionally distinct stages (e.g., Bock, 1996; Dell, 1986; Garrett, 1980; Levelt, 1989; MacKay, 1972; Shattuck-Hufnagel, 1979; van Turennout et al., 1997). Furthermore, investigations into the temporal characteristics of these stages strongly suggest that the onset of semantic information precedes the onset of phonologic information (e.g., Levelt et al., 1991; Rogers, Belleville et al., 1999; Schmitt et al., 2000; Schriefers et al., 1990), although there is ongoing debate as to whether processing between these stages is discrete and serial (e.g., Levelt, 1999; Levelt et al., 1999a; Roelofs & Meyer, 1998), or interactive, allowing for feedback between levels (e.g., Dell et al., 1999; O'Seaghdha et al., 1992; O'Seaghdha & Marin, 1997).

The data indicate that the encoding of phonologic information entails manipulation of a number of units: syllables and syllable schemas (e.g., Collins & Ellis, 1992; Dell, 1986; Ferrand & Segui, 1998; Meijer, 1996; Sevald et al., 1995; Sullivan & Riffel, 1999), onset and rimes (e.g., Collins & Ellis, 1992;

Garrett, 1975; MacKay, 1970; Shattuck-Hufnagel, 1986, 1987, 1992; Sullivan & Riffel, 1999), phonemes (e.g., Dell, 1986; MacKay, 1970; Nadeau, 2001; Nootboom, 1969; Roelofs, 1999; Shattuck-Hufnagel, 1979), and distinctive features (e.g., MacKay, 1970; Meyer & Gordon, 1985; Rogers & Storkel, 1998). During the stages of pre-motor encoding, the appropriate metrical information is accessed, and segments are associated to frames in a left-to-right sequential manner (e.g., Levelt & Wheeldon, 1994; Meyer, 1991; Meyer & Schriefers, 1991a; Santiago et al., 2000; Sevald & Dell, 1994; Sullivan & Riffel, 1999).

Phonologic Assembly and the Generative Linguistics Tradition

Within the generative linguistics tradition, a computational apparatus retrieves and combines a finite number of stored symbolic units to generate potentially infinite output. Chomsky (1972) noted that having knowledge of one's language means having internalized system of rules that relate sounds and meaning in a particular way. The construction of a grammar involves proposing a hypothesis concerning that internalized system. A grammar, then, is conceptualized as an explicitly formulated set of syntactic, semantic, morphological and phonological rules which specify how to form, interpret, and pronounce a given set of sentences (Radford, 1988).

The generative linguistic account provides a broad theoretical context that can account for the evidence that suggests that sublexical units are assembled during the processes of pre-motor encoding; a finite set of stored units, i.e., syllables, phonemes and distinctive features, are combined to produce a potentially infinite output, i.e., words. According to this account, then, the speech token is necessarily assembled afresh each time from the finite set of units. While the data do support the notion of sublexical assembly, the question remains, however, as to whether the assembly sublexical units is, in fact, obligatory, or whether there are cases in which this assembly process can be bypassed. This chapter will address this question, and will present a theoretical alternative to the notion of obligatory assembly.

The Obligatory Assembly Hypothesis

It appears that inherent to the conception of phonetic encoding and motor programming is the notion that these processes are, in fact, intimately tied to the processes of the assembly of sublexical units; i.e., that the mechanisms of phonetic encoding and motor programming do not work *independently* of phonologic assembly. Evidence supports the notion that these sublexical units include phonetic features, which ostensibly play a role in the specification of articulatory goals features (e.g., MacKay, 1970; Meyer & Gordon, 1985; Rogers

& Storkel, 1998). Central to the issue motivating the experiments discussed in this document is the issue of whether sublexical assembly is, in fact, obligatory. One argument that has been made to support the obligatory assembly hypothesis (Rogers & Spencer, 2001) concerns an additional variable of interest that was manipulated by Rogers and Storkel (1998) in an investigation of the role of phonetic features in speech production. Participants read aloud visually presented prime-stimulus pairs of monosyllabic words. Using a form-based priming task, Rogers and Storkel manipulated the relationship between words pairs; word pairs differed in the number of features shared by the initial consonants and the type of feature shared. There were five featural similarity conditions, two conditions in which two features were shared (*shared voicing and manner* and *shared place and manner*), two conditions in which one feature was shared (*shared voicing only* and *shared manner only*) and one control condition in which no features were shared. The authors predicted that if features are independently selected during the processes of pre-motor encoding, then the mechanisms of post-selection inhibition should render the just-selected feature nodes temporarily unavailable, creating a processing delay that will increase response times in shared feature conditions relative to the control condition. Results indicated that the conditions *shared voicing and manner* and *shared manner* consistently yielded response latencies that were significantly longer than those of the control condition. The *phonologic similarity effect*

(PSE), the finding that similar sound structure among words interferes with processing, suggests that in addition to phonemes, the distinctive features that specify phonemes, are actively manipulated to some extent as independent units during pre-motor encoding. The PSE also provides evidence for the process of sublexical phonologic assembly.

The additional variable manipulated in the Rogers and Storkel (1998) experiments, stimulus set size, provides insight into whether this sublexical assembly is an obligatory component of pre-motor encoding. Stimulus sets consisted of either six or eighteen words. If words could be maintained as whole units within the phonologic buffer, thus precluding the need for sublexical assembly processes, it was hypothesized:

- 1) That phonologic similarity effects would not be observed in the smaller stimulus set since it would be more likely that whole word representations for could be maintained within the buffer for the small set rather than for the large set; and
- 2) That faster latencies would be observed for the words in the small stimulus set since whole word retrieval would ostensibly result in faster production than sublexical assembly.

Results indicated that shared feature interference effects were obtained for both small and large stimulus sets. Moreover, shared feature interference effects obtained from small sets were significantly greater than interference effects obtained from larger stimulus sets. Thus, even when the set size was small enough to hypothetically promote the storage or retrieval of several whole word forms in the phonologic buffer, a significant phonologic similarity interference effect was obtained. Since the presence of the PSE indicates that reprogramming of the buffer has occurred, these findings suggest that even when speakers know that only six words will be produced, retrieval of whole word forms does not occur.

Further evidence for obligatory assembly is found in an item analysis of target words. Rogers & Spencer (2001) note that although word frequency was not a controlled variable, the target words used in the Rogers and Storkel (1998) experiments were all relatively high frequency words, with the exception of one. Item analysis of targets showed that the phonologic similarity effect was evident across all tokens. Participants repeated the tokens over 50 times, yet the effect remained.

The Rogers and Storkel (1998) results indicate that effects of shared phonologic form were robust even under conditions that would promote the maintenance of whole word representations. A significant PSE was obtained when stimulus set size was small enough to encourage the maintenance of whole word representations within the buffer. Additionally, when the frequency of use of the word would make it a likely candidate for a whole word representation, a significant PSE was still observed. These findings provide strong support for a theory of pre-motor encoding that involves the obligatory assembly of sublexical units.

The Dual Route Hypothesis

One theoretical alternative to the traditional generative linguistics in which pre-motor encoding proceeds by means of accessing a finite set of sublexical units and combining them into words suggests that speech-encoding mechanisms are capable of “learning” (Varley & Whiteside, 2001). This alternative suggests that the pre-motor encoding system consists of dual routes (e.g., Levelt, 1989, 1992; Levelt & Wheeldon, 1994; Varley & Whiteside, 2001), a concept that is well established in other processing domains, such as reading (e.g., Beeson & Hillis,

2001; Coltheart, Besner, Jonasson, & Deavelaar, 1979; Hillis, 2001; Hino & Lupker, 1996; Monsell, 1991).

According to the dual route hypothesis, as proposed by Varley and Whiteside (2001), pre-motor encoding involves the storage of whole word forms as movement gestalts. Retrieval of these movement gestalts, in Varley and Whiteside's view, bypasses the assembly of sublexical units altogether. This hypothesis is limited to the processes associated with high frequency forms. Only low frequency forms are modeled as proceeding by means of phonologic assembly. This hypothesis is based on the robust word frequency effect (i.e., words that occur frequently, high frequency words, are produced faster than words that do not occur as frequently, low frequency words).

Thus pre-motor encoding is hypothesized to proceed by means of two routes depending on the frequency of the item being produced: an *indirect route* through which sublexical units are assembled to produce a phonological representation, and a *direct route* through which whole units are retrieved, precluding the need for assembly. This model is illustrated in Figure 5.1. Within this theory, the word frequency effect is accounted for by means of the

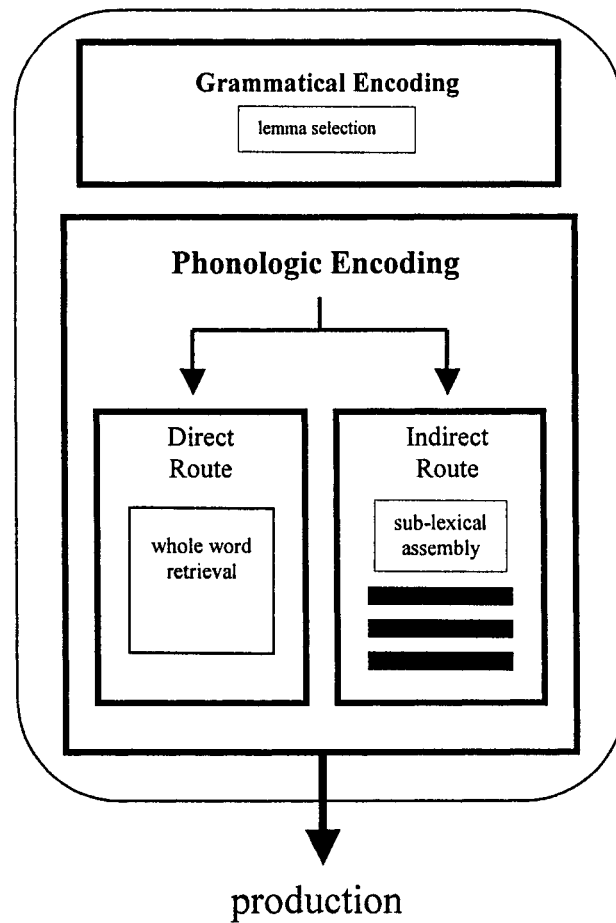


Figure 5.1. The dual route model for pre-motor encoding. Processing along the direct route involves whole word retrieval, and is modeled as the route along which high frequency words are processed. Processing along the indirect route involves the assembly of sublexical units, and is modeled as the route along which low frequency words are processed.

assumption that the processing of low frequency words is protracted due to the processing time required to accomplish sublexical phonologic assembly through the indirect route. Processing time for the direct route is modeled as being inherently quicker than the processing time required by the indirect route, thus the faster processing observed for high frequency is attributed to the notion that the processing involved in the retrieval of whole word units is intrinsically faster than the processes of sublexical assembly. The dual route theory, then, suggests that there are *fundamental* differences in the processing mechanisms involved in the production of low frequency and high frequency words.

In addition to accounting for the word frequency effect, the dual route hypothesis makes two predictions (Varley, Whiteside, & Luff, 1999; Whiteside & Varley, 1998):

- 1) Products of the direct route, high frequency words, are predicted to have shorter durations than phonetically matched low frequency targets ostensibly due to there being fewer computational steps involved in retrieving a word gestalt as opposed to assembling the word from sub-syllabic components; and
- 2) If forms are retrieved directly from storage and without mediating assembly from sub-syllabic processes, for example, they will differ in

phonetic characteristics from forms that do require greater reliance on sub-syllabic computational processes.

The sections that follow will address data relevant to each of these predictions.


The Mental Syllabary

Evidence obtained by Levelt and Wheeldon (1994) has been interpreted by Varley and Whiteside (1998, 2001) as support for the first of the above predictions. Naming durations of high frequency syllables were shown to be consistently shorter than naming durations for low frequency syllables. The authors interpreted these results within the framework of a *mental syllabary*, which has been characterized as a repository of the abstract, syllabic gestural scores, or detailed specifications of the articulatory tasks to be performed by each of the five “tiers” that correspond to the subsystems involved in articulation: the glottal, velar and oral systems, the latter of which consists of the tongue body, tongue tip, and lips (Crompton, 1982).

The stages during which these gestural scores are retrieved are modeled as occurring subsequent to phonologic assembly. The input to the mental syllabary is the phonological specification that results from segment-to-frame association

during phonologic assembly, and the output is the gestural score itself. The authors maintain that most syllables used by speakers are highly overlearned articulatory gestures, and that a large percentage of spontaneous speech consists, not of novel sequences, but of a set of frequently used syllables. Thus Levelt and Wheeldon argue that the mental syllabary offers a “natural” and efficient means of accounting for the transition from the abstract phonologic form, the product of sublexical assembly, to the actual phonetic realization for those frequently used syllables.

To investigate the theorized mental syllabary, Levelt and Wheeldon (1994) conducted a series of four experiments designed to test predictions consistent with its hypothesized nature and role in production. Experiment 1 was designed to test the prediction that if speakers must access a mental store of syllabic gestural scores, syllable frequency will affect access in a manner analogous to the effects of word frequency in accessing the mental lexicon (i.e., response latencies to low frequency syllables should be longer than response latencies to high frequency syllables).

In a symbol naming task, subjects first learned to associate each of a small number of disyllabic Dutch target real words to an arbitrary symbol (e.g., ). During the experimental phase, the symbols were presented on a

computer screen, and subjects produced the corresponding target words; response times were measured. Both word frequency (WF) and syllable frequency (SF) were manipulated as follows, based on frequency counts obtained from the CELEX database:

High SF + High WF

Low SF + High WF

High SF + Low WF

Low SF + Low WF

Main effects of both word and syllable frequency were significant, and there was no significant interaction of word and syllable frequency. Thus the results supported the existence of independent syllable frequency effects as predicted.

To further refine the results, in Experiment 4, syllable complexity, as defined by number of phonemes, was manipulated. It was predicted that an effect of complexity would be observed only if motor programming involved the online computation of the motor program as opposed to the retrieval of a gestural score, a result that would be inconsistent with the notion of a mental syllabary. When the word and syllable frequencies for bisyllabic words were held constant, differences in syllable complexity were found to have no significant effects on response times. Results from both experiments taken together, then demonstrated that responses to syllables are sensitive to syllable frequency,

regardless of the number of phonemes and thus support the notion that articulatory scores for syllables are stored as whole units rather than being created anew during production.

The mental phonetic syllabary, then, describes a mechanism for translating an abstract phonologic representation of an utterance into a context-dependent phonetic representation which is detailed enough to guide articulation, i.e., a *gestural score* (Levelt & Wheeldon, 1994)). Within this framework it is hypothesized that the mechanisms of motor programming and phonetic encoding work *independently* of phonologic assembly.⁴ While within the obligatory assembly model, phonological encoding and the subsequent pre-motor stages of processing are not differentiated (due to the lack of clear methods to disambiguate these stages), Levelt and Wheeldon make a distinction between the assembly and/or retrieval of abstract phonological representations and the subsequent stages of motor programming and phonetic encoding. The model proposed by Levelt and Wheeldon is fully compatible with the notion of sublexical phonologic assembly at the level of the phonologic representation. It is the latter stages that are modeled as relying on the whole-unit gestural scores

⁴ The authors, however, give no account of how motor programming/phonetic encoding may proceed for low frequency items that do not have entries in the mental syllabary.

that are stored in the mental syllabary when the utterance is produced with sufficient frequency.

While data reported by Levelt and Wheeldon lend support to notion of the direct retrieval of the gestural scores of syllables, the data do not preclude the notion of phonologic assembly itself. The construct of the mental syllabary presents an alternative account of the nature of processes that follow phonologic sublexical assembly rather than address whether it is obligatory. Varley and Whiteside (2001) however, appeal to the Levelt and Wheeldon (1994) findings and the concept of the gestural score in the formulation of their version of a dual route model. In contrast to Levelt and Wheeldon, though, in the Varley and Whiteside dual route model, such movement gestalts or gestural scores are not limited to syllable-size units, but may include variable units of linguistic output such as monosyllabic words, multisyllabic words, and multi-component clauses, assuming they were used with sufficient frequency. The Varley and Whiteside model blurs the distinction between phonologic encoding and subsequent pre-motor stages of processing in their conceptualization of the difference between direct and indirect routes.

Insights from Acquired Apraxia of Speech

Varley and Whiteside derive further support for their dual route model through a review of the extant research on acquired apraxia of speech (AOS), a disorder characterized by (taken from Varley & Whiteside, 2001, who summarized a number of authors):

- (1) Errors in segment production that may lie within phonemic boundaries (“distortions”) or result in violations of phonemic boundaries (“substitutions”);
- (2) Prolongations of steady-state components of segments, and intersyllabic pauses;
- (3) Inconsistency in output;
- (4) Reduced and variable coarticulation;
- (5) Prosodic abnormality as a result of prolongation;
- (6) Initiation difficulties, as indicated by articulatory groping and struggle;
- (7) Loss of speech automaticity.

The nature of the observed disturbances in AOS suggests that it is a disorder of pre-motor encoding (e.g., Rogers, Jones-Redmond et al., 1999). Within the dual route framework, Whiteside and Varley (1998) propose that the underlying

impairment in AOS may be conceptualized as damage to the direct route of pre-motor encoding citing Lebrun (1990, p. 385) who writes:

“Because they know that their articulation goes astray, speech apraxics endeavor to control it at every step. This may be one reason why in apraxia of speech the rate of delivery is abnormally slow and phonemes are often protracted.”

Thus Varley and Whiteside propose that with the disruption of processing by means of the direct, whole-word route, AOS may represent a “strategic compensation to an underlying impairment” that entails the assembly of sublexical units by means of the indirect route, a route that is more demanding of computational resources than the direct route, especially in individuals with damage to left-hemisphere systems of motor control (Varley & Whiteside, 2001).

One of the predictions of the Varley and Whiteside (1998; 2001) dual route model relates to the phonetic characteristics of utterances. If forms are retrieved directly from storage and without mediating assembly from sub-syllabic processes, they will differ in phonetic characteristics from forms that do require greater recourse to sub-syllabic computational processes. A number of

researchers have reported increased variability and reduced coarticulation in the speech of AOS speakers in comparison with the speech of neurologically intact individuals (e.g., Itoh & Sasanuma, 1984; McNeil, Hashi, & Southwood, 1994; Zeigler & von Crammon, 1985).

Experimental evidence in support of the dual route hypothesis from AOS speakers relates to the syllable frequency effect. Data from Levelt and Wheeldon (1994) supported this prediction with data from neurologically intact individuals. These results were interpreted as providing support for the existence of a mental syllabary, or repository of stored syllable programs for high frequency syllables. Based on these results, Varley, Whiteside and Luff (1999) predicted that a disruption in the direct retrieval route would result in the *absence* of frequency effects in the duration measurements of the output of AOS speakers since *all* words would have to be produced by means of sublexical assembly. High frequency words would no longer enjoy a “privileged status” that allows them to bypass assembly and thus be produced with shorter durations.

In an investigation of production latencies and utterance durations for high frequency and low frequency words for speakers with AOS and matched brain-damaged and non-brain-damaged controls (Varley et al., 1999), participants

repeated a stimulus word after the experimenter, preceding each word with either the article “a” or “the.” Response latencies were measured for each participant, reflecting time elapsed from the cessation of the experimenter’s utterance to the initiation of the participant’s utterance. A significant frequency x group interaction was obtained; only the response latencies and durations of the AOS group did not reflect effects of frequency. The authors interpreted this null effect as support for both the notion of dual routes of encoding, but also as evidence of a direct route deficiency in speakers with apraxia of speech.

The Central Role of Word Frequency

The issue of word and syllable frequency has emerged as the crux of the question of obligatory assembly versus whole word retrieval during pre-motor encoding. The data presented by Levelt and Wheeldon (1994) and Varley and Whiteside (Varley & Whiteside, 2001; Varley et al., 1999; Whiteside & Varley, 1998) suggest that the encoding of forms used frequently may involve the bypassing of assembly processes. In contrast, data obtained by Rogers and Storkel (1998) suggest that even high frequency words, which are the most likely candidates for whole word storage and retrieval are subject to the

phonologic similarity effect. If the high frequency word form and its motor programs were retrieved as a whole, post-selection inhibition of sublexical units, such as the nodes for phonetic features, should have no effect on the reprogramming of the buffer.

Thus the data are far from conclusive with regard to the issue of obligatory assembly versus whole word retrieval. The architecture of the dual route theory has at its foundation the notion that word frequency determines the nature of pre-motor processing and thus assumes that the word frequency effect arises during the stages of pre-motor encoding during which phonologic representations are activated, retrieved, and sublexical units are sometimes or always assembled. The word frequency effect will be discussed in detail in the next chapter as it relates to the dual route model; specifically, data that address the locus of the word frequency effect will be discussed.

CHAPTER 6: THE WORD FREQUENCY EFFECT AND THE DUAL ROUTE DEBATE

The Word Frequency Effect

As early as 1964, word frequency was found to affect speech production (Oldfield & Wingfield, 1965; Oldfield & Wingfield, 1964). The word frequency effect (WFE) is the finding that responses to words that are used less frequently are slower than responses to words that are used more frequently. Word frequency has been shown to influence speech errors (del Viso, Igoa, & Garcia-Albea, 1991; Dell, 1986, 1990; Hotopf, 1980; Stemberger & MacWinney, 1986; Vitevich, 1997). It has also been demonstrated in a variety of tasks, reflecting the robust nature of the effect. These tasks include: picture naming (Humphreys, Riddoch, & Quinlan, 1988; Jescheniak & Levelt, 1994; La Heij, Puerta-Melguizo, van Oostrum, & Starreveld, 1999; Rogers, Belleville et al., 1999); lexical decision and word recognition (e.g., Andrews & Heathcote, 2001; Balota & Chumbley, 1984; Becker, 1979; Bowers, 2000; Gerhand & Barry, 1999; Hino & Lupker, 1996; Jastrzembski, 1981; Kroll & Potter, 1984; Luce, Pisoni, & Goldinger, 1990; Plourde & Besner, 1997; Schilling, Rayner, & Chumbley, 1998) and pronunciation tasks (e.g., Balota & Chumbley, 1984; Grainger,

Spinelli, & Ferrand, 2000; Hino & Lupker, 1996; Huttenlocher & Kubicek, 1983; Lupker, Brown, & Colombo, 1997; Ostergaard, 1998; Schilling et al., 1998).

Word Frequency and the Dual Route Hypothesis

Determining the locus of the word frequency effect is fundamental to understanding its role in spoken language production. The dual route hypothesis assumes that word frequency is linked to the stages of pre-motor encoding during which word-forms are activated. After semantic processing is initiated, phonologic encoding may proceed by means of one or two routes: an *indirect route* through which sublexical units are assembled to produce a phonological representation, and a *direct route* through which whole units are retrieved, precluding the need for assembly. According to this view, the specific route through which pre-motor encoding proceeds is dependent on the frequency of use of the word being produced. Within this theory, the protracted phonological processing of low frequency (LF) words is attributed to the processing time required to accomplish sublexical assembly through the indirect route.

Processing time for the direct route is modeled as being inherently quicker than the processing time required by the indirect route, ostensibly because the high frequency (HF) words can be retrieved as whole word units. According to the

dual route theory, there are *fundamental* differences in the processing of LF as opposed to HF words.

A fundamental assumption of the dual route hypothesis, then, is that the word frequency effect arises during the stages of phonologic encoding through motor programming. This section will review the literature on the word frequency effect, and discuss evidence that speaks to its locus.

Automatic and Controlled Processing and the Word Frequency Effect

The nature of attention in cognitive processing has been of central concern to cognitive psychology. Posner and Snyder (1975) and Shiffrin and Schneider (1977) have conceptualized attention in terms of two types of processing: automatic processing and controlled processing.

Automatic processes are described as fast processes that do not require attention for their execution, are executed without explicit intention, are highly efficient, are not available to conscious introspection, and proceed in a reflex-like, involuntary manner manner that is difficult to stop once it is initiated (Cohen, Dunbar, & McClelland, 1990; Levelt, 1989; Posner & Snyder, 1975; Shapiro, Swinney, & Borsky, 1998; Shiffrin & Schneider, 1977). Thus automatic

processes do not require substantial cognitive resources, and performance on such tasks is not sensitive to the adoption of a particular strategy (Carrol, 1999).

In contrast, controlled processes are described as processes that are under continuous cognitive control and consequently draw substantially from a limited pool of cognitive resources (Posner & Snyder, 1975; Shiffrin & Schneider 1977). Furthermore, they are slow relative to automatic processes and are potentially susceptible to strategy effects (Carrol, 1999; Levelt, 1989; Posner & Snyder, 1975; Shapiro et al., 1998; Shiffrin & Schneider, 1977). Controlled processing is typically associated with performance of novel tasks. It has been suggested, however, that with extensive practice, processing of some tasks may shift from controlled to automatic (e.g., Shiffrin & Schneider, 1977).

This conception of automatic versus controlled processing, and particularly the latter notion that with sufficient practice, processing may shift from automatic to controlled, is relevant to the central tenet of the dual route model – that during pre-motor processing, words that are produced frequently can be encoded by means of automatic processes whereas sublexical assembly is indicative of controlled processing. This controlled processing, which is described as inherently slower and more demanding of cognitive resources than automatic

processing, accounts for the word frequency effect. Furthermore, the automatic versus controlled processing framework suggests that with the introduction of interference, as in dual-task paradigms, automatic processes would, by definition, be less susceptible to interference effects than controlled processes. This would suggest, then, that high frequency words are less susceptible to interference than low frequency words. This issue will be revisited in later chapters.

The Lexeme-as-Locus Hypothesis

Evidence from Speech Errors

Speech error evidence supports the notion that word frequency plays a role in speech production. Analyses of naturally occurring phonologic speech errors have shown that LF words are more susceptible to error than HF words (Stemberger & MacWinney, 1986). Dell (1990) replicated this result using unrelated word pairs to elicit speech errors. Word pairs were either both HF words or both LF words. Subjects were presented with the word pairs on a computer screen and were instructed to say the pair as quickly and accurately as possible. The results showed that there were significantly more sound misordering errors for LF words (30) than for HF words (12).

Speech error analyses also have revealed patterns in the frequency characteristics of intended words and intruding words in word substitutions. Meaning-based word substitution errors are hypothesized to arise during the processing of semantic information before phonologic information becomes active whereas form-based word substitution errors are hypothesized to arise during the processing of phonologic information (Garrett, 1980). In analyses of word and sound substitutions, the intruding word in form-based word substitution errors, or malapropisms, was usually of a higher frequency than the intended word (del Viso et al., 1991; Hotopf, 1980). In meaning-based substitutions, however, analyses suggest that word frequency is not a factor that influences what word will intrude; words of higher or lower frequency were equally likely to intrude. This same pattern was observed by (Vitevich, 1997) who conducted an analysis of the phonological neighborhood characteristics of 138 malapropisms, and found that more target words were replaced by words that were of a higher frequency than by words that had relatively lower frequency. These patterns suggest that there are differential effects of word frequency depending on the stage of processing; word frequency appears to influence processing only at the stages of phonologic encoding.

Additional data from Dell (1990) contributes to the lexeme-as-locus argument. In addition to eliciting errors through the use of word pairs, he used non-homographic homophone pairs put into phrases in which either spelling could occur (e.g., *by the pin, buy the pin*). He found that, in contrast to LF non-homophones, when LF words had a HF homophone, those LF words were no more prone to error than their HF homophones. Since homophones share word-form representations, or lexemes, and not lemma representations, this result offers additional evidence in support of a phonologic encoding locus for the WFE.

The Essential Role of Online Methodology in the Study of the Word Frequency Effect

Speech errors analyses have provided a foundation for the notion that the word frequency effect arises during the stages of processing that involve lexeme retrieval and/or other processes of pre-motor encoding. This foundation is tentative, however, because of the inherent limitations of speech error data. This section will outline these limitations, address the limitations of *offline methodology* in general, and will provide a rationale for the use of behavioral *online methodology* in the study of the WFE.

Limitations of Speech Error Methodology

Fundamental issues

A fundamental issue concerning the analysis of speech errors is the extent to which errors in performance can be viewed as a window into normal performance. It may seem obvious that an adequate theory of language should explain not only fluent, correct speech, but also the occurrence of speech errors (Baars, 1992). However, this is not a view universally held. For example, one of Chomsky's criteria for evaluating a theory of language is that it generate all grammatical strings of a language, and *only* grammatical strings (Carroll, 1999). Furthermore, not all current models of language production afford speech errors a central role. For example, Levelt and colleagues (Levelt et al., 1999b; Levelt et al., 1991; Meyer, 1992) purport that the ultimate test of a model of language cannot lie in how it accounts for "infrequent derailments of the processes," but rather how it deals with *normal* processes.

A case can be made for the role of speech errors, however. Reason (1984, as discussed in Baars, 1992) suggests that slips are not a sign of incompetence, but of "misplaced competence," and this is underscored by the observations that speech errors conform to a large number of very precise and very demanding constraints (e.g., Baars, 1992; Bock, 1991; Fromkin, 1971; Garrett, 1982).

Practical considerations

Naturally occurring speech errors, although they may be considered more ecologically valid, occur with very low frequency (Stemberger, 1992). A corpus of naturally occurring errors might realistically take years to build, and individual corpora might still reflect relatively high degrees of variability when compared to each other as a reflection of differences in collection procedures. It is therefore more practical and controlled to experimentally induce errors. Table 6.1 summarizes these techniques.

Analysis considerations

The validity of analyses of naturally occurring errors has been called into question for a number of reasons. A major concern is linked to the inherently uncontrolled means through which naturally occurring speech errors are collected, which traditionally involves phonetic transcription (e.g., Mowrey & MacKay, 1990). In all cases in which phonetic transcription is used, the recording of suspected errors is necessarily a function of the perceiver's own perception, which may, in fact, be biased (Frisch & Wright, 2002; Stemberger, 1992). Biases resulting from categorical perception have been documented, for example, in the phenomenon of the phoneme restoration effect (Warren, 1970)

Table 6.1. Techniques for inducing speech errors. From Stemberger (1992).

<u>SLIPS technique:</u>	Phonological priming is used to induce phonological errors. Subjects silently read pairs of words, one after the other. Several pairs build up expectation that Word 1 will begin with Phoneme A and that Word 2 of the pair will begin with Phoneme B. The order of the phonemes is then reversed in the target pair. Errors occur when phonemes are produced in the primed order rather than the target order.
<u>Tongue twisters:</u>	Subjects repeat tongue twisters with words or nonwords.
<u>Reversing order method:</u>	Subject must reverse the order of two units. If the units are words, then phonological errors result. Word-ordering errors result from units that are phrases or clauses.
<u>Cued recall:</u>	After subjects are taught two options, one option is used as a cue for the subject to produce the other option from memory. Blends of words or sentences can be produced if the subjects blend the two options together.
<u>Morphological errors:</u>	Subjects are presented with one form of a word, a base or an inflected form, and are required to produce a given inflected form. Errors occur when subjects produce ungrammatical forms, or produce the base form.

or in the finding that listeners appear to be more sensitive to strong syllables than weak syllables (e.g., Cutler, 1992). To underscore the potential impact of such biases, consider that all analyses of speech errors have found that errors tend to occur more often at the beginnings of words than elsewhere (Stemberger, 1992). It is not possible to determine if this finding is representative of the actual distribution of errors, or if it reflects the perceptual biases of the error recorder.

With the development of techniques for generating experimentally induced errors, some degree of control was granted to speech error analyses. Taking advantage of this, Stemberger (1992) conducted an extensive analysis to compare data from experimentally induced and naturally occurring errors. He found that most studies show comparable results with the use of both types of data. He concluded that despite legitimate concerns regarding the reliability of naturally occurring speech errors, the experimental data show that naturalistic data are reliable and replicable, and accordingly, he rules out perceptual bias as the sole factor leading to any given result.

Issues surrounding the potential confounding role of perceptual bias, however, persist, and acoustic analysis of speech has been used as a means of bypassing problems of perceptual bias that may arise during phonetic transcription as a result of factors like categorical perception (e.g., Frisch & Wright, 2002;

Mowrey & MacKay, 1990). Furthermore, Stemberger's (1992) conclusions do not address another criticism of traditional speech error analyses that is perhaps more pervasive in implication than perceptual bias. This criticism involves the inability of phonetic transcription to capture subcontrastive or gradient errors, introducing the possibility that the errors contained in the speech error corpora represent only a subset of the actual errors produced. This has important implications for models based solely on transcription evidence, as they cannot address issues related to phonetic details of speech errors (Frisch & Wright, 2002). Studies conducted by Frisch and Wright (2002), and Pouplier, Chen, Goldstein and Byrd (1999, as discussed in Frisch & Wright, 2002; Mowrey & MacKay, 1990) provide support for such speech errors that may occur at the level of the acoustic properties of a given sound.

Baars (1992), in his chapter on the uses of error, defines "slips," which include speech errors, as "actions that mismatch their own guiding intention.

Operationally, they may be defined as actions that are quickly recognized to be errors as soon as we become aware of them" (p. 6).

However it appears as if this definition is inadequate with respect to data obtained from acoustic analyses since such data have demonstrated that it is possible that neither the speaker nor the listener is aware of the true nature of the

errors being made, or whether or not an error has been made at all (Mowrey & MacKay, 1990).

The Case for Behavioral Online Methodology

Traditional methods, or *offline methods*, such as those previously mentioned, primarily yield data that reflect the end products of several stages of processing, and give little insight into the mechanisms of these component stages. Thus, such methods, with their inherent focus on end products, lack the temporal sensitivity to probe fleeting processes at distinct levels, as they occur in real time. This proves problematic when attempting fine-grained analyses of pre-motor processing. In the lexicalization of a single word during picture naming, for example, phonologic encoding has been estimated to encompass a mere 125 ms and represent but a single stage in a complex combination of stages whose total duration often exceeds 500 ms (Levelt, 1989). Once the end product has been generated, the processes of phonologic encoding may have long since been completed.

Online methods, in contrast, allow the system to be probed locally, and can be used during ongoing processing to measure effects at various points in time (Shapiro et al., 1998). One category of online methods is imaging techniques,

such as electroencephalography (EEG), and magnetoencephalography (MEG), which provide direct information concerning either electromagnetic activity in the brain. Such techniques are useful for investigating the time course of discrete stages of language processing, especially as these techniques have high temporal resolution. These techniques, however, while extremely valuable, are expensive, require access to equipment that is very often in high demand, and require the contributions of highly skilled technicians and specialists for data collection and analysis. Furthermore, the application of these techniques to the investigation of spoken language production has been limited due to difficulties controlling movement artifact introduced by the act of speaking.

Online Evidence for the Lexeme-as-Locus Hypothesis

Data from experiments using behavioral online methodology have provided much experimental evidence that addresses hypothesis that the word frequency effect arises during the stages of pre-motor encoding. This section will discuss these data and how they relate to the lexeme-as-locus hypothesis.

Ruling Out Object Recognition as the Locus of the WFE

This question of whether the word frequency effect arises during the processes of object recognition, rather than during post-decision processes has been investigated experimentally using object recognition and object decision studies. If word frequency is tied to lexical, or word-based processing, then frequency effects should only be evident in tasks that require lexical processing; tasks consisting of pre-lexical processing alone, such as object decision, should not be sensitive to word frequency.

Results obtained by Kroll and Potter (1984), however, were not consistent with this prediction. In an object decision task, participants were shown line drawings and asked to make a judgment as to whether they represented real objects, and to press either a *yes* or *no* button to indicate their answers. The names of true objects were chosen to be of either high (mean of 122 per million from Kucera & Francis, 1967) or low frequency (mean of 10 per million). These items represented a large number of semantic categories, including animals, food, clothing, furniture, tools, vehicles and music instruments. Analyses revealed a significant 24 ms frequency effect in an object decision experiment, although this effect was smaller than the frequency effect obtained in a concurrently run lexical decision experiment (35 ms). If object decision is a measure of purely

non-lexical processing, this finding suggests that a component of word frequency may involve pre-lexical processing.

A number of studies, however, have failed to yield similar results. For example, Wingfield (1968) investigated the locus of the WFE using object recognition. He found no differences in the exposure durations necessary to recognize the pictures with high frequency versus low frequency targets. In other investigations, Bartram (1973, 1976) also found that word frequency did not affect object decision latencies.

In a later study, Jescheniak & Levelt (1994), in Experiment 2, also conducted an investigation of object decision. In this task, participants saw a picture and then decided if the word that appeared after it was the correct name of the previously pictured object. Participants were instructed to press a *yes* or *no* button to indicate their responses. Results indicated that, although high frequency words were responded to, on average, 6 ms faster than low frequency words, this was not a statistically significant difference. Furthermore, the 6 ms nonsignificant effect contrasts strikingly with the 62 ms word frequency effect obtained in Experiment 1, a picture naming task in which the same picture stimuli as the critical stimuli of the object recognition experiment were used.

Although the Kroll and Potter (1984) results remain a point of counter-evidence, most investigations have lent support to the notion that the WFE arises during the stages of lexical processing, not during object recognition.

Ruling Out An Articulatory Locus of the WFE

The delayed naming, or delayed pronunciation paradigm has been used extensively to address the role of articulatory processes in the word frequency effect. Within this paradigm, a word is presented on a computer screen, and after some delay, a cue is presented, indicating that the word was to be read aloud. If the WFE arises out of production-related processes, then it would be expected that the WFE would be observed at all delay intervals, including the longest delays. If, in contrast, the WFE arises during stages of lexical processing as opposed to during recognition or articulation, then frequency effects should be observed only at the earliest intervals, and should disappear after participants have had time to prepare the word, (i.e., after sufficient time has elapsed for all stages of lexical processing to have been completed).

Balota and Chumbley (1985) investigated the locus of the WFE using this paradigm and six delay intervals, ranging from 150 to 1400 ms in 250 ms increments. Experiment 1A was conducted as a control, and results indicated

that the stimuli used in the experiments that followed did indeed evoke a significant frequency effect in an immediate, rather than a delayed, pronunciation task. In the delayed pronunciation task, significant frequency effects were obtained at all delay intervals when delay intervals were blocked (Experiment 1), and at all delay intervals through 900 ms, when they were randomized (Experiment 2).

The potential confound of silent rehearsal was ruled out in Experiment 3 in which six delay intervals, ranging from 400 to 2900 ms in 500 ms increments were used, and participants were instructed to whisper the alphabet forward starting from a randomly chosen letter as quickly as possible during the delay interval, until the cue to read the word aloud appeared. When the cue appeared, the participants were to pronounce the word aloud as quickly as possible. Significant frequency effects were obtained at all delay intervals except for the 2400 ms interval.

Connine, Mullenix, Shernoff, & Yelens (1990) replicated the Balota and Chumbley (1985) results, also finding frequency effects at long delay durations. Thus the results of these experiments strongly suggest that frequency effects cannot be fully accounted for by the encoding that occurs during the stages of lexical processing, that such frequency effects are also traceable to the

generating of articulatory programs, or the articulation of the stimulus word itself. Results suggest that the WFE can be accounted for in that the articulatory programs of words used frequently (HF) may be compiled and executed faster than those programs of words used infrequently. In delayed pronunciation, it is assumed that participants prepare their responses when they see the word, and that response preparation proceeds as far as is possible without an overt response. If the cue delay is long enough, then the word will have already been recognized, and an articulatory program will have already been assembled and stored in a buffer. When presented with the cue to produce an overt response, the participant can retrieve this code from the buffer and execute the motor program. Thus, for delay intervals that are sufficiently long, any word frequency effect observed must be attributed to the stages of response execution (Balota & Chumbley, 1985, Jescheniak & Levelt, 1994).

There have been a number of studies, however, that failed to corroborate the presence of a word frequency effect in naming at long delay durations (Andrews & Heathcote, 2001; Jescheniak & Levelt, 1994; Savage, Bradley, & Forster, 1990). For example, Hino & Lupker (1996, Experiment 3) found significant word frequency effects at their early 700 ms and 1,000 ms delay durations, but not at the longest delay interval, 1,300 ms. when delay intervals were blocked, and in a delayed pronunciation study using the original Balota and Chumbley

(1985) stimulus materials, Savage, Bradley and Forster (1990, Experiment 3) failed to replicate the word frequency effect when delays were restricted to the 800 ms to 1200 ms range. In a subsequent experiment, when shorter delay durations (150, 400 and 650 ms) were included only for filler items, then a significant frequency effect of 14 ms was observed at the 900 ms delay interval but no significant effect was obtained at the longer delay durations (Savage, et al., 1990, Experiment 4).⁵ It appears, then, that the presence or absence of the word frequency effect in delayed pronunciation depends on the presence or absence of short delays in the experiment, even if these durations are not used on critical trials.

Jescheniak and Levelt (1994, Experiments 3 and 7) investigated the potential contribution of articulation to the word frequency effect using 1000, 1300 and 1600 ms delay intervals. Results indicated that there were no significant effects of word frequency in delayed naming in either experiment. The lack of a WFE in Experiment 3 was especially significant because a significant word frequency effect had been obtained using the same experimental stimuli as represented by pictures in a picture naming task (Jescheniak & Levelt, 1994, Experiment 1).

⁵ It is important to note that, although the authors consider this main effect reliable, they report a p-value of $p < 0.10$.

McRae, Jared and Seidenberg (1990), also found that a significant frequency effect obtained during immediate naming disappeared at the longest delay intervals in a delayed pronunciation task. These results were also replicated by Andrew and Heathcote (2001), who controlled for initial phoneme across stimuli and also found that the word frequency effect disappeared at the longest delay intervals. These findings indicate that the existence of the word frequency effect observed in other experiments at longer delay intervals may be attributed to the related characteristics of initial phonemes rather than to production processes. Thus similarities in initial phonemes may be a confound in the delayed pronunciation task.

Another potential explanation for the presence of WFE in delayed pronunciation may lie in an alternative account to the single-access account originally espoused by Balota and Chumbley (1984) – the potential for lexical re-access after the presentation of a cue. While Balota and Chumbley (1985) did control for the potential for rehearsal during the delay interval, the authors admit that this did not preclude the possibility that some form of “reaccess” occurred immediately prior to producing an overt response after the cue was presented. Once the subject had prepared the response, this “preparation” could be maintained in the form of an abstract code that is used to retrieve and implement a motor program once the pronunciation cue is presented. The time required for

the retrieval and implementation of this code could be frequency-dependent and could account for the WFE observed in some studies. Furthermore, both the Balota and Chumley (1985) single-access and the re-access conclusions are based on the assumption that, in the delayed naming paradigm, once a word is presented, processing will proceed as far as it can in the absence of an overt response. This may not be the case. Partial preparation may be involved, with final completion of the “preparation” processes occurring only after the presentation of the pronunciation cue. These alternative accounts allow for the notion that WFE is not linked to articulation *per se*, and are compatible with the hypothesis that word frequency effects arise during the processes of pre-motor encoding. Thus, the majority of the evidence suggests that the WFE cannot be accounted for by the process of articulation alone, and, while conflicting results have been obtained, a closer investigation of alternative accounts indicates that such data are not incompatible with a non-articulation-based locus of the WFE.

Support for the Lexeme-as-Locus Hypothesis

Support for the lexeme-as-locus hypothesis has stemmed from online investigations using tasks designed to isolate specific stages of processing. The word frequency effect has been observed to be robust in tasks that require both lemma and lexeme access. In tasks that are designed to require lemma access

alone, results are mixed. This section summarizes the findings of investigations that have used a variety of methods, each tapping into different stages of processing, to determine the locus of the WFE.

Tasks that require both Lemma and Lexeme Retrieval

The word frequency effect has been consistently found in tasks that require both lemma and lexeme retrieval. For example, Balota & Chumbley (1984, Experiment 3) used a pronunciation tasks to investigate the word frequency effect and found that response times to low frequency words were significantly longer than high frequency words by 50 ms. Ostergaard (1998) investigated word frequency effects in pronunciation when target words appeared on a screen instantly and when target words appeared gradually. Although the frequency effect was greater when words appeared gradually, low frequency words were produced significantly slower in both conditions. Similar results indicating a word frequency effect in pronunciation tasks were obtained in a number of other investigations (e.g., Grainger et al., 2000; Hino & Lupker, 1996; Huttenlocher & Kubicek, 1983; Lupker et al., 1997; Schilling et al., 1998).

Lexical decision and word recognition tasks have also yielded data reflecting significant effects of word frequency. Hino & Lupker (1996) used the lexical decision task to test the effects of polysemy and word frequency. Polysemous words are words with multiple meanings. Twenty ambiguous-unambiguous word pairs were selected. Ambiguous words were selected to have equal “meaning frequencies,” or the frequency with which a particular meaning is attached to a polysemous word. Fifteen of each word type were classified as high frequency (more than 80 per million) and 15 as being low frequency (less than 30 per million) according to the Kucera and Francis (1967) norms.

Unambiguous words were matched to ambiguous words in word frequency and word length. Analyses indicated a main effect for both polysemy and word frequency, but no significant interaction between the two factors. (Bowers, 2000) also found significant effects of word frequency in a lexical decision task in three experiments, and also found significant word frequency effects in two experiments using a word identification task in which a target word presented for either 35, 30 or 27 ms was preceded and followed for 1 second by a mask composed of a series of pound characters (#####).

A number of other investigations have also obtained word frequency effects in lexical decision and word identification tasks (e.g., Andrews & Heathcote, 2001; Balota & Chumbley, 1984; Becker, 1979; Gerhand & Barry, 1999; Jastrzembski,

1981; Kroll & Potter, 1984; Luce et al., 1990; Plourde & Besner, 1997; Schilling et al., 1998). Additionally, Andrews and Heathcote (2001) used lexically contingent naming, a task combining the demands of both lexical decision and pronunciation. Participants were presented with both words and nonwords and were instructed to read the word aloud only if it is a word. Results also indicated a significant effect of word frequency.

The word frequency effect observed in pronunciation and lexical decision tasks is extremely robust. As each of these tasks requires visual word recognition in addition to pronunciation or lexical decision, it is possible that some of the WFE could be accounted for by factors related to orthographic frequency. This would place its locus at the early processes involved in visual recognition. However, the word frequency effect has also been shown to be robust in picture naming, a task that does not require word recognition by means of orthography.

For example, Humphreys, Riddoch and Quinlan (1988) used picture naming to investigate the semantic priming effects and word frequency. Low frequency picture names had an occurrence of less than 10 per million and high frequency picture names an occurrence of greater than 10 per million according to Kucera and Francis (1967). On half of the trials, a given picture was preceded by the picture of a semantically related object, on half of the trials it was preceded by

the picture of an unrelated object. Significant main effects were obtained for both prime relatedness and word frequency in the absence of an interaction suggesting that semantic priming and word frequency operate at different levels of processing. These results replicated those obtained by Huttenlocher and Kubicek (1983), who also used a picture naming task to investigate effects of semantic priming and word frequency.

La Heij, Puerta-Melguizo, van Ostrum and Starreveld (1999) investigated the effects of identity priming and word frequency in picture naming. In identity priming, the name of the picture that is to be named is presented shortly before the picture itself. The experiment included both identity and unrelated primes. In both Experiment 1, in which primes were masked, and in Experiment 2, in which primes were not masked, main effects of both word frequency and prime type were obtained in the absence of an interaction between the two variables.

Jescheniak and Levelt (1994, Experiment 1) used picture naming to investigate the word frequency effect in the absence of priming. They found that when target words were controlled for length and morphologic complexity, a highly significant word frequency effect was obtained. The pictures with high frequency names were named 62 ms faster than those with low frequency words.

Thus, while it may be the case that frequency of occurrence or use has an influence at the visual recognition stages of lexical processing, data reflecting a robust effect in a task that does not require word recognition suggests that the main locus of this effect lies beyond the stages of visual recognition. The evidence discussed thusfar supports the hypothesis that the WFE arises primarily during post- word or object identification processes, since robust word frequency effects were obtained from tasks involving both the lemma and lexeme levels.

Tasks that Require Lemma Access Alone

Further localization of the word frequency effect is suggested by data obtained by means of tasks that presumably involve semantic processing alone, and the absence of phonologic processing. There has been some evidence to suggest that the word frequency effect is not observed with such tasks.

In a series of two experiments, Huttenlocher and Kubicek (1983) found evidence that differentiates semantic effects from frequency effects in an investigation of the effects of semantic relatedness on naming latency. The method entailed presentation of a prime picture, which was either semantically related or

unrelated to the picture target that was to follow. Participants were instructed to name the pictures as quickly as possible. Their responses then triggered the presentation of the target picture, which was also to be named. There were two expectancy groups of target-stimulus pairs. In the low-expectancy group, 5 of the 40 pairs were semantically related and in the high-expectancy group, 35 of the 40 pairs were related. An analysis of the results indicated that although there were significant main effects for word frequency, semantic relatedness and expectancy group, there was no interaction between word frequency and expectancy group nor between word frequency and semantic relatedness. In Experiment 2, in which the task was reading words rather than naming pictures, similar results were obtained. While there were main effects for frequency, relatedness and expectancy group, there were no significant interactions with word frequency. The lack of interactions with word frequency suggests that semantic relatedness and word frequency affect different processes involved in naming and that the word frequency effect is not linked to semantic processing.

Balota & Chumbley (1984, Experiment 1) used a category-exemplar verification task in which a category name (e.g., “bird”) was presented first and then followed 800 ms later by an exemplar either from that category (e.g., “robin”) or from another category (e.g., “chair”). Participants were instructed to make a *yes-no* judgment as to whether the exemplar presented belonged to the category

presented. Frequency of the exemplar, among a number of other variables, such as number of letters and number of syllables was manipulated. A full multiple regression analysis was conducted to consider the relative importance of the multiple variables within the categorization task. This analysis did not find any significant correlation of frequency to response times in either *yes* or *no* responses.

These results are in agreement with findings of Balota and Chumbley (1990) and Wingfield (1968) who found no effects of word frequency on semantic decision tasks. Additionally, Simmer and Smyth (1999) found no frequency effect in anaphor reading times, a processes which is also believed to require lemma access only.

In contrast to these results, however, are findings obtained by Monsell, Doyle, and Haggard (1989, Experiments 1 and 2). In Experiment 1, the results of a semantic categorization task reflected a significant effect of word frequency, although the frequency effect was significantly smaller than the effect observed in a lexical decision task using the same words. Results from experiment 2 indicated that response times in a task requiring participants to classify words as nouns or adjectives were also significantly influenced by the frequency of those

words. Similar results were obtained by Forster & Shen (1996) using a semantic judgment task.

As data obtained in the aforementioned studies, results are mixed as to the role of word frequency in semantically-based tasks. It may be that these tasks, although believed to involve lemma access alone, actually do involve some degree of lexeme access as well. It may also be the case that, to some extent, semantic processes are influenced by lemma frequency. The fact that the word frequency effect has not been consistently obtained in tasks requiring only semantic processing but has been consistently found in tasks requiring phonologic encoding lends support to the lexeme-as-locus hypothesis.

Insights from special cases

Special cases afford unique opportunities to isolate specific aspects of language processing. Homophones such as *bank* (the institution) and *bank* (the side of a river) have separate meanings and thus have different semantic representations, or lemmas. However, since the two meanings share pronunciation, they necessarily share lexemes, or phonologic representations. Words that have the same orthographic form but have different meanings are of particular interest in the study of the word frequency effect because while they have different

semantic representations, or lemmas, they share the same phonologic word-form, or lexeme. Thus, the use of homophones in the study of word frequency provides an opportunity to test contrasting predictions generated by lemma versus lexeme hypotheses regarding the origin of the WFE.

Homophones and the WFE

Ziegler, Tan, Perry and Montant (2000) investigated whether phonologic frequency affects character naming and lexical decision in Chinese, a character-based language in which the basic units of the written language correspond directly into the units of meaning. Three groups of Chinese characters were selected: 12 characters with no homophone mates, 12 characters with few homophone mates (<6), and characters with many homophone mates (>7). Characters were matched for orthographic frequency, along with a variety of factors that might influence character identification such as character complexity, as measured by a character's number of strokes. If phonologic frequency plays a more dominant role than orthographic frequency, the authors hypothesized that characters with homophone mates should benefit from having higher phonologic frequencies since the shared lexeme of such characters is accessed more frequently.

Significant phonologic frequency effects were obtained in both the character naming and lexical decision tasks. Although there were no significant differences between the response times for characters with few homophone mates and those with many, characters with homophone mates were responded to faster than nonhomophone characters. Since orthographic frequency was held constant across characters, these results suggest that the observed frequency effects cannot be attributed to orthographic frequency. Additionally, the advantage observed for characters with homophone mates disappeared in a delayed naming task with a 1,200 ms delay interval, a result that suggests that the WFE is linked to phonologic rather than articulatory factors. In sum, these findings support the lexeme-as-locus hypothesis.⁶

Jescheniak and Levelt (1994) provide further evidence that the locus of the word frequency effect is at the stages of lexeme retrieval in a homophone translation study based on previous results obtained by Dell (1990). Dell's (1990) analysis of speech errors indicated that high frequency words were less susceptible to phonological errors than low frequency words. Additionally, the low frequency member of a homophone pair was observed to be as little prone to induced

⁶ See the section, "Ruling out articulatory contributions" in this chapter for an in-depth discussion of delayed naming paradigms and their implications for the lexeme-as-locus hypothesis.

phonological error as its high frequency twin. These results suggest that the low frequency member of a homophone pair inherits a processing advantage from its nonhomophonic twin, an advantage that stems from the shared and frequently used lexeme representation.

In an English-to-Dutch translation tasks, Jescheniak and Levelt investigated the apparent homophone advantage suggested by Dell's (1990) error analyses. The authors reasoned that if the word frequency effect were tied to the lexeme level rather than to the lemma level, response times to low frequency homophones would mimic response times to their high frequency twins since both words share phonologic representations – a homophone inheritance phenomenon. They found that response times for producing low frequency meanings matched response times for producing high frequency nonhomophone controls thus suggesting that it is not the frequency of the lemma that induces the word frequency effect, but rather the frequency of the lexeme. This investigation has provided strong evidence for the lexeme-as-locus hypothesis.

Contrary to the evidence obtained by Jescheniak and Levelt (1994) however, Bonin and Fayol (2002, Experiment 2), found no evidence that low frequency homophones inherit a processing advantage from their higher frequency mates in French. In both written and spoken picture naming tasks, participants were

presented with a word which was immediately followed by a picture and were asked to decide as quickly as possible whether a word appearing on a screen denoted the object in the picture and to press a *yes* or *no* button accordingly. Pairs of heterographic homophonic picture names with high and low frequency printed frequency were selected (e.g., *verre*, HF, meaning “glass,” and *ver*, LF, meaning “worm”). Results indicated a significant word frequency effect in both the spoken and written picture naming tasks.

In more recent experiments, however, Jescheniak, Meyer and Levelt (2003) replicated the Jescheniak and Levelt (1994) homophone inheritance results in both Dutch and German. Thus despite conflicting results, results appear to favor the notion that low frequency words with high frequency homophone mates inherit a processing advantage from the high frequency mate. Since homophones have different lemmas but share lexemes, it can be inferred that the word frequency effect is linked to the stages of phonologic encoding.

Repetition and the Word Frequency Effect

The repetition effect and its relationship to word frequency also has relevance to the lexeme-as-locus hypothesis. A number of investigations have addressed the question of whether there is an interaction between word frequency effects and

repetition. For example, in picture naming experiments conducted by Griffin and Bock (1998), the significant word frequency effect observed in initial productions was no longer observed after three repetitions. Similar results were found by Bonin & Fayol (2002) in which word frequency effects were attenuated with repetition.

Several other studies, however, have found the word frequency effect to be robust over repetitions. Jescheniak and Levelt (1994) found a word frequency using a picture naming task in Experiment 1 to be robust across three repetitions, in Experiments 5a and 5b across two repetitions, and in a homophone translation reading task in Experiment 6 across three repetitions. These results were further corroborated by Levelt et al. (1998), in which the word frequency effect was stable across twelve repetitions in the pre-experiment using items from the Jescheniak and Levelt (1994) study. Additionally, Rogers, Belleville et al. (1999) found a significant frequency effect using the cross-modal picture-word interference paradigm even though words had been repeated three, four or more times.

It is unclear why there are disparate results regarding the effects of repetition on the word frequency. When the task requires both semantic and phonologic processing, word frequency effects that remain robust with repetition have been

found in a variety of paradigms such as picture naming (Jescheniak & Levelt, 1994; Levelt et al., 1998; Rogers, Belleville et al., 1999) and word reading (Levelt et al., 1998). The effects do not appear to be stimuli specific. In the picture naming experiments conducted by Jescheniak and Levelt (1994) and Levelt et al. (1999) in which the WFE was maintained across repetition, the same stimuli were used. However, in studies conducted by Jescheniak and Levelt (1994) and Rogers, Belleville et al., (1999) the stimuli were different, but the same robust WFE was obtained.

Subject variability or experimental context may account for some of the inconsistent results. For example, the stimuli that evoked a robust word frequency effect across twelve repetitions in the pre-experiment conducted outside of the MEG apparatus by Levelt et al. (1998) failed to evoke the word frequency effect at all when the same experiment was conducted on a new group of participants inside the MEG apparatus. This finding defied explanation by the authors, but may be attributable to subject and/or contextual factors.

Despite the lack of complete consensus, the robust nature of repetition effects does provide additional support for the lexeme-as-locus hypothesis. With the exception of the Griffin and Bock (1998) findings, it appears that the word frequency effect is robust across repetitions when the task requires both lemma

and lexeme access. The effect does not appear to be as robust in tasks that require lemma access alone. Jescheniak and Levelt (1994) found robust effects in a number of experiments requiring both semantic and phonologic processing across a number of repetitions. The WFE observed in a gender decision task, however, was not comparable to the WFE observed in tasks that include lexeme access. In the gender decision task, the authors found what they called an “ephemeral effect” of word frequency that was not robust across repetitions.⁷ The striking difference between the effects of repetition on word frequency effect in tasks that require both semantic and phonologic processing as opposed to tasks that are primarily semantic further supports the notion that the primary word frequency effect arises during the stages of pre-motor encoding.

Pre-Motor Encoding: The Locus of the Word Frequency Effect?

The evidence, taken as a whole, strongly suggests that the robust frequency effect arises during the stages of phonologic encoding. In data obtained by means of tasks that require both lemma and lexeme access, such as word pronunciation, lexical decision, lexically contingent naming, and picture

⁷ Jescheniak and Levelt (1994) account for this in terms of recency effects, suggesting that the connection strength between a lemma and its gender node increases each time the word’s gender information is used and then only slowly decays. Since selection of high frequency words is more recent than low frequency words, then accessing gender information for high frequency words is faster than accessing gender information for low frequency words.

naming, a high frequency word advantage is consistently observed, and appears to be robust despite repetition. In contrast, data obtained by means of tasks designed to require lemma access alone, the effect is inconsistent and is ephemeral across repetitions. Furthermore, studies using a delayed naming paradigm strongly suggest that the locus of the word frequency effect lies at stages that precede motor execution, and data from object and word recognition studies together with picture naming studies, suggest a post-identification locus. This pattern in the data strongly suggests that, while frequency of use or exposure may influence processing at a variety of stages, the more robust and consistent word frequency effect arises during the stages of pre-motor encoding.

CHAPTER 7: EXPERIMENT I. THE EFFECT OF WORD FREQUENCY ON PRE-MOTOR ENCODING.

Purpose

As discussed in the previous chapter, the dominant hypothesis accounting for word frequency effects places its primary locus during the stages of pre-motor encoding. This lexeme-as-locus hypothesis forms the foundation of the dual route model, which states that the pre-motor encoding processes of low frequency and high frequency words are fundamentally different. Low frequency words are processed by means of the indirect route in which sublexical units are assembled to generate a phonologic representation. High frequency words, in contrast, are not processed by means of sublexical assembly, but rather are stored and retrieved as whole word units via the direct route. This dual route model accounts for the finding that high frequency words are responded to faster than low frequency words. The purpose of Experiment 1 was to test the hypothesis that the word frequency effect arises out of the stages of pre-motor encoding using the cross-modal picture-word interference paradigm. The section that follows will provide a detailed description of this paradigm and its theoretical bases.

Description of the Experimental Paradigm

In cross-modal interference paradigms, response times are measured as participants produce target words as quickly as possible while ignoring an auditory stimulus. Target words are elicited by simple line drawings, or participants are instructed to read target words as they appear in type on a computer screen. Within the general paradigm, there are a variety of variables that may be manipulated or controlled:

- (1) *Target word characteristics*. Target word characteristics such as word class, frequency of occurrence, number of syllables, and neighborhood density, may be manipulated, or controlled.
- (2) *Prime characteristics*. The relationship of the prime, or *interfering stimulus* (IS) to the target word may be manipulated. For example, the prime may be semantically related, phonologically related, or unrelated to the target. Other prime characteristics, such as frequency of occurrence, neighborhood density, and loudness level of presentation, may be manipulated or controlled.
- (3) *Stimulus onset asynchrony (SOA)*. The temporal relationship between prime and stimulus presentation can be systematically varied. For example, the IS may be presented *before* the presentation of the

picture, as indicated by a negative SOA (e.g., -300 ms),
simultaneously with the picture (0 ms SOA), or *after* picture
presentation (e.g., SOA of +150 ms).

Mechanisms and Theoretical Bases

The lexical network and activation spreading.

At the basis of priming and interference paradigms is the lexical network, which provides a conceptualization of the organizational scheme of the mental lexicon, and spreading activation, or the means by which information within the lexicon is activated and selected (e.g., (Dell, 1986; Dell et al., 1999; Levelt, 1989).

Lexical entries are items within the mental lexicon, which consists of nodes that correspond to lexical concepts, their associated *lemmas* and *lexemes*, or word forms (Levelt, 1989; Levelt et al., 1999b). Models detailing the nature of the lexical network differ in their in terms of kinds of nodes, use of excitatory and inhibitory connections between nodes, the possibility of bidirectional spreading of activation, time characteristics of activation spreading, summation of the function of input activations to a node, possible range of activation stages of a node, the output function of the node, and the control of timing and order, but converge on general, connectionist principles (Levelt, 1989). Figure 7.1 represents a simplified fragment of this lexical network, showing the

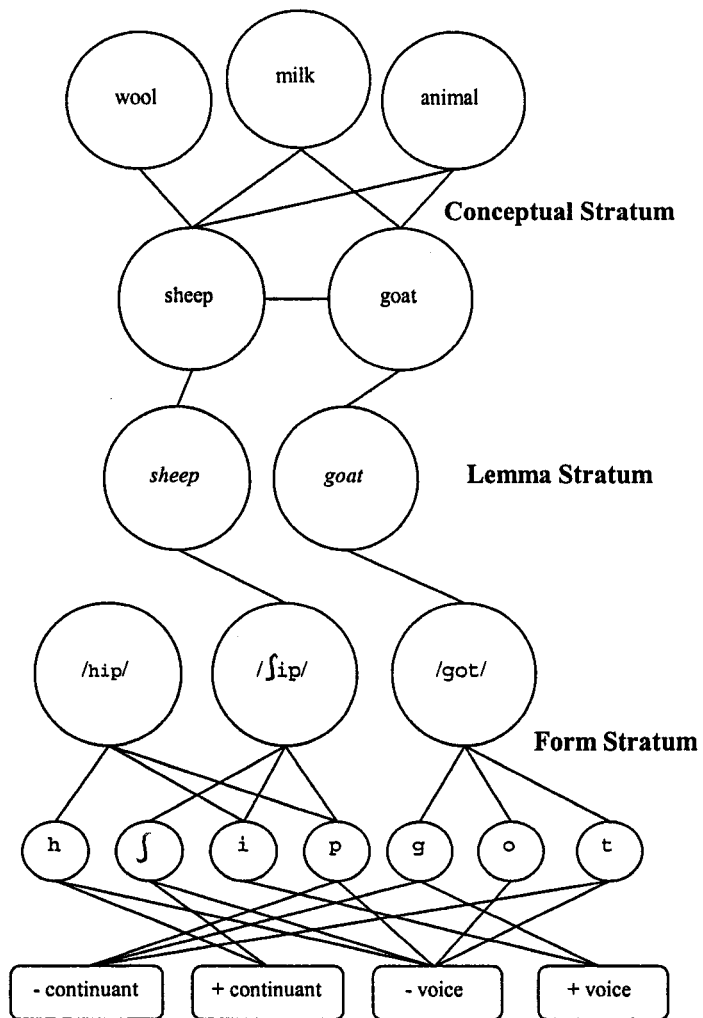


Figure 7.1. A fragment of the lexical network. Nodes within the conceptual stratum link to nodes within the lemma stratum. Lemma nodes link to word form, phoneme and distinctive feature nodes within the form stratum. From Dell (1986).

relationship between *sheep* and *goat* in terms of their concepts, lemmas, and word-form components (adapted from Dell, 1986).

For language production, activation spreading begins at the conceptual stratum, among related concepts. Activated concepts then activate associated lemma nodes in the lemma stratum. The phonologic shapes of the words are then selected at the form stratum. This includes information regarding the words' phonologic makeup, metrical shape and segmental makeup (Dell, 1986; Levelt et al., 1999b; Roelofs, 1992). The spread of activation is influenced by factors such as semantic relatedness (e.g., Glaser & Dungelhoff, 1984) and phonologic similarity (e.g., Meyer, 1992).

Based on evidence obtained from types and distributions of speech errors, eventual selection ostensibly involves some degree of competition among activated elements (e.g., Shattuck-Hufnagel, 1979). During grammatical encoding, lemmas compete for selection and activation of associated word-form elements. During phonologic encoding, these word-form elements compete for selection and assignment to the appropriate frame. Selection is based on degree of activation (Dell et al., 1999; Levelt, 1989; Shattuck-Hufnagel, 1979).

Figure 7.2 presents a schematic of the scope of the spread of activation in response to a picture of a sheep. Recognition of the picture involves lead in processes of picture recognition, but ultimately results in both lemma and word-form activation (Indefrey & Levelt, 2000). Nodes from the conceptual stratum spread their activation throughout the network to a subset of all lemma nodes that encompasses all animals, for example, in addition to other lemmas related to the target *sheep*. Upon selection of the appropriate lemma, activation spreads at the word form stratum to include all forms semantically and associatively related to the form for *sheep*. This includes similarity at a number of different levels, such as initial phoneme and rime (e.g., Marlslen-Wilson, 1990).

Dual-task, domain specific interference.

Within cognitive psychology, inhibition, or interference, as it will be referred to in this discussion, can be defined as a “construct whose effects within the information processing stream are inferred to exist on the basis of observable human behavior” (Klein & Taylor, 1994), p.113). Within interference paradigms, the ‘observable human behavior’ is typically reaction time. Reaction times that are longer than baseline responses are presumed, in accord with this

Such interference was first described by Stroop (1935), who demonstrated that significant delays in naming the color of ink used to write a color word occur when the ink color is different from the color name (the *incongruous* condition). Kantowitz (1974) expanded on the Stroop foundations by developing the double stimulation technique, a dual-task paradigm that is based on a limited capacity model of information processing. According to Kantowitz, when the capacity is taxed or exceeded, systematic deficits in performance are observed, which allow inferences about internal relationships between cognitive processes to be drawn. Within this paradigm, the time required to perform one task alone is compared to the time required to perform the same task in concert with some additional task.

Using this technique, domain-specific interference effects have been demonstrated by comparing response times in dual-task experimental and control conditions. For example, in studies by Rosinski and by Lupker (both 1979, as discussed in Rogers, Belleville et al., 1999), subjects named pictures while ignoring printed words (the IS). They found greater interference when the IS belonged to the same semantic category as the target word, than when it belonged to another, unrelated category. These results suggest that the mechanisms implicated in the resultant prolonged processing are domain-

specific, centered at the lemma stratum, during the selection and specification of semantic information (i.e., grammatical encoding).

Domain-specific interference effects, summarized in Figure 7.3, result from simultaneous processing of two stimuli whose activation and selection processes overlap within a single cognitive domain. The primary task of picture naming requires the activation and selection of the lemma that corresponds to the to-be-named target, in this case, *sheep*. While the participant is aware of the output requirement (i.e., the naming of the picture), the presence of the semantically related IS nevertheless results in processing competition at the level of lemma selection. For example, the subsets of activated lemmas that correspond to the target *sheep* and the IS *goat*. Consequently, the semantic IS activates the nontarget lemma *goat* that is also receiving activation from the picture. Thus the lemma of the IS *goat*, due to a convergence of activation, becomes the strongest of all nontarget competitors for selection. This competition for selection results in increased naming latencies. While the semantic IS will result in the spread of activation at the word-form level, as well (corresponding to subset B in the figure), this activation does not overlap with the activation associated with the response pathway (i.e., subset A). Word form selection for the target *sheep* does not involve heightened activation of a single nontarget word form competitor, thus interference effects do not result from processes occurring at the word form

definition, to reflect some interfering effect on the information processing system.

stratum. However, dual-task paradigm investigations focused at the word form level have been conducted that similarly demonstrate domain-specific phonologic interference (e.g., Goldinger, Luce, & Pisoni, 1989; Meyer, 1991; Schriefers et al., 1990).

Cross-Modal Interference

Several studies have used cross-modal versions of the Stroop paradigm (e.g., Cowan, 1989a, 1989b; Miles & Jones, 1989; Miles, Madden, & Jones, 1989). Figure 7.4 represents a schematic of cross-modal interference, which directly builds upon the principle of domain-specific dual-task interference. The traditional double-stimulation technique developed by Kantowitz (1974) utilized the same visual modality for the presentation of IS and picture. Cross-modal interference takes advantage of the similar patterns lexical activation that are caused by auditory input (e.g., Cluff & Luce, 1990; McQueen & Cutler, 2001; Protopapas, 1999).

There is evidence in the literature to suggest that auditory interfering stimuli can produce priming and interference effects in tasks that involve visual processing. Driver and Baylis (1993, Experiment 2) investigated whether priming and interference could be observed cross-modally when auditory distractors were presented 150 ms prior to presentation of a visual target. Four digits were used as visual targets (1, 2, 4, and 9), and there were three conditions for auditory distractors. The *baseline* set consisted of the schwa vowel sound. The *redundant distractor* set consisted of the repetition of a single digit four times throughout the series, and the *interference* set consisted of the four target digits, the order of which varied with each presentation, and was always different from the order of the target digits. Analyses indicated that there was significant cross-modal interference. Mean response time in the baseline condition was 396 ms, but was 414 ms and 423 ms for the redundant distractor and interference conditions, respectively. These findings suggest that auditory information cannot be completely ignored when subjects are attending to visual information, even though the relevant and irrelevant information are distinguished by the modality of input.

Evidence supporting cross-modal priming has also been obtained using a lexical decision task. Whatmough, Arguin and Bub (1999, Experiment 2) investigated whether a simultaneous auditory input could influence lexical decision times to

orthographic information in normal readers using homophonic nonwords as their nonword foils (e.g., height/hite). Whatmough and colleagues assessed the contribution that the presence of a phonologically congruent auditorily presented prime might confer on visual lexical decision by including two conditions: a silence condition and auditory identity prime condition in which participants heard the same word that they were to read aloud. In the identity prime condition (referred to as “with audio,” in their study), subjects heard a digitized recording of the prime 16 ms after the presentation of the visual word/nonword pair. Target words were equally divided between five word frequency ranges: 1-20, 21-50, 51-100, 101-200, and more than 200 per million, based on Francis and Kucera (1967) word frequency counts, and each word group was made up of equal numbers of four-, five-, and six-letter words. Additionally, the set of target words consisted of 100 regular and 100 irregular words.

Results showed overall main effects for auditory condition (with/without audio), word length (4, 5, or 6 letters), stimulus type (regular/irregular) and word frequency (1-20, 21-50, 51-100, 101-200, 200+) in both the silence and auditory identity prime conditions as well as a significant interaction between word frequency and auditory condition in the subjects’ analysis. Compared to the silence condition, response times in the auditory prime condition were 45 ms slower for high frequency and 18 ms slower for low frequency words indicating

that auditory primes produced an interference effect. Only the 45 ms interference effect for high frequency words was statistically significant. These results support the notion of cross-modal auditory priming in lexical decision and foreshadow and upcoming discussion concerning the disproportionate degree of interference exhibited by high frequency words, as compared to low frequency words, under conditions of cross-modal priming.

Rationale

Choice of task

Table 7.1 presents a comparative task analysis reflecting general processing components that have been shown to be involved, or are believed to be involved in picture naming, verb or noun generation, reading, pseudoword reading, generation from initial letters, and word repetition, both immediate and delayed. The analysis divides processes into two types: lead-in processes (i.e., those processes that involve perceptual processing of the input) and core processes (i.e., those processes that are directly involved in language production). In order for the cross-modal picture-word interference paradigm to claim sensitivity to component processing levels of language production, the associated task must include processing at all relevant levels.

Table 7.1. Comparative task analysis based on a stage model of language production. Core processes are indicated by boxes (left). Italicized components indicate output of these processes. Parentheses refer to the *delayed* condition. Adapted from Indefrey & Levelt (2000)

Tasks	Picture naming • visual object recognition	Verb or noun generation • visual or auditory word recognition, • visual imagery, retrieving associated actions from LTM • word association	Reading • visual word recognition	Pseudoword reading • visual grapheme recognition, • conversion of graphemic to phonological code	Generation from initial letters • retrieving and “reading” orthographic word patterns, some semantic processing	(delayed) Word repetition • auditory word perception or audio-phonological parsing (articulatory loop rehearsal)
<div style="border: 1px solid black; border-radius: 15px; padding: 10px;"> <p>Core Processes</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">conceptual preparation</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>lexical concept</i></p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">lexical selection</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>lemma</i></p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">phonologic code retrieval</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>phonological code</i></p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">phonologic encoding</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>phonological word</i></p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">phonetic encoding</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>gestural score</i></p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">articulation</div> <div style="margin-left: 20px;">↑</div> </div> <p><i>spoken word</i></p> </div>	YES	YES	possibly	possibly	possibly	↑
	YES	YES	possibly	possibly	YES	(YES)
	YES	YES	YES	YES	YES	(YES)
	YES	YES	YES	YES	YES	YES
	YES	YES	YES	YES	YES	YES
	YES	YES	YES	YES	YES	YES

Picture naming is chosen as the primary task for Experiment 1. According to the task analysis developed by Indefrey and Levelt (2000) and analyses by others (e.g., Hillis, 2001) picture naming includes processing at all component processing levels. It is a relatively natural task, owing to its close association with object naming, a main component of everyday language use, and tampering with this normal process rarely results in substantial “derailments” of the processes, such as naming errors (Levelt et al., 1999a). Lead-in processes for picture naming involve visual object recognition, one of the best understood of all of the lead-in processes included in Table 7.1 (Indefrey & Levelt, 2000). Furthermore, and of specific importance in the interference framework, interference effects have been shown to be stronger with the picture naming response as opposed to the word pronunciation task (Smith & Magee, 1980).

Choice of Prime Modality

Auditory primes are chosen for the cross-modal picture word interference paradigm. There is evidence to support the notion of a shared lexical representation accessed for comprehension and production. Neuroimaging studies have found similar patterns of activation in the posterior superior temporal lobe in tasks involving both comprehension and production (e.g., Price et al., 1996). Auditory word recognition has also been shown to produce patterns

of spreading activation within the lexical network similar to those of picture recognition (Cluff & Luce, 1990; McQueen & Cutler, 2001; Protopapas, 1999). Automatic spreading activation induced by auditory stimuli that are irrelevant to the task (i.e., interfering stimuli) is ostensibly responsible for the patterns of cross-modal interference observed in both picture naming tasks (e.g., Rogers, Belleville et al., 1999; Schriefers et al., 1990) and tasks that involve word recognition, such as lexical decision (e.g., Cowan & Barron, 1987; Salame & Baddeley, as discussed in Cowan & Barron, 1987). Further rationale for the use of auditory rather than written primes derives from the potential confounding effects of orthography. Effects from written primes may be partially attributed to orthographic overlap between prime and target rather than to effects at the phonologic output level (Lupker & Colombo, 1994; McEvoy, 1988; Schiller, 2000).

Choice of Dependent Variable

Observable behavior in language production consists of the end product of a number of component stages. While a number of approaches have been developed to directly analyze the behavioral component, or “output” of the system, (i.e., offline tasks), the intermediate component stages have no overt behavioral component that can be measured or analyzed directly. Offline tasks

are distant in time from cognitive operations not sensitive to intermediate stages of language processing because they lack the temporal sensitivity necessary to study processing as it unfolds over time (Tompkins & Baumgaertner, 1998). The only property of mental events that can be studied directly, while the events are taking place, is their duration. The processes under investigation are filling real time, and thus real time itself is the variable of interest. Consequently, one can make inferences about events that are unobservable by studying subsequent behavior that results from, or is dependent upon, this cognitive activity (Pachella, 1974). Response time measurements tap into automatic processes that proceed without conscious awareness (Levelt et al., 1999a; Shapiro et al., 1998), requiring a response to some aspect of a stimulus *during*, rather than after the process (Tompkins & Baumgaertner, 1998). Furthermore, such measurements interact very little with the phenomena under investigation, allowing measurement to bypass the confounding effects of metalinguistic examinations, and other controlled processes (Shapiro et al., 1998; Tompkins & Baumgaertner, 1998).

Purpose and Hypothesis

As discussed in previous sections, interfering stimuli that are phonologically and semantically related to the target word are used within the cross-modal picture-

word interference paradigm to selectively affect the stages of phonologic encoding and semantic processing during lexicalization. The purpose of this study was to test the hypothesis that the WFE arises during pre-motor encoding by utilizing the cross-modal picture-word interference paradigm to compare the effects of semantic and phonologic interfering stimuli on the processing times of HF and LF words. Since the variable of word frequency has been shown to affect processing speeds during lexicalization, the introduction of this variable into the cross-modal picture-word interference paradigm should provide insight regarding susceptibility to interference at different points in the time course of pre-motor encoding for HF and LF words.

The cross-modal picture-word interference paradigm has shown that semantic and phonologic information is processed differently during lexicalization. The presentation of an interfering stimulus causes processing speeds to slow or become faster, and IS that are phonologically related to the target word do not produce the same effects at the same points in time as semantically related IS. This lack of synchronicity in cross-modal priming effects indicates fundamental differences in the processing of semantic and phonologic information during lexicalization.

In an analogous manner, it has been hypothesized in the dual route model that LF and HF words differ in the way phonologic information is processed, and that the observed protracted processing of LF words can be attributed to the inherently slower processing of phonologic information. As discussed in Chapter 6 these two routes can also be conceptualized within the framework of automatic versus controlled processing. Automatic processes, fast processes that do not require attention for their execution, are highly efficient, and proceed in a reflex-like, involuntary manner that is difficult to stop once it is initiated (Cohen et al., 1990; Levelt, 1989; Posner & Snyder, 1975; Shapiro et al., 1998; Shiffrin & Schneider, 1977). In contrast, controlled processes are processes that are under continuous cognitive control and consequently draw substantially from a limited pool of cognitive resources (Posner & Snyder, 1975; Shiffrin & Schneider 1977). Furthermore, they are slow relative to automatic processes (Carroll, 1999; Levelt, 1989; Posner & Snyder, 1975; Shapiro et al., 1998; Shiffrin & Schneider, 1977).

Within the dual route model, then, during pre-motor processing, words that are produced frequently can be encoded by means of more automatic processes whereas sublexical assembly is indicative of more controlled processing. This controlled processing, which is described as inherently slower and more demanding of cognitive resources than automatic processing, may provide an

account for the word frequency effect. Furthermore, the automatic versus controlled processing framework suggests that with the introduction of interference, as in dual-task paradigms, automatic processes would, by definition, be less susceptible to interference effects than controlled processes. This would suggest, then, that high frequency words are less susceptible to interference than low frequency words.

If it is the case, then, that the word frequency effect, and thus the encoding of low frequency words, is linked to the more cognitively demanding processes of sublexical assembly while high frequency words may proceed by means of more automatic and reflex-like whole word retrieval, then the presentation of phonologically related interfering stimuli should result in differing amounts of interference for LF and HF words. More specifically, more phonologic interference should be observed for LF than for HF words. Phonologic IS should interfere most with the processing of words whose phonologic processing is protracted by the resource-demanding processes of sublexical assembly, while the automatic nature of the whole retrieval of HF words should make them less susceptible to interference effects. Furthermore, if the word frequency effect is linked to the stages of pre-motor encoding, then the magnitude of semantic interference should not vary with frequency. Thus a greater magnitude of interference for LF words as compared to HF words in the phonologic condition

and a concurrent lack of frequency effects in the semantic condition would provide support for the lexeme-as-locus hypothesis.

Methods

Participants

Fourteen adult subjects, ten female, four male, 22 to 42 years of age, with no history of neurologic, speech, language, or hearing disorder participated in this investigation. All subjects were native speakers of American English, with at least thirteen years of education.

Materials

The experimental pictures consisted of black line drawings and were designed to elicit twenty-eight monosyllable target words, fourteen of high frequency and fourteen of low frequency, as designated by Kucera & Francis (1967). Low frequency words had an average frequency of occurrence in written English of less than 7 per million, and high frequency words, of more than 20 per million. Targets were matched across frequency type for initial phoneme or phoneme cluster. The selected targets were piloted to verify high picture-word agreement. During the pilot stage, participants were presented with the experimental

pictures and asked to write names for them. Only those experimental pictures that were named using the intended target word at 95% accuracy or higher across participants were included in the final stimulus set.

For each of the twenty-eight target words, one semantic and one phonologic IS was selected, based on either semantic or phonologic similarity to the target. These IS were digitized at 22 kHz using the IBM M-Audio Capture and Playback Adapter into CSpeech for presentation in the auditory modality through headphones. Phonologically related IS shared the rime and presence or absence of onset consonant cluster with the target word (e.g., “slam” for the picture labeled *clam*). Semantically related IS were common associates of the target (e.g., “goose” for the picture labeled *duck*, (Battig & Montague, 1969). Type of semantic relationship between the IS and the target was balanced across both the low and high frequency word sets.

Design

Type of interfering stimulus (IS Type) and SOA were systematically manipulated across trials. There were two types of IS (*semantic* and *phonologic*), a *silence* condition, and five SOAs (-100 ms, +100 ms, +300 ms, +500 ms and +700 ms). Each of the 28 targets was presented a total of 55 times,

five times in each SOA by IS condition, plus five times in silence for a total of 1540 total experimental trials.

The order of experimental targets and conditions across trials was randomly determined except that the same picture did not appear twice within six trials, and the same IS-Type by SOA combination was never be repeated across three consecutive trials.

Procedure

Subjects were tested individually in a quiet room at a comfortable viewing distance from a computer monitor. Before beginning the experimental trials, subjects first viewed the set of twenty-eight experimental pictures and ten fillers in random order while simultaneously hearing their corresponding names through speakers. Subjects were not asked to produce any names during this familiarization phase. Following the familiarization phase, subjects were fit with headphones, and were instructed that during the experimental phase, they were to name the pictures as quickly as possible, ignoring any words they might hear in the headphones. Participants were given three short breaks during the course

of the experiment. Naming errors, as well as hesitations, dysfluencies or other regularities in naming, were recorded by the examiner.

Instrumentation

Presentation of the experimental stimuli and response registration was managed by custom software that relied on Turbo Pascal High Resolution Timer Toolbox (TPHRT, 1989) v.3.00. Presentation of the picture stimuli triggered the timing algorithm that was stopped by the onset of voicing, as measured by a neck microphone. This microphone was positioned just lateral and inferior to the subject's thyroid cartilage with a neck collar, and was connected to custom signal detection circuitry that amplified, full wave rectified, and lowpass filtered ($f_p=20$ kHz), the signal. Speech onset registration and calculation of the speech onset latencies were completed using a Gateway 2000 computer, which interfaced with the aforementioned peripherals. The IS was presented to the subjects through AKG K270 headphones at a 75 dB SPL.

CHAPTER 8: EXPERIMENT I. RESULTS

Errors and Outliers

Speech onset latencies from all erred responses were removed from the data.

Such errors included incorrect naming of pictures, and responses with hesitations, and/or dysfluencies, and made up 3.7% of the total data set.

Percentages of error for HF and LF words were 1.8% and 1.9% of the total data set, respectively. Percentages of error for the *phonologic*, *semantic* and *silence* conditions were 1.7%, 1.7%, and 0.28%, respectively.

After errors were removed, means and standard deviations were calculated for each token, by subject, for the remaining SOLs. Speech onset latencies greater than or less than two standard deviations of each participant's grand mean were removed as outliers. Outliers comprised 5.0% of the total data set. Percentages of outliers for HF and LF words were 2.4% and 2.6%, respectively, and percentages of outliers for the *phonologic*, *semantic*, and *silence* conditions were 2.3%, 2.2% and 0.44%, respectively.

Errors and outliers combined made up 8.7% of the total data set. Percentages for errors and outliers were as follows: 8.4% HF, 8.9% LF, 8.9% *phonologic* IS condition, 8.6% *semantic* IS condition, 7.9% *silence* condition.

General ANOVA for SOLs

A repeated measures analyses of variance (ANOVA) was performed on the SOLs from the interference conditions and the SOLs from the *silence* condition.

Silence condition ANOVA

A repeated measures analysis of variance for the *silence* condition was performed, using SOL as the dependent variable, and the within-subjects factor of FREQUENCY (high and low frequency). A significant main effect of FREQUENCY was obtained ($F=80.72 [1], p<0.001$).

Interference conditions ANOVA

A repeated measures analysis of variance for the interference conditions was performed, using SOL as the dependent variable, and the within-subjects factors of FREQUENCY (high and low frequency), IS TYPE (semantic, phonologic) and SOA (-100, 100, 300, 500, and 700). There were four significant main effects:

FREQUENCY ($F=57.24$ [1] $p<0.001$), IS TYPE ($F=26.15$ [1] $p<0.001$) and SOA ($F=16.02$ [4] $p<0.001$). In addition, there were two significant two-way interactions: FREQUENCY X SOA ($F=47.26$ [4], $p<0.001$), IS TYPE X SOA ($F=25.27$ [4] $p<0.001$). The FREQUENCY X IS TYPE interaction was not significant ($F=0.420$ [1] $p<0.530$). The three-way FREQUENCY X SOA X IS TYPE interaction was significant ($F=5.22$ [4] $p<0.001$). These results, along with the results from the analysis of the silence condition are summarized in Table 8.1

The 700 ms SOA was excluded from further analysis. A post hoc Bonferroni analysis of SOA indicated that the SOAs of 500 ms and 700 ms did not differ significantly from each other ($p=1.0$). Furthermore, the mean reaction times for LF and HF words were 599 ms and 562 ms, respectively, and thus the participants had produced the word before hearing the IS in the 700 ms SOA condition.

Interference Functions

In the *phonologic* and *semantic* IS conditions, the deviation from the baseline of silence across SOA determines the overall shape of the interference functions. Bonferroni analyses were conducted to determine SOAs of interference in both the *semantic* and *phonologic* conditions. Figure 8.1 displays the interference

Table 8.1. Experiment 1: Repeated measures ANOVA results for silence condition (top) and interference conditions (bottom).

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
FREQ	1.466E-02	1	1.466E-02	80.720	.000

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
FREQ	3.479E-02	1	3.479E-02	57.239	.000
IS_TYPE	1.377E-02	1	1.377E-02	26.151	.000
SOA	4.940E-02	4	1.235E-02	16.020	.000
FREQ * IS_TYPE	6.591E-05	1	6.591E-05	.420	.528
FREQ * SOA	6.634E-02	4	1.658E-02	47.259	.000
IS_TYPE * SOA	2.640E-02	4	6.601E-03	25.265	.000
FREQ * IS_TYPE * SOA	3.561E-03	4	8.903E-04	7.539	.000

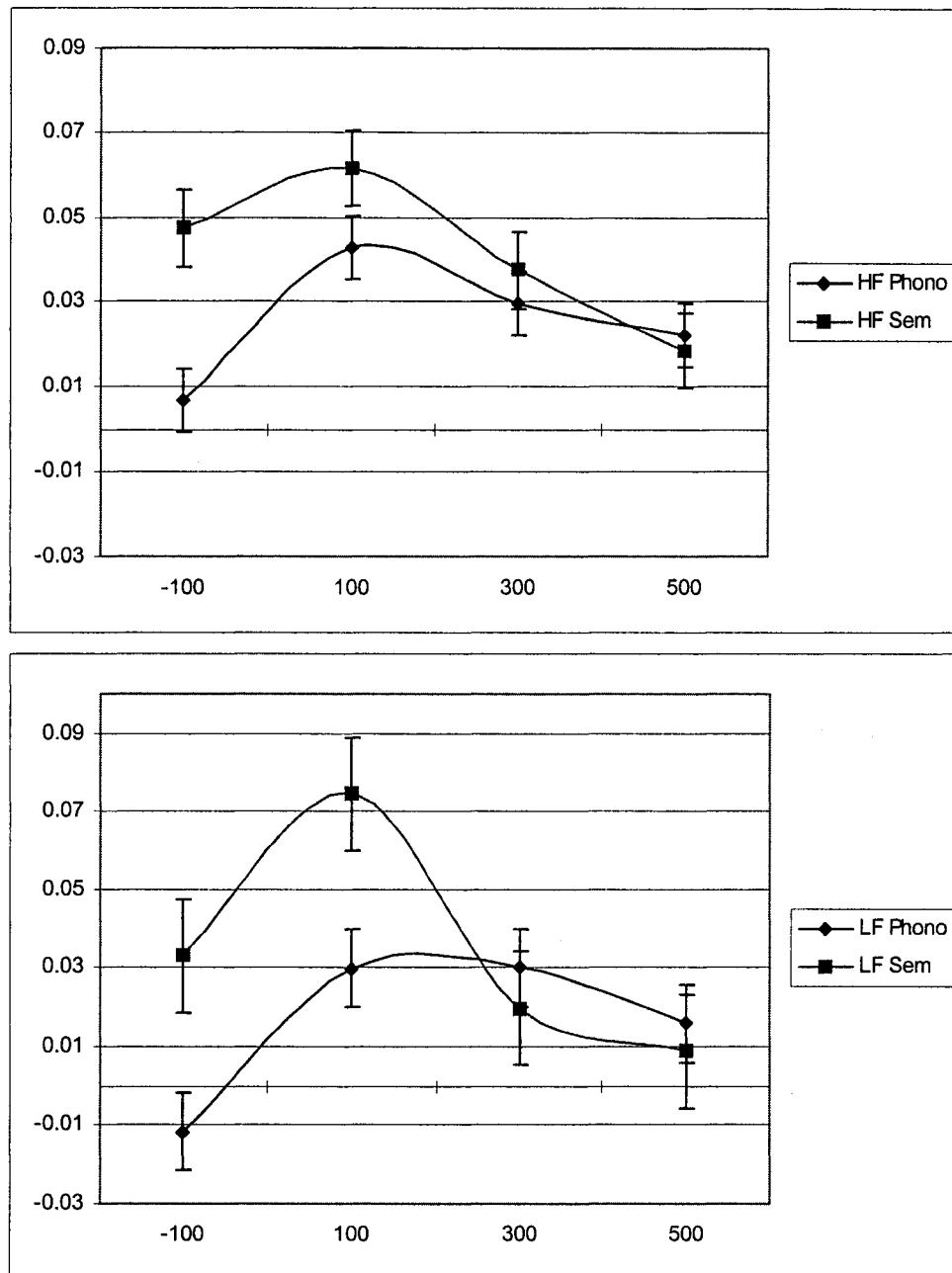


Figure 8.1. Experiment 1: Interference functions for HF (top) and LF (bottom) words. Significant semantic interference was obtained for both HF and LF words at all SOAs. Significant phonologic interference was obtained for both HF and LF words at all but the -100 ms SOA. Error bars indicate standard error of the mean.

functions for HF and LF words, in each interference condition at the SOAs – 100, 100, 300 and 500 ms, using Interference Values.

Fifteen t-tests were conducted on the SOLs. With Bonferroni adjustments, a p-value of less than .003 was necessary for significance. For high frequency words, SOAs of significant phonologic interference were: 100 ($t = -6.113$, $p < 0.001$), 300 ($t = -5.038$, $p < 0.001$), and 500 ($t = -5.472$, $p < 0.001$). The –100 ms SOA did not produce significant phonologic interference for high frequency words ($t = -1.242$, $p < 0.24$). Stimulus onset asynchronies of significant semantic interference for high frequency words were: -100 ms ($t = -7.747$, $p < 0.001$), 100 ms ($t = -6.828$, $p < 0.001$), 300 ms ($t = -5.079$, $p < 0.001$) and 500 ms ($t = -3.887$, $p = 0.002$). For low frequency words, SOAs of significant phonologic interference were: 100 ms ($t = -4.473$, $p = 0.001$), 300 ms ($t = -4.407$, $p = 0.001$), and 500 ms ($t = -4.284$, $p < 0.001$). The –100 ms SOA did not produce significant phonologic interference for low frequency words ($t = 2.414$, $p < 0.032$). Stimulus onset asynchronies of significant semantic interference for low frequency words were: -100 ms ($t = -5.501$, $p < 0.001$), 100 ms ($t = -9.539$, $p < 0.001$) 300 ($t = -3.887$, $p = 0.002$) and 500 ms ($t = -4.284$, $p = 0.001$).

Magnitude of Interference

Magnitude of interference is defined as the deviation in milliseconds of the mean SOLs in the interference conditions from the baseline *silence* condition SOLs. *Interference Values* were calculated by subject for HF and LF words at each of the SOAs by subtracting the mean silence SOL of that frequency condition from the interference SOLs. Interference Values were then averaged across all subjects. Interference Values with positive values indicated that SOLs were longer in the interference condition than in the *silence* conditions.

Interference Values with negative values indicate that SOLs were shorter in the interference condition than in the *silence* conditions. Interference Values allow the comparison of magnitude of interference for the HF and LF words in the *semantic* and *phonologic* conditions, taking into account their differing baseline *silence* condition SOLs.

Figure 8.2 displays the interference functions for the *semantic* and *phonologic* conditions. Significant phonologic interference effects were obtained for both LF and HF words at the 100, 300 and 500 ms SOAs. The difference between mean interference values for LF and HF words is greatest at the 100 ms SOA for the *phonologic* condition. Thus the 100 ms SOA was selected for further analysis of magnitude of phonologic interference. T-tests with Bonferroni

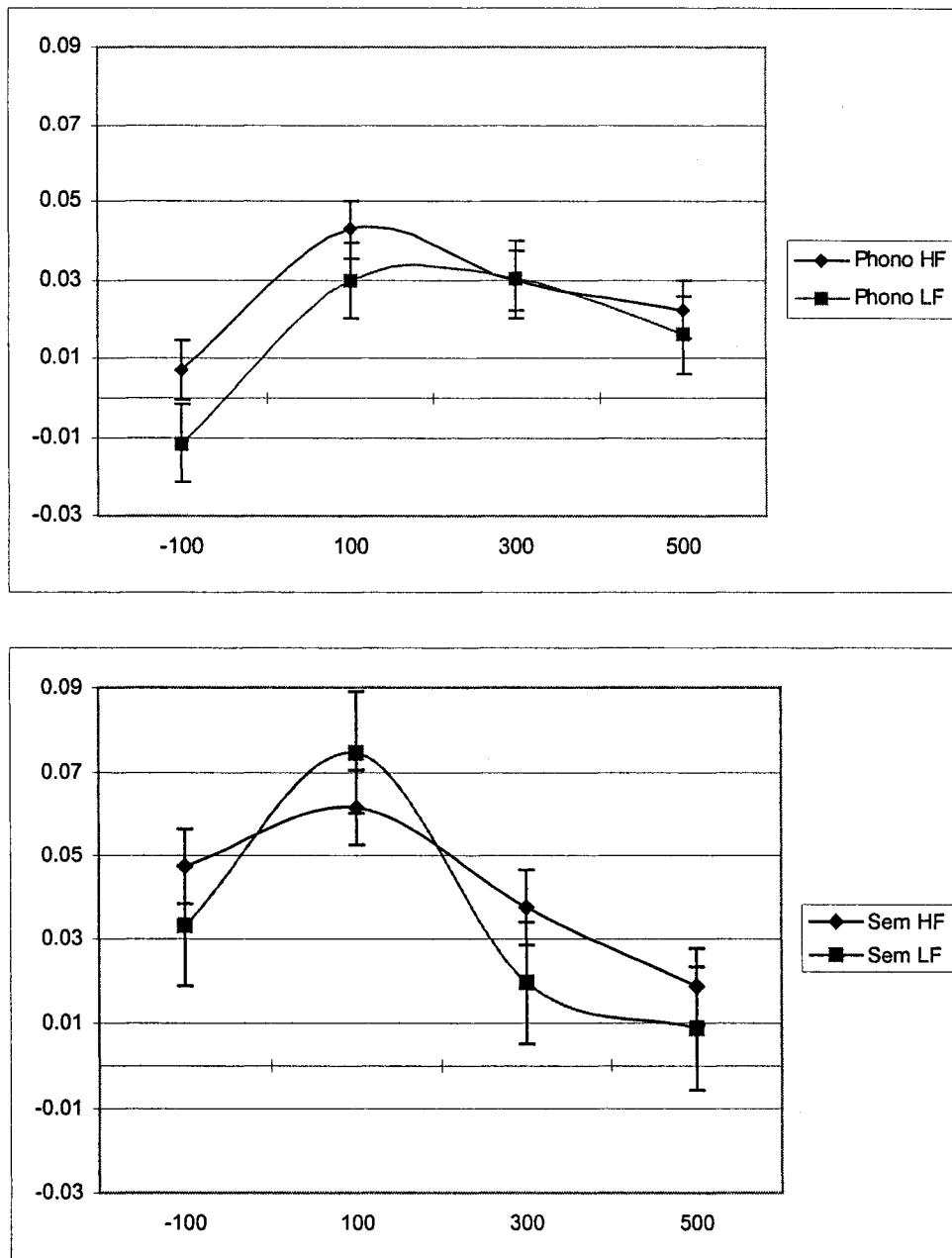


Figure 8.2. Experiment 1: Interference functions for phonologic (top) and semantic (bottom) conditions at each SOA. At the 100 ms SOA, the difference between significant HF and LF phonologic interference is the greatest, thus the 100 ms SOA was chosen for further analysis. Error bars indicate standard error of the mean.

adjustments were conducted on the interference values at the 100 ms SOA in the *semantic* and *phonologic* conditions to determine if there were significant differences in the magnitude of interference for HF and LF words. With the Bonferroni adjustments for two tests, a p value of less than .025 was necessary for statistical significance. In the *semantic* condition, there was no difference between the magnitude of interference induced for HF and LF words ($t = -1.614$, $p < 0.135$). However, in the *phonologic* condition, there was significantly more interference for HF words than for LF words ($t = 2.750$, $p < 0.018$).

CHAPTER 9. EXPERIMENT I. DISCUSSION

Analyses of the data from Experiment 1 corroborated the results of previous studies that found significant effects of word frequency in picture naming in conditions of silence (e.g., Griffin & Bock, 1998; La Heij et al., 1999; Levelt et al., 1998; Levelt et al., 1991; Rogers, Belleville et al., 1999; Rogers, Jones-Redmond et al., 1999; Schilling et al., 1998; Schriefers et al., 1990) and in conditions of semantic and/or phonologic interference (e.g., Rogers, Belleville et al., 1999; Schriefers et al., 1990). Furthermore, the -100 ms SOA onset of semantic interference effects preceded the 100 ms SOA onset of phonologic interference effects for both LF and HF words. These results lend additional support to two stage models (e.g., Bock, 1996; Dell, 1986; Garrett, 1980; Levelt, 1989; MacKay, 1972; Shattuck-Hufnagel, 1979; van Turennout et al., 1997) and further support other data indicating the onset of semantic information precedes the onset of phonologic information (e.g., Levelt et al., 1991; Rogers, Belleville et al., 1999; Schmitt et al., 2000; Schriefers et al., 1990).

Magnitude of Interference

Analyses of the Experiment 1 data did not, however, yield all of the hypothesized results. The experiment was designed to test the hypothesis that

the locus of the word frequency effect lies at the stage of phonologic encoding using the cross-modal picture-word interference paradigm. It was hypothesized that if processing delays associated with LF words results primarily from the cognitively demanding process of sublexical assembly during pre-motor encoding, then, more phonologic interference should be observed for LF words than for HF words. The data revealed the opposite pattern. Rather than eliciting greater interference effects for LF words as hypothesized, phonologically related interfering stimuli induced greater interference effects for HF frequency words. A secondary prediction was also made that if the word frequency effect is linked to stages of pre-motor processing, then frequency effects should not be observed when comparing the magnitude of interference for LF and HF words in the *semantic* condition. The data did support the secondary prediction; there was no interaction between magnitudes of interference and word frequency in the *semantic* condition.

High Frequency Words, Automaticity and the Dual Route Hypothesis

As has been elaborated in previous chapters, Varley and Whiteside (Varley & Whiteside, 2001; Varley et al., 1999; Whiteside & Varley, 1998) have developed a dual route hypothesis of lexicalization. They hypothesize that

LF and HF words differ in the way phonologic information is processed, and that the observed protracted processing of LF words can be attributed to the inherently slower processing of phonologic information. These two routes can also be conceptualized within the framework of automatic versus controlled processing. The *direct route* of whole word retrieval for HF words is associated with fast automatic processing that is highly efficient, and proceeds in a reflex-like, involuntary manner (Cohen et al., 1990; Levelt, 1989; Posner & Snyder, 1975; Shapiro et al., 1998; Shiffrin & Schneider, 1977). The *indirect route*, through which LF words are processed via sublexical assembly, is associated with more controlled processing which is inherently slower than automatic processing and that draw substantially from a limited pool of cognitive resources, and are susceptible to interference (Carroll, 1999; Levelt, 1989; Posner & Snyder, 1975; Shiffrin & Schneider 1977; Shapiro et al., 1998). Thus according to the dual route hypothesis, there are *fundamental* differences in the processing routes used in the production of LF and HF words. Furthermore, the distinct characteristics of automatic and controlled processing would suggest that high frequency words would be less susceptible to interference than low frequency words, not more.

In Experiment 1, the magnitude of phonologic interference for LF words was not greater than the magnitude of phonologic interference for HF words. Rather,

the opposite pattern was observed: the magnitude of phonologic interference was greater for HF words than for LF words, and no comparable statistically significant differences were observed in the *semantic* condition. A further analysis of the Rogers, Belleville et al. data (1999) motivated by the present results revealed the same pattern: the amount of phonologic interference observed was greater for HF than for LF frequency words. While the lack of frequency effects on magnitude of interference in the *semantic* condition observed in the present experiment lend support to the lexeme-as-locus hypothesis, the pattern in the magnitude of interference data from both the present study and the study by Rogers, Belleville et al. (1999) suggests that the Varley and Whiteside dual route hypothesis may not present a complete picture in modeling the lexicalization of LF versus HF words. While the dual route hypothesis is based on observational and experimental data, this body of data does not include data obtained through the use of interference paradigms, which, as shown in the present study, allow the comparison of interference effects across frequency types.

The present findings suggest that the observed differences in the phonologic encoding of LF and HF words may not simply reflect inherent properties of the word, but rather reflect an interaction of these properties with production context. It is hypothesized that HF words are more susceptible to interference

than LF words because they cannot be retrieved as whole word units under conditions of competing interference and thus have to be produced using the same indirect assembly route as LF words. Greater interference exhibited by HF words is hypothesized to be due to the additional time imposed by an initial failed attempt at whole word retrieval via the direct route compounded by the time required for assembly via the indirect route.

That interference can be induced in HF words at all is crucial to the understanding the processes of pre-motor encoding and the influence of word frequency. A dual route hypothesis that assigns HF and LF words to mutually exclusive processing routes may not ultimately account for data that reflect an interaction between magnitude of interference and word frequency in different production contexts. Furthermore, the susceptibility of HF words to interference suggests that the processing of high frequency words may not be as automatic as is implied in the dual route model.

A Reconceptualization of the Dual Route Hypothesis: The Interference-Induced Assembly Hypothesis

The finding that HF words exhibited a greater magnitude of interference effects can be accounted for through a reconceptualization of the dual route theory. It is

hypothesized that the introduction of phonologic interference causes the nature of the phonologic encoding of HF words to change from whole word retrieval via the direct route to phonologic assembly via the indirect route. In conditions of interference, the greater deviation from baseline for HF words may be attributed to an initial failed attempt at whole word retrieval due to the presence of interference, and a consequent shift to processing via phonologic assembly. Thus, phonologic interference for HF words is hypothesized to be additive; it is comprised of the latency involved in the failed attempt at whole-word retrieval and the latency that results from the process of phonologic assembly, as well as the delay associated with processing of dual tasks.

Insights from Reading

There is precedence in the literature to suggest that production context may have an effect on the nature, or route, of processing in a particular task. The process of reading, for example, like lexicalization within the dual route model, is hypothesized to proceed by means of two routes. In the *lexical-semantic* route, written words are processed by means of a Grapheme Input Lexicon in which graphemic representations of the spelling of words known to the reader are stored. Selection of the appropriate graphemic representation allows grammatical encoding, which is then followed by phonologic encoding, motor

programming and articulation (e.g., Hillis, 2001; Indefrey & Levelt, 2000). The lexical-semantic route is frequency sensitive (e.g., Lupker et al., 1997).

In the second route, the *grapheme-to-phoneme conversion* (GPC) route, processing of words consists of the parsing of letter strings into letter groups that correspond to a single phoneme. The application of grapheme-to-phoneme conversion rules allow the generation of a phonologic representation based on a set of rules which are determined by the frequency of grapheme-to-phoneme correspondence in the language (Coltheart et al., 1979). This route is considered a nonlexical route; it does not depend on the retrieval of semantic information from the lexicon, and grammatical encoding is bypassed (Hillis, 2001; Hino & Lupker, 2000; Monsell, 1991). Furthermore, the GPC route is insensitive to word frequency (e.g., Lupker et al., 1997). It is by means of this route that pseudowords (pronounceable nonwords) are read, as they have no corresponding meaning information in the mental lexicon, nor do they have graphemic representations.

Although processing via the lexical-semantic and GPC routes is often modeled to occur in parallel (e.g., Coltheart et al., 1979; Hillis, 2001; Hino & Lupker, 2000; Monsell, 1991), data obtained by Baluch & Besner (1991) suggests that when reading context is manipulated, greater or lesser emphasis can be placed

on one of the two routes. Reading context can be manipulated by systematically varying the degree to which the pronunciations of the words in an experimental format are predicted by their spelling. For example, Baluch and Besner (1991) investigated whether the lexical-semantic or GPC is the default, or typical route for oral readings by testing the effect of word frequency on the naming of words whose pronunciation is fully predictable by orthography (phonologically transparent words) and words whose vowels are not predictable by orthography (phonologically opaque) in the Persian language. Based on the dual route reading model, opaque words require lexical knowledge to be read aloud correctly since their pronunciations are not obvious from the orthography, whereas transparent words can be read aloud correctly via the GPC since their pronunciations are predictable. In Experiment 1, participants named 34 transparent, 34 opaque words and 68 transparent nonwords in a mixed format. Results indicated that there was a significant correlation of response times with word frequency for opaque words only. These results suggest that processing of transparent words proceeded by means of the GPC route, which is not frequency sensitive.

Experiment 2 was designed to test whether the use of the GPC route is typical by removing nonwords from the trial block. The authors hypothesized that if frequency effects were observed in the naming latencies of transparent words in

addition to opaque words when nonwords are not present in the trial block, it could be inferred that the lexical-semantic route is the preferred route for oral reading. They reasoned that the inclusion of nonwords in Experiment 1 might have served to bias participants to read the transparent words by the same routine as that employed for reading the nonwords. The same stimuli as Experiment 1 were used, including both transparent and opaque high and low frequency words, but excluding nonwords from the trial block. Results showed a significant correlation of response times to word frequency for opaque words, and, in contrast to the findings from Experiment 1, a significant correlation of response times to word frequency was also obtained for transparent words, suggesting that the presence of nonwords did indeed bias the nature of processing in Experiment 1.

Experiment 3A was designed to examine the reading of high and low frequency transparent words in the absence of nonwords and opaque words. High frequency transparent words were named 35 ms faster than low frequency transparent words, a statistically significant effect. Experiment 3B included the same transparent words from Experiment 3A with the addition of nonwords to the trial block. Response times to high and low frequency words were not significantly different when nonwords were present, thus replicating the finding of Experiment 1.

The Baluch and Besner (1991) findings, along with other similar data obtained for English (e.g., Lupker et al., 1997; Monsell, Patterson, Graham, & Milroy, 1992), suggest that while the lexical-semantic route may be a preferred route for processing during reading, the context in which the reading task is performed, can strongly influence the nature of processing. In the Baluch and Besner (1991) study, the presence or absence of words processed by means of the GPC route in the trial block influenced the processing route of transparent words. In an analogous manner, then, it may be possible that although the direct route of whole word retrieval is the preferred or default type of processing for HF words, production context may also strongly influence the processing route. It is possible that the presence of phonologically related interfering stimuli may cause HF words to be assembled by means of the indirect route.

CHAPTER 10. INVESTIGATING THE INTERFERENCE-INDUCED ASSEMBLY HYPOTHESIS

In Experiment 1, the word frequency effect was found to be robust not only in silence, but also in conditions of semantic and phonologic interference.

However, although it was hypothesized that a greater magnitude of phonologic interference effects would be observed for LF words, it was HF words that showed the greatest effects of phonologic interference. This finding was counterintuitive because it had been reasoned that if HF words are retrieved as whole units, then, based on the conceptualization of automatic processing, the processing of HF words should be less susceptible to interference (Posner & Snyder, 1975; Shiffrin & Schneider, 1977). This unexpected finding led to the interference-induced assembly hypothesis which states that it may be the case that production context may have a greater influence on the nature of processing for HF words than for LF words. While HF words may typically be processed via the direct route of encoding through which they are retrieved as whole word units, under conditions of increased cognitive demand, such as with the introduction of phonologic interference, whole word assembly is blocked, thus necessitating sublexical assembly via the indirect route.

It was noted that there is a precedent for the notion that a shift in preferred processing route can be induced by context. In the case of reading aloud, which, like pre-motor encoding, has been modeled as proceeding by means of dual routes, the processing of transparent words typically proceeds via the preferred lexical-semantic route but was observed to shift to being processed via the less efficient grapheme-to-phoneme conversion route. This occurred when the transparent words were being read in a context that included nonwords, which can only be processed via grapheme-to-phoneme conversion.

Thus reading, because it, like pre-motor encoding, is also modeled as proceeding by means of dual routes of processing, provides an additional framework through which the effects of word frequency may be examined. This chapter will discuss how the variable of orthographic regularity, like word frequency, has been shown to affect response times, and will outline how spelling regularity, word frequency and the interface between the dual route processing of written words and the dual routes of pre-motor encoding can be used to further investigate the counterintuitive findings of Experiment 1 (i.e., that the greatest magnitude of interference was obtained for HF words).

Spelling Regularity and Lexicalization

There have been many demonstrations that spelling regularity affects naming latency. Naming latencies for irregularly spelled words have been shown to be longer, and irregular words have been shown to be named less accurately than regular words (e.g., Baron & Strawson, 1976; Berndt, Reggia, & Mitchum, 1987; Stanovich & Bauer, 1978). Spelling regularity thus represents an additional variable by means of which the processes of lexicalization may be examined, and may present an additional variable that affects pre-motor processing. Like the variable of word frequency, regularity has been shown to affect naming latencies; irregularly spelled words take longer to produce than regularly spelled words.

The Dual Route Model of Reading

Figure 10.1 shows a model of spoken language production for the processing of reading words. As discussed in the preceding chapter, lexical processing for written words has been modeled as proceeding by means of two independent routes that operate in parallel. In the *lexical-semantic route*, written words are processed by means of a Grapheme Input Lexicon in which the graphemic

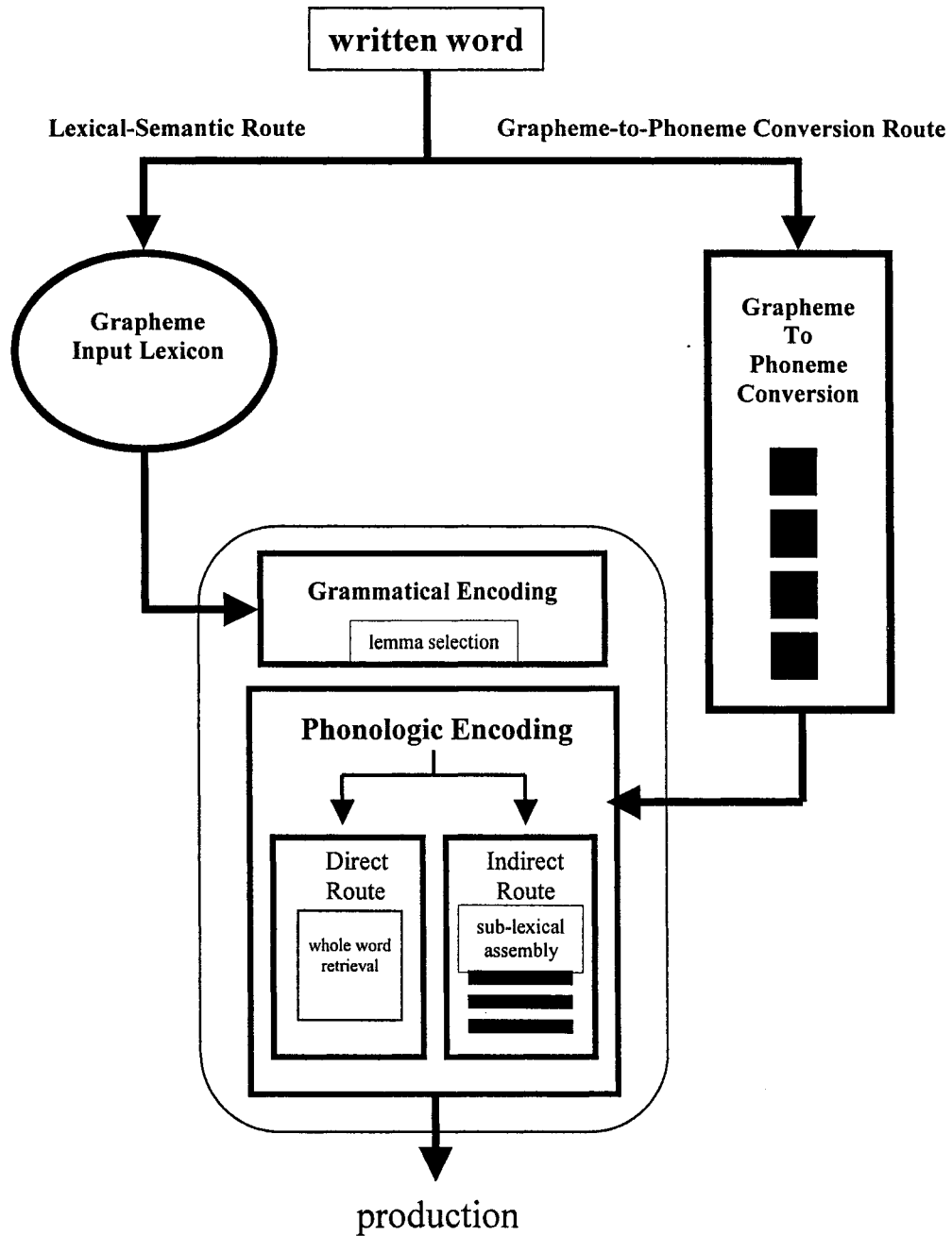


Figure 10.1. Dual-route model for reading. Processing along the Lexical-Semantic Route involves retrieval of the appropriate orthographic representation from the Grapheme Input Lexicon. Processing then proceeds to grammatical encoding. Processing along the grapheme-to-phoneme conversion route bypasses grammatical encoding and proceeds directly to the stages of phonologic encoding.

representations of the spelling of words known to the reader are stored.

Selection of the appropriate graphemic representation allows grammatical encoding, which is then followed by phonologic encoding, motor programming and articulation. In the second route, the *grapheme-to-phoneme conversion* (GPC) route, reading of words aloud consists of the application of grapheme-to-phoneme conversion rules to allow the generation of a phonologic representation. This route is considered a nonlexical route; it does not depend on the retrieval of semantic information from the lexicon, and grammatical encoding is bypassed (Beeson & Hillis, 2001; Hillis, 2001; Hino & Lupker, 2000; Monsell, 1991). It is by means of this route, then, that unfamiliar words or pseudowords (pronounceable nonwords) are read, as they have no corresponding meaning information in the mental lexicon, nor do they have graphemic representations. Thus the GPC route is modeled to be sensitive to spelling regularity; it is only successful if the letter-to-sound correspondences of the word being read follow the sequences predicted by the conversion rules.

Pronunciation of irregular words, or those words whose spellings defy the sequences predicted by the conversion rules, will not be accurately produced by means of the GPC route. Pronunciations of such words would be processed successfully only by means of processing via the lexical-semantic route during which the appropriate graphemic representation is selected from the Grapheme Input Lexicon, and processing proceeds through the stages of grammatical and

pre-motor encoding. Since the Grapheme Input Lexicon consists of graphemic representations of individual words and not on the application of GPC rules, it is not sensitive to regularity.

The Regularity Effect and Regularity x Frequency Interaction

The dual route model of the processing of written words predicts an interaction between spelling regularity and word frequency. Studies investigating this interaction have found that the response times for LF words are affected by the regularity or irregularity of their spelling while the regularity effect for HF words has not been obtained, or has been found to be much smaller for HF words (e.g., Brown, Lupker, & Colombo, 1994; Hino & Lupker, 1996; Monsell, 1991; Paap & Noel, 1991).

The regularity x frequency interaction has been accounted for within the dual route framework by means of a relative speed of processing assumption. Within the dual route framework, although processing along the two routes is typically parallel, it is assumed that processing for the lexical-semantic route proceeds faster than the GPC route for HF words (Jared, 1997, 2002; Monsell, 1991). Thus an absence or attenuated regularity effect for HF words is observed because processing via the lexical-semantic route proceeds fastest; the correct

pronunciation is obtained via the lexical route before the incorrect pronunciation is produced by the GPC route and thus no conflict resolution is necessary (e.g., Baron & Strawson, 1976; Stanovich & Bauer, 1978). The presence of a reliable regularity effect for LF words is accounted for because for LF words, processing along the lexical-semantic route is frequency sensitive, with the speed of processing being a direct function of the word's frequency (Lupker et al., 1997). Thus for LF words, processing along both routes is slow, and so for irregular words, additional time required to resolve the incongruity of the pronunciations produced by the lexical-semantic and GPC routes, which are generated at approximately the same time.

The Role of Spelling Regularity in the Investigation of Pre-Motor Encoding

Spelling regularity represents an additional variable by which the processes of lexicalization may be examined, and may present an additional variable that affects pre-motor processing. Like the variable of word frequency, regularity has been shown to affect naming latencies; irregularly spelled words take longer to produce than regularly spelled words. An interaction between regularity and word frequency has also been observed; effects of spelling regularity for the production latencies are typically larger for LF words than for HF words. These effects have been accounted for within a dual route model of reading.

The proposed experiment employs a variation of the cross-modal interference paradigm that involves reading words rather than naming pictures, and combines the variables of spelling regularity, word frequency and production context (silence vs. interference condition) in a single experiment. Through the systematic manipulation of these variables, which have all been shown to significantly affect lexicalization, the hypothesis that phonologic assembly can be induced in HF words will be investigated.

CHAPTER 11. EXPERIMENT II. THE EFFECT OF SPELLING REGULARITY ON THE PRE-MOTOR ENCODING OF HIGH FREQUENCY WORDS

Purpose and Hypotheses

The purpose of this experiment was to test the interference-induced-assembly hypothesis using a variation of the cross-modal interference paradigm in which written words, rather than pictures, are used to elicit target words. The interference-induced assembly hypothesis states that in conditions of interference, phonologic assembly is induced in the pre-motor encoding of HF words. The design of this experiment is based on the effect of spelling regularity on the pre-motor encoding of LF and HF words.

High frequency words are produced faster than LF words. Despite the presence of the word frequency effect, however, data obtained in Experiment 1 indicated that when production context was manipulated (i.e., in conditions of phonologic interference), the magnitude of interference was greatest for HF words. Based on these findings, there are two hypotheses for Experiment 2. It is hypothesized 1) that a greater regularity effect will be observed for HF words in the *phonologic* condition as compared to the *silence* condition and 2) that the greatest interference effects will be observed for irregularly spelled, HF words.

The dual route model for the processing of written words accounts for the absence or attenuation of regularity effects HF words by making assumptions about the relative speed of processing for the lexical route versus the GPC route. The lexical route is modeled as proceeding at a faster speed, ostensibly due to the faster pre-motor encoding of HF words by means of whole word retrieval (Jared, 1997, 2002; Monsell, 1991). Thus the correct pronunciation is obtained by means of whole word retrieval before the incorrect pronunciation is produced via GPC. Consequently, no conflict resolution is necessary.

The interference-induced assembly hypothesis predicts, however, that with the introduction of interference, comparable regularity effects will be observed in both LF and HF words. It is hypothesized that LF words are processed by means of phonologic assembly in both a silence and interference production context. The interference-induced assembly hypothesis states that there is no change in the route of pre-motor encoding for LF words when production context is altered. While it is expected that processing of LF words along both routes will be slowed in an interference context, processing along both routes should still proceed at roughly the same speed. The introduction of interference should affect processing along both the lexical and the GPC routes of written word processing in a similar manner. Thus even in the context of interference, the

simultaneous generation of the output pronunciations will result in longer latencies for irregularly spelled LF words due to the need for conflict resolution.

For HF words, the interference-induced assembly hypothesis states that the nature of pre-motor encoding shifts from the direct to the indirect route in the context of interference. If phonologic assembly is induced for HF words, then HF words processing via the lexical route will be slowed due to the latency associated with the failed attempt at whole-word retrieval, the latency associated with the process of phonologic assembly, as well as the delay associated with the processing of dual tasks. It is predicted, then, that with the slowing of the lexical-semantic route consequent to the failed attempt at whole word retrieval and shift to phonologic assembly, processing via the lexical-semantic route will not be completed before processing via GPC, as is the case in a silence context, but rather the incorrect pronunciation of irregular words produced by GPC rules will create a conflict. This conflict will take time to resolve; thus a regularity effect is predicted for HF words that is comparable to or larger than the regularity effect for LF words in an interference context. In the silence condition, however, a smaller regularity effect is predicted for HF words as compared to LF words.

In addition to the regularity effect for HF words, the interference-induced assembly hypothesis also predicts that there will be a greater magnitude of interference (as measured by *interference values*) for HF words than for LF words. More specifically, the magnitude of interference should be greatest for HF irregular words because of the latencies associated with 1) a failed attempt at whole word retrieval, 2) processes of sublexical phonologic assembly, and 3) the conflict resolution necessary due to the incongruous output from the GPC and lexical-semantic routes.

In summary, there are two main hypotheses for Experiment 2:

Prediction 1: Magnitude of Regularity Effects

- (1) Under conditions of interference, the regularity effect will be greater for HF words as compared the regularity effect for HF words produced in the silence context;

In the silence context, HF words are hypothesized to be retrieved as whole word units and for HF irregular words to be processed too quickly to encounter conflict created by the erroneous output of the GPC route. In contrast, under conditions of phonologic interference, sublexical phonologic assembly is

induced in HF words and therefore processing along the lexical-semantic route is hypothesized to be slowed. In this case, for irregular words, but not for the regular words, additional time will be needed to resolve the conflict created by the erroneous output of the GPC route.

Prediction 2: Magnitude of Interference Effects

- (2) For irregularly spelled words, greater interference effects will be observed for HF words than for LF words.

If sublexical phonologic assembly is induced in HF words in conditions of phonologic interference, the magnitude of interference is predicted to be greater for HF irregular words than for LF irregular words, due to the added time associated with failed whole-word retrieval. Both the HF and LF irregular words will be subject to the processes of sublexical assembly, and the need for the resolution of the conflict created by the erroneous GPC route output. The main difference in reaction time between HF and LF irregular words is thus accounted for by the time associated with failed whole word retrieval for the HF words.

Methods

Participants

Twenty-one adult subjects, seventeen female, four male, 21 to 37 years of age, with no history of neurologic, speech, language, or hearing disorder participated in this investigation. All subjects were native speakers of American English, with at least thirteen years of education with normal hearing and normal or corrected vision.

Materials

The stimulus set consisted of 20 HF words and 20 LF words equally divided into regular words (i.e., words that conform to the regular rules of spelling-to-sound conversion) and irregular words (i.e., exception words, or those words whose pronunciation does not conform to the regular rules of spelling-to-sounds conversion).

For each of the target words, one phonologically related IS was selected. Each IS was digitized at 22 kHz using the IBM M-Audio Capture and Playback Adapter into CSpeech for presentation in the auditory modality through headphones.

Target Stimulus Selection and Characteristics

Target stimulus characteristics are summarized on Table 11.1.

Stimulus frequency

Stimulus set frequency was determined by the frequency counts of Francis and Kucera (1982) who reported frequency counts for each part of speech of a word that occurred in the corpus. Mean frequency for HF regular words was 144.8, for HF irregular words was 145.9, for LF regular words was 18.8 and for LF irregular words was 14.3.

Stimulus regularity

The degree of spelling regularity of the target stimuli was determined using the frequency and percentage tabulations of the distribution of phoneme-grapheme correspondences published by (Hanna, Hanna, Hodges, & Rudorf, 1966). Hanna et al. used a 17,310 word corpus to calculate frequency and percentage tabulations of the distribution of phoneme-grapheme correspondences both for consonants and vowels by syllable position. For a grapheme to be assigned a percentage of 99.67 means that 99.67% of the time that a phoneme occurs in that syllable position, it is represented by that particular grapheme. According to this study, for example, the phoneme /b/ in syllable initial position is represented by

Table 11.1. Experiment 2: Stimulus Type Characteristics. For parts of speech, N denotes noun, Adj denotes adjective, V denotes verb.

	HF regular	HF irregular	LF regular	LF irregular
Mean Frequency	144.80	145.9	13.80	14.30
Mean Regularity Index	87.21	37.44	87.14	38.74
Parts of Speech	3 N 3 Adj 4 V	5 N 3 Adj 2 V	6 N 2 Adj 2 V	5 N 3 Adj 2 V

the letter “b” 99.67% of the time, by “bb” .27% of the time, and “pb” .05% of the time.

For the present study, the percentages of occurrence by syllable position were used to calculate a *regularity index*, a numerical value that can be used to estimate the degree of regularity of spelling. This regularity index was calculated by taking the percentages for each grapheme-phoneme correspondence in a word and determining the average. In the case of the word “game,” for example, “g” represents /g/ in initial position 96.24% of the time, “a-e” represents /e/ in medial position 63.90% of the time and “m” represents /m/ in final position 91.03% of the time. These percentages average to an 83.72% regularity index for the whole word. Hanna et al. suggest that regular words can be defined as those whose spellings represent a particular phoneme at least 80% of the time. Thus, for the present study, words with at least an 80% regularity index were accepted for inclusion as a regular word (Hanna et al., 1966). The criterion for inclusion as an irregular word was determined by calculating the regularity indices of words used in studies of irregularity. Words with less than a 60% regularity index were used in the determination of irregular words.

Stimulus characteristics

The stimulus list appears in Appendices B-E. High frequency and LF target words within each regularity category were matched for initial phoneme with the exception of two pairs. The exceptions were the HF regular word *eat* and the HF irregular word *eight*, and the LF regular word *elm* and the LF irregular word *axe*. Words within each regularity category were also matched for initial letter or letter cluster with the exception of the HF regular irregular pairs, *drop* and *doubt*, *cost* and *key*, *net* and *knock*, *range* and *write* and *eat* and *eight*, and the LF regular-irregular pairs, *cough* and *crib*, *nest* and *knight*, *reek* and *writhe* and *elm* and *axe*.

As shown in Table 11.1, regular words were matched for average regularity across frequency (87.21 for HF and 87.14 for LF), as well as irregular words (37.44 for HF and 38.74 for LF). The LF words were matched for frequency across regularity categories (14.7 for regular and 14.30 for irregular words), as well as the HF words (144.8 for HF and 145.9 for LF words).

Interfering Stimulus Selection and Characteristics

The phonologically related IS share the rime with the target word (e.g., “slam” for the picture labeled *clam*). Interfering stimuli for HF and LF target words within each regularity category were matched for initial phoneme and presence or absence of initial consonant cluster.

Calibration of interfering stimuli for audio presentation

IS stimuli were calibrated for audio presentation. Interfering stimuli were calibrated using a 2218 sound level meter with a Bruel and Kjaer 4152 artificial ear with a flat plate coupler, and a 4144 1 inch Bruel and Kjaer sound pressure microphone. The earphone was placed on the flat plate coupler with the transducer centered over the microphone. Headphone tension was estimated to be equal to the amount of tension present when worn by a study participant. The stimuli were played through the headphones for calibration. With the average for the meter function set to linear, the interfering stimuli averaged 75 dbSPL when the play control volume on the computer is set just above the second bar. These settings were maintained for presentation of the interfering stimuli during the experiment.

Design

SOA and Production Context were manipulated across trials. Targets were presented in two production contexts (*silence* and *phonologic Interference*) and the two SOAs of peak phonologic interference in Experiment 1 (+100 ms, +300 ms). Each of the 40 targets was presented a total of 20 times, 5 times at each SOA and 10 times in silence, for a total of 800 total trials. Table 11.2 summarizes the design.

Procedure

In a variation of the cross-modal interference paradigm, participants read words presented on a computer monitor while ignoring an auditory interfering stimulus presented through headphones. Participants were encouraged to read the words as quickly as possible.

The procedure for each trial was as follows: A fixation mark (“+”) would appear at the center of the computer screen to signal that a trial was about to begin.

Then the target word would appear on the screen. The onset of voicing, as measured by the throat microphone, triggered the start of the next trial.

Maximum inter-stimulus interval was 2000 ms. Three short breaks were given to participants during the course of the experiment.

Table 11.2. Experiment 2: Design and number of presentations for each stimulus type in each condition.

Stimuli			Production Contexts		
			Phonologic Interference		Silence
			100 SOA	300 SOA	
Frequency Type	20 HF	10 Regular	5	5	10
		10 Irregular	5	5	10
	20 LF	10 Regular	5	5	10
		10 Irregular	5	5	10

Instrumentation

Presentation of the experimental stimuli and response registration was managed by *ePrime*, a software package designed for reaction time experiments (Psychology Software Tools, 2001). Presentation of the orthographic word stimuli triggered the timing algorithm that was stopped by the onset of voicing, as detected by a throat microphone. This microphone interfaced with a Dell computer and the *ePrime* software, which registered the speech onset latency in milliseconds, in association with the stimulus that elicited it. Interfering stimuli were recorded using Cspeech audio editing software. Audio files were duplicated to create two versions: one with 100 ms of silence preceding the onset of the audio signal, and one with 300 ms of silence preceding the onset of the audio. These two versions of the audio files represented the two SOA conditions (100 ms and 300 ms SOA). For the silence condition, an audio file was played during the trial. For trials with phonologic interference, the audio files were presented simultaneously with the visual word stimuli. The presence of either 100 ms or 300 ms of silence before the onset of the word in the audio files created the stimulus onset asynchrony with the appearance of the orthographic word stimuli.

CHAPTER 12: EXPERIMENT II RESULTS

Errors and Outliers

Speech onset latencies from all erred responses were removed from the data in a manner identical to Experiment 1. Such errors included incorrect reading of words and responses disrupted by hesitations, dysfluencies, coughs, laughs and clearing of the throat. During the experiment, participants' responses, whether correct or erroneous, triggered the start of the successive trial. An error on a specific trial typically resulted in a series of errors on successive trials because participants often reacted to their errors by laughing, coughing, or clearing their throats. It was not possible to differentiate these reactionary errors from true errors in naming.

Overall means and standard deviations were calculated for each subject for the remaining SOLs. Speech onset latencies greater than or less than two standard deviations of each participant's grand mean were removed as outliers. Errors and outliers combined made up 10.27% of the total data set. Table 12.1 summarizes the percentages of missing data for each of the conditions.⁸

⁸ See Appendices F and G for full error reports.

Table 12.1. Experiment 2: Percentages of errors and outliers for each condition.

Condition	SOA			Totals
	0	100	300	
HF	8.85%	9.03%	9.06%	8.93%
LF	11.36%	11.65%	10.11%	11.17%
Regular	10.15%	10.60%	7.95%	9.89%
Irregular	10.04%	10.09%	11.21%	10.20%
HF Regular	10.48%	9.80%	8.34%	9.88%
HF Irregular	7.27%	8.26%	9.78%	7.98%
LF Regular	9.83%	11.39%	7.57%	9.90%
LF Irregular	12.82%	11.01%	12.65%	12.43%
Totals	10.14%	10.44%	9.39%	10.05%

Target stimulus words were also analyzed by means of a t-score analysis to determine if any target words should be removed as outliers. In a t-score analysis, the mean of a specific target word is compared to the mean error rate for all targets. In Figure 12.1, all target words are displayed along with the corresponding percent error for each. T-score analyses indicated that the target word *writhe*, with a 36.2% error rate, differed significantly from the mean error rate for all targets ($t=8.2$, $p<0.001$). Thus the target *writhe* was removed as an outlier. No other targets were identified as outliers, however, to maintain the balance of initial phonemes across the four word sets, all responses to the targets that share /r/ as initial phoneme (i.e., *range*, *write*, and *reek*) were also removed from the data set.

Figure 12.2 shows mean SOLs for each of the 38 remaining target words. The figure illustrates that target words with initial voiceless consonants had longer SOLs. This difference could be attributed to instrumentation in that the voice key used to record response times is triggered by the onset of voicing. Thus in the production of target words that begin with voiceless consonants, the voice key is not triggered until the onset of the voicing of the vowel. It is for this reason that the stimulus sets were balanced for initial phoneme or phoneme cluster. As much of the variability in the SOLs of the remaining targets appeared to be attributable to differences in the voicing of initial phonemes rather than to

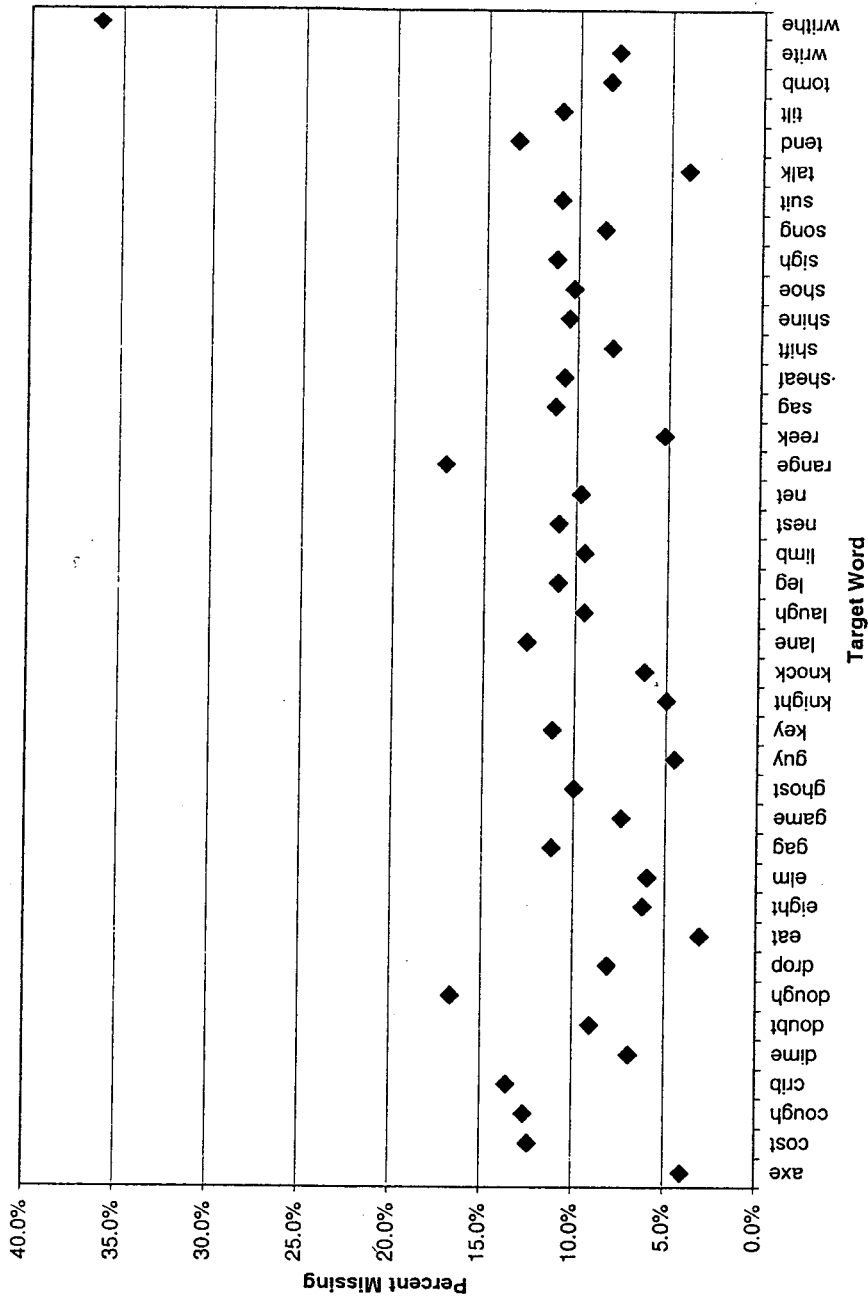


Figure 12.1. Experiment 2: Percent error for each of the target words in the data set.

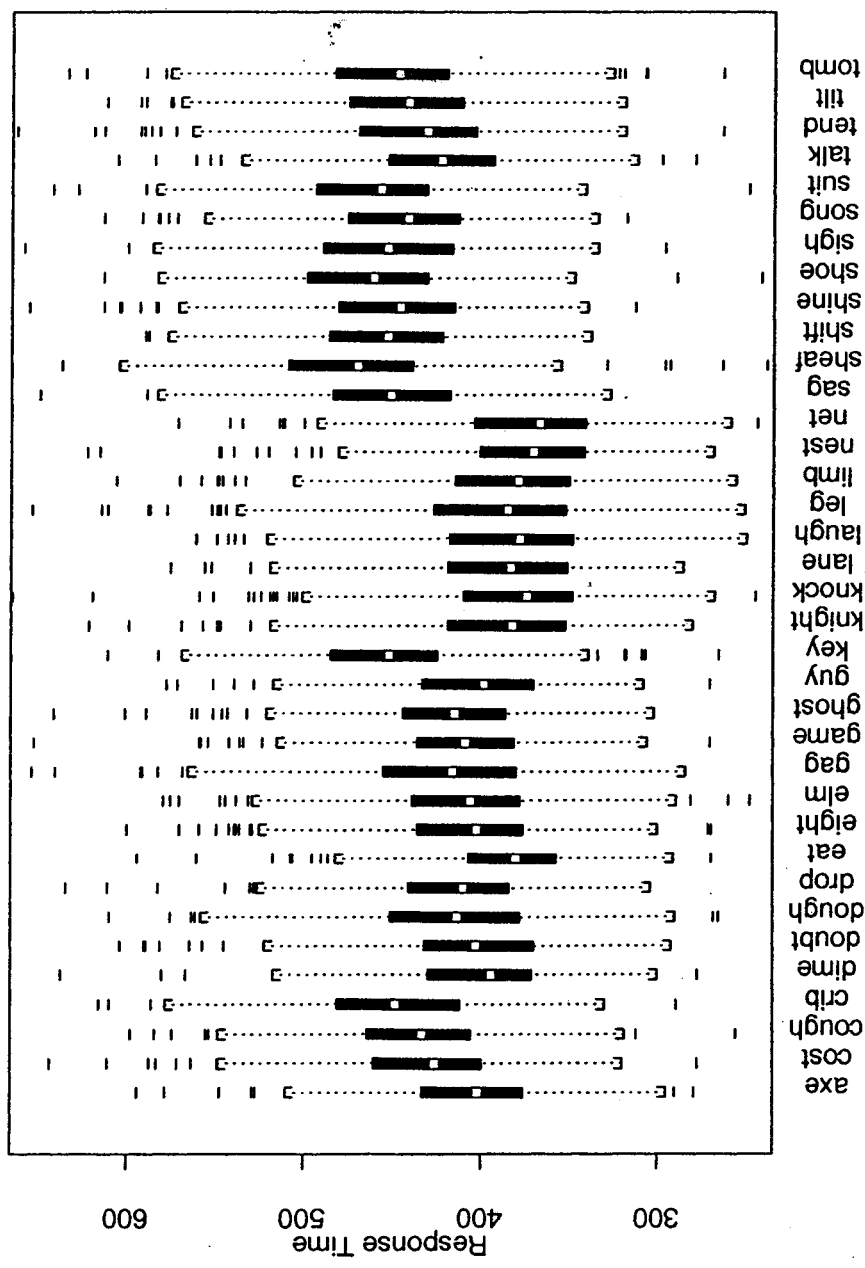


Figure 12.2. Experiment 2: Mean SOLs for each of the target words in the data set after the removal of outliers.

Descriptive Statistics

Mean SOLs

Table 12.2 shows grand mean SOLs and standard deviations for HF and LF words for Experiments 1 and 2, and the mean SOLs and standard deviations for HF and LF words for the conditions that were shared in both Experiments 1 and 2: silence, and at the 100 ms and 300 ms SOAs. Response times are consistently longer for LF words than for HF words. Response times in the reading task (Experiment 2) are consistently faster than response times in the picture naming task (Experiment 1), but for both tasks, response times are longer for LF words than for HF words, although the frequency effect is smaller for reading than for picture naming. Table 12.3 shows means and standard deviations for data from Experiment 2 only, for each of the stimulus types, in silence, and at the 100 ms and 300 ms SOAs. Response times for LF words are consistently longer than response times for HF words for both regular and irregular words, with the exception of regular words at the 300 ms SOA, which differ by only 1 ms.

SOL distributions and Mean SOLs

Figure 12.3 shows the distribution of SOLs for Experiments 1 and 2, respectively. Both distributions are approximately normal, thus log transformations were not deemed necessary. Figure 12.4 shows a boxplot of the

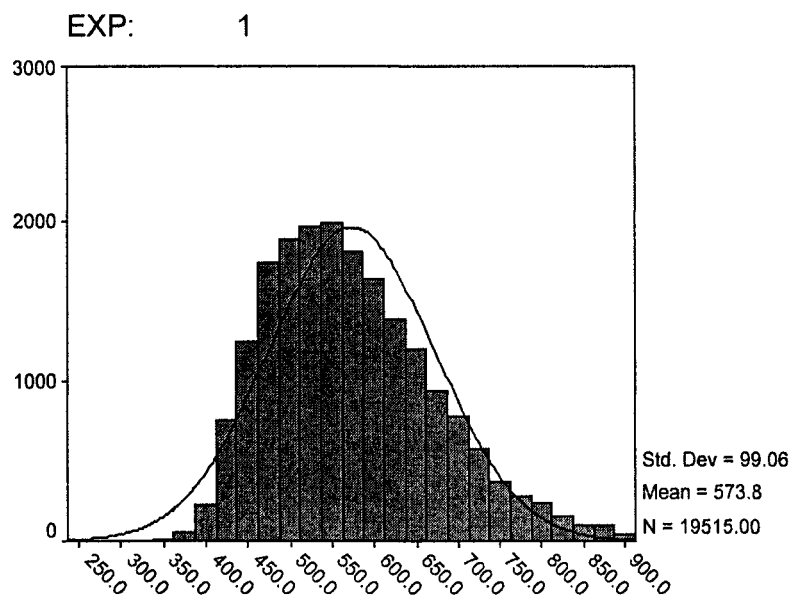
Table 12.2. Experiments 1 and 2: Means and standard deviations for Experiment 1 (picture naming) and Experiment 2 (reading) for HF and LF words averaged across silence and all SOAs (top). Experiments 1 and 2: Means and standard deviations for Experiments 1 and 2 for conditions that were shared in both experiments (silence, 100 ms and 300 ms SOA, bottom).

	HF		LF	
	Mean	Std Deviation	Mean	Std Deviation
Experiment 1	557	95	591	100
Experiment 2	419	58	423	59

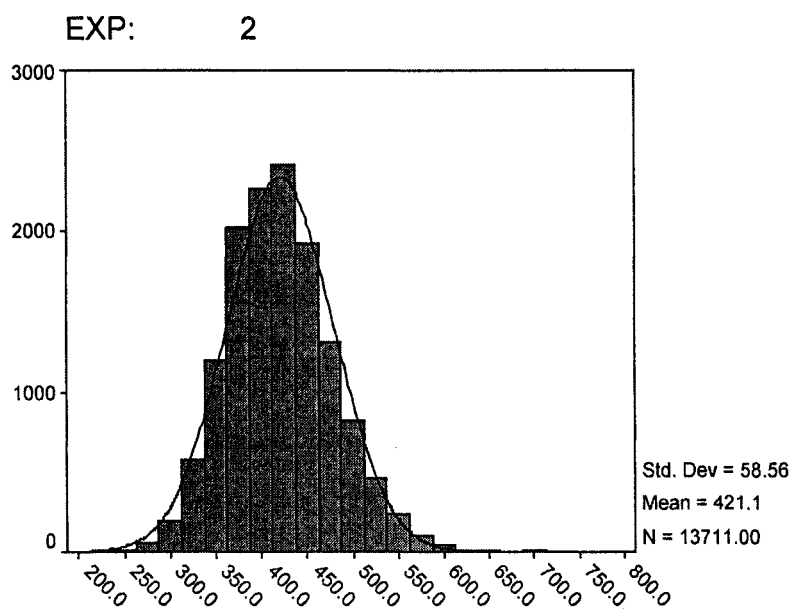
		HF		LF	
		Mean	Std Deviation	Mean	Std Deviation
Silence	Experiment 1	531.6	88.9	576.5	99.2
	Experiment 2	419.2	57.4	424.0	57.9
100 ms SOA	Experiment 1	573.6	98.2	605.5	113.4
	Experiment 2	416.9	59.5	423.2	61.3
300 ms SOA	Experiment 1	561.8	101.7	606.5	113.6
	Experiment 2	419.9	57.9	422.2	58.6

Table 12.3. Experiment 2: Means and standard deviations for each frequency x regularity stimulus group in silence and at the 100 ms and 300 ms SOAs.

Frequency	Regularity		Mean	Std Deviation
HF	irregular	0	422	58
		100	420	61
		300	421	57
	regular	0	417	57
		100	414	58
		300	419	58
LF	irregular	0	426	59
		100	424	60
		300	427	58
	regular	0	422	57
		100	422	63
		300	418	59



SOL



SOL

Figure 12.3 Experiments 1 and 2: Histograms of SOL distribution in Experiment 1 (top) and Experiment 2 (bottom).

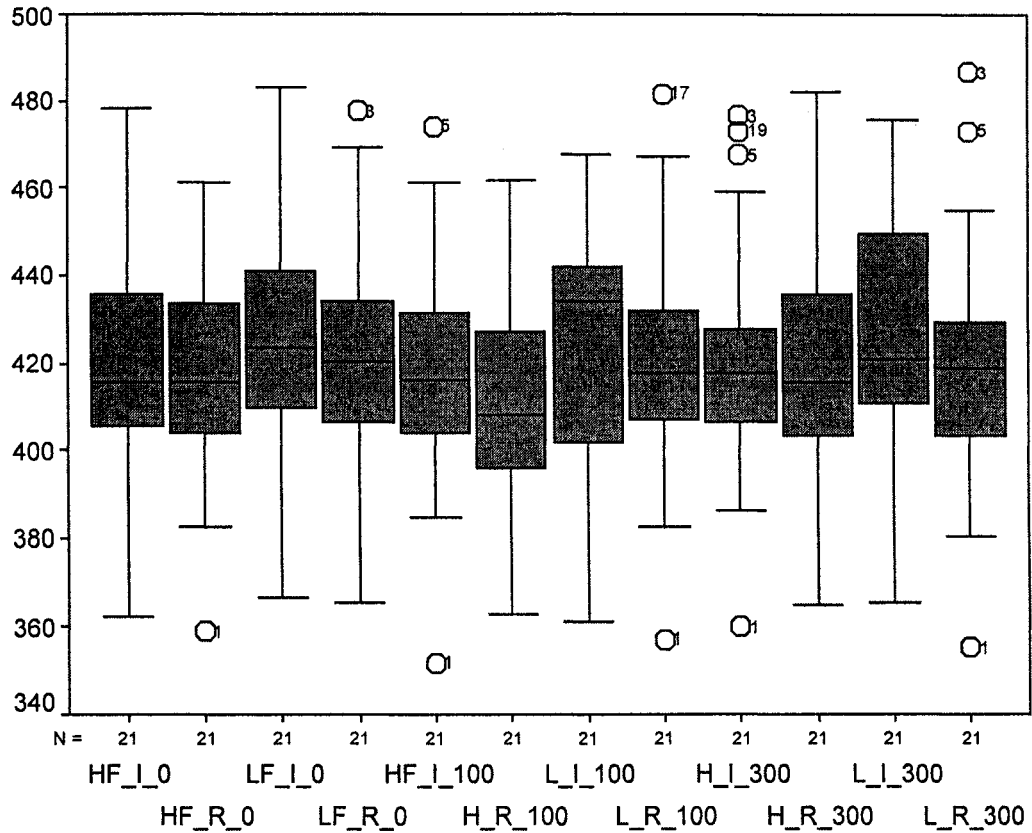


Figure 12.4. Experiment 2: Boxplot of SOLs for each frequency by regularity by SOA condition, averaged across subjects. Dark bars indicate median SOLs. I = irregular, R = regular, 0 = silence condition. Outliers are indicated, with the number of data points that share the value.

SOLs for each frequency by regularity by SOA condition from Experiment 2 averaged by subject. These by subject means were used for the repeated measures ANOVA analysis. Figure 12.5 shows the same data (i.e., by subject means of the SOLs from Experiment 2 for HF, LF, regular and irregular words in silence and at the 100 ms and 300 ms SOA.) in bar chart format. This figure highlights the frequency effects across conditions.

Primary Analyses

SOL analysis

A repeated measures ANOVA was conducted on the SOLs including the variables FREQUENCY, REGULARITY, and SOA as within-subjects variables. Table 12.4 summarizes the ANOVA results. Main effects were obtained for FREQUENCY ($p < 0.001$) and REGULARITY ($p < 0.001$), but not for SOA ($p < 0.50$). A marginally significant interaction was obtained for FREQUENCY x SOA ($p < 0.102$), but not for FREQUENCY x REGULARITY ($p < 0.953$) or REGULARITY x SOA ($p < 0.729$). The three-way FREQUENCY x REGULARITY x SOA interaction was significant ($p < 0.02$).

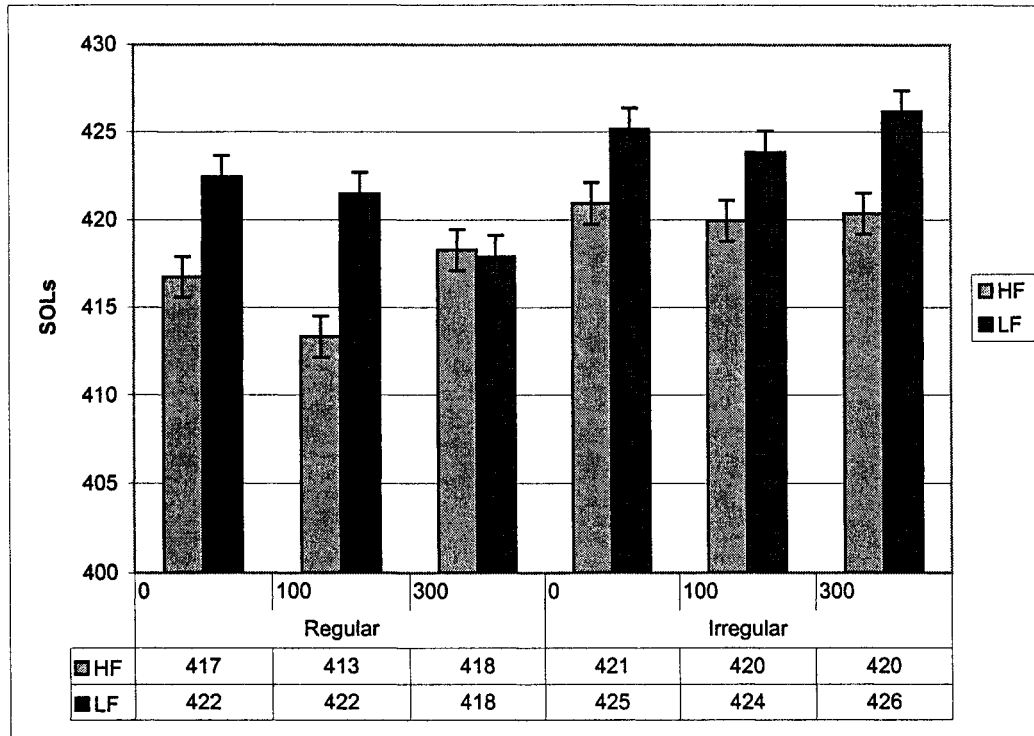


Figure 12.5. Experiment 2: Mean SOLs based on subject means for regular and irregular HF and LF words in silence and at the 100 ms and 300 ms SOAs. Error bars indicate standard error.

Table 12.4. Experiment 2: Repeated Measures ANOVA conducted on the SOLs, including the variables frequency, regularity, and SOA and within-subjects variables.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
FREQ	1316.420	1	1316.420	36.921	.000
REG	1204.258	1	1204.258	24.018	.000
SOA	119.842	2	59.921	.710	.498
FREQ * REG	.264	1	.264	.004	.952
FREQ * SOA	121.030	2	60.515	2.433	.101
REG * SOA	31.192	2	15.596	.321	.728
FREQ * REG * SOA	309.516	2	154.758	4.438	.018

The significant three way FREQUENCY x REGULARITY x SOA interaction was further investigated to determine SOAs of significant phonologic interference effects. Eight t-tests with Bonferroni adjustments for multiple comparisons were conducted to compare silence and interference SOLs for LF and HF regular and irregular words at the 100 ms and 300 ms SOAs. A Bonferroni adjustment for four multiple comparisons necessitates that the p value be less than 0.006 to reach significance. Results, summarized on Table 12.5, indicated that the only significant phonologic effect obtained was for LF regular words at the 300 ms SOA ($p=0.003$). The effect was one of facilitation rather than interference. Low frequency regular words were produced on average 5 ms faster in the 300 ms SOA condition than in the silence condition.

The significant three way FREQUENCY x REGULARITY x SOA interaction was further investigated with reference to Predictions 1 and 2.

Prediction 1 Analysis

Prediction 1 stated that the regularity effect for HF words should be greater in conditions of interference than in silence. Figure 12.6 displays the mean SOLs

Table 12.5. Experiment 2: P-values for t-tests with Bonferroni adjustment comparing mean SOLs for interference condition with mean SOLs for the silence condition for each frequency x regularity x SOA condition.

Frequency	Regularity	SOA	p- value
HF	Regular	100 ms	0.069
		300 ms	0.343
	Irregular	100 ms	0.653
		300 ms	0.758
LF	Regular	100 ms	0.709
		300 ms	0.003
	Irregular	100 ms	0.519
		300 ms	0.656

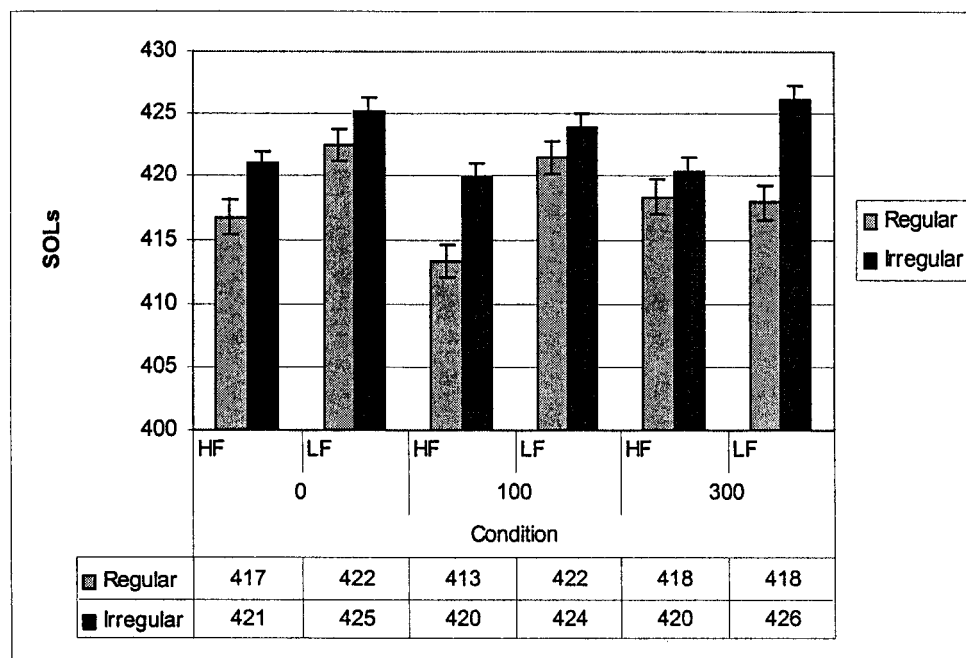


Figure 12.6. Experiment 2: Mean SOLs for each regularity by frequency condition for silence and the 100 ms and 300 ms SOA. Error bars indicate standard error.

for each regularity x frequency x SOA condition. To investigate this prediction, *regularity effect values* were calculated for both HF and LF words in the silence, 100 ms SOA and 300 ms SOA conditions by subtracting the mean SOLs for regular words from the mean SOLs for irregular word by subject. A repeated measures ANOVA was conducted on the regularity effect values for HF and LF words to determine if there were any significant differences in the size of the regularity effect across SOAs. Table 12.6 displays the size of the regularity effect for HF and LF words across SOA and results of t-tests comparing regularity effect values for HF versus LF words at silence and at each SOA. Regularity effect values across SOAs were not significantly different for HF and LF words in silence ($p=0.843$) or at the 100 ms and 300 ms SOAs ($p=0.547$, $p=0.656$, respectively).

Table 12.7 summarizes t-tests comparing the regularity effect values for LF words and HF words in silence with the values for at each SOA. Results for both LF and HF words indicate no significant differences between the regularity effect values in silence versus values at the 100 ms SOA ($p=0.977$, LF; $p=0.338$, HF) or at the 300 ms SOA ($p=0.628$, LF; $p=0.858$, HF).

Table 12.6. Experiment 2: Mean regularity effect values in millisecond for each SOA by frequency condition (top). P values for t-tests with Bonferroni adjustment comparing HF and LF regularity effect values in silence and at each SOA (bottom).

	Mean	Std Deviation
HF Silence	5.912	5.283
LF Silence	6.266	6.556
HF 100 SOA	8.118	8.892
LF 100 SOA	6.337	9.213
HF 300 SOA	6.371	8.664
LF 300 SOA	7.782	12.802

Paired t-test for LF vs.	p-value
Silenc	.843
100 ms	.547
300 ms	.656

Table 12.7. Experiment 2: P-values for t-tests with Bonferroni adjustment comparing regularity effect values in silence and each SOA for LF words (top) and HF words (bottom).

Paired t tests for LF words	p- value
Silence vs. 100 ms SOA	.977
Silence vs. 300 ms SOA	.628

Paired t tests for HF words	p- value
Silence vs. 100 ms SOA	.338
Silence vs. 300 ms SOA	.858

Prediction 2 Analysis

Prediction 2 stated that for irregular words, greater interference effects should be observed for HF words than for LF words. To investigate this prediction, as in Experiment 1, *interference values* were calculated by subtracting the mean SOL for the silence baseline condition from the mean SOL in an interference condition. Interference values were calculated based on subject means. Figure 12.7 shows interference values for both Experiments 1 and 2 for HF and LF words for shared SOAs. Figure 12.8 shows interference values for HF and LF words at each SOA. Two t-tests conducted on these interference values determined that there were no significant differences in the interference values of HF and LF words at either the 100 ms SOA ($p=0.298$) or the 300 ms SOA ($p=0.185$).

Figure 12.9 shows interference values for each frequency x regularity condition for the 100 ms and 300 ms SOAs for Experiment 2. Four t-tests with a Bonferroni adjustment for multiple comparisons were conducted on these interference values. A Bonferroni adjustment for four multiple comparisons necessitates that the p value be less than 0.0125 to reach significance. T-tests determined that in the 100 ms SOA condition, there was no significant difference between the values of HF and LF regular words ($p<0.320$) or HF and

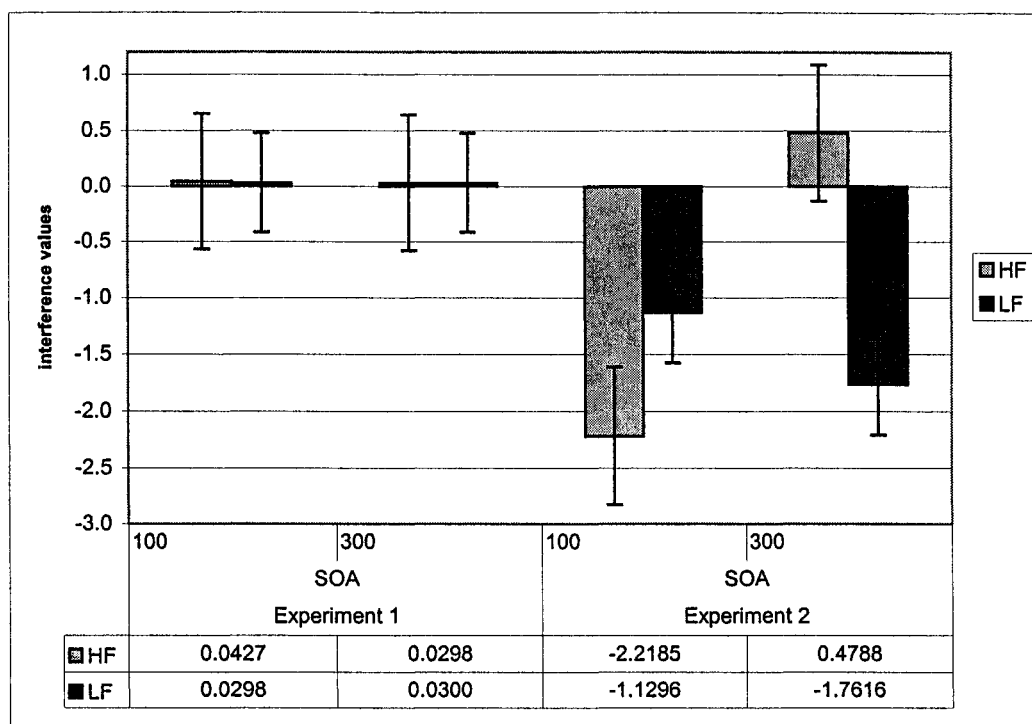


Figure 12.7. Experiments 1 and 2: Mean interference values for picture naming (Experiment 1) and reading (Experiment 2) for HF and LF words at the 100 and 300 ms SOAs. Error bars indicate standard error of the mean.

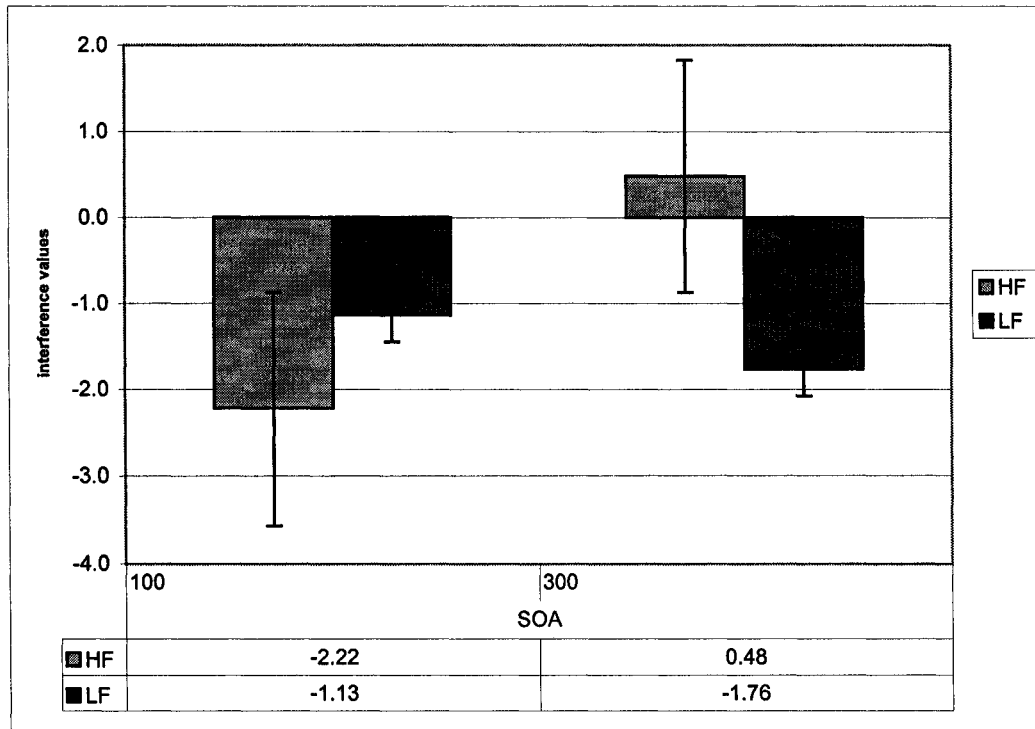


Figure 12.8. Experiment 2: Mean interference values for LF and HF words at each SOA averaged across regularity. Interference values are calculated by subtracting the mean SOLs of the silence condition from the mean SOLs for 100 ms and 300 ms SOA conditions for each subject. T-tests indicated that there were no significant differences in the interference values of HF and LF at either the 100 ms ($p=0.298$) or the 300 ms ($p=0.185$) SOA. Error bars indicate standard error of the mean.

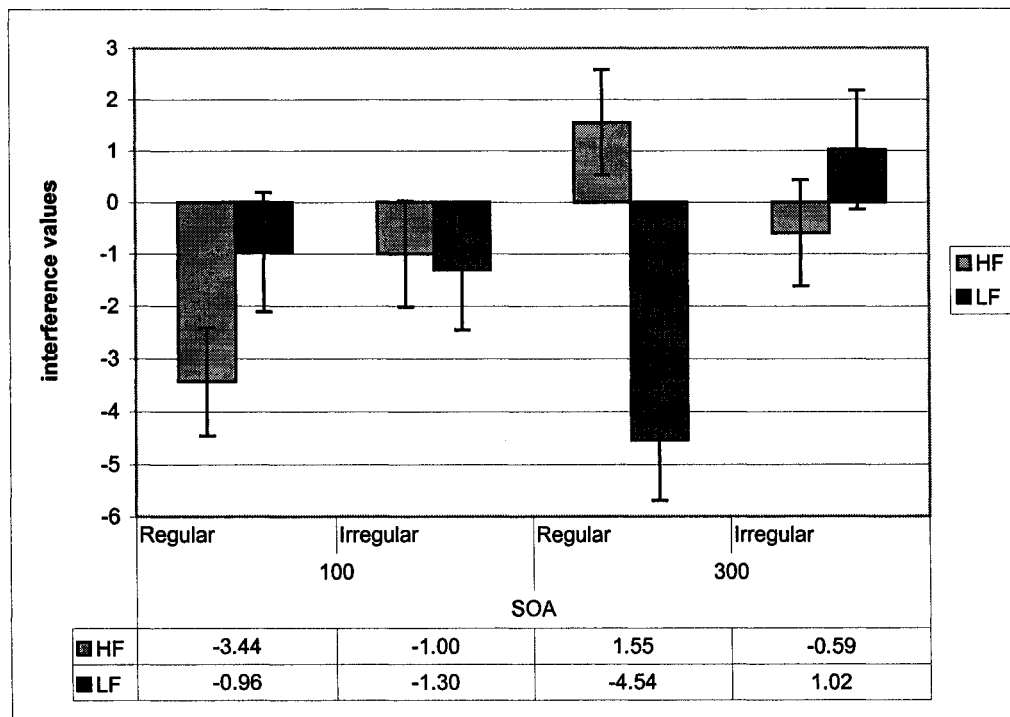


Figure 12.9. Experiment 2: Mean interference values LF and HF regular and irregular words at each SOA. T-tests indicated that interference values for HF and LF words differed significantly only for regular words at the 300 ms SOA. ($p < 0.005$). T-tests conducted on SOLs indicated that the only source of significant phonologic effect was for the LF regular words at the 300 ms SOA, which were produced, on average, 4 ms faster in the 300 ms SOA than in silence. Additional t-tests indicated that only the difference between the mean interference values for HF regular words at the 100 ms and 300 ms SOA approached significance ($p = 0.05$). Error bars indicate standard error of the mean.

LF irregular words ($p < 0.872$). In the 300 ms SOA, there was no difference between interference values of HF and LF irregular words ($p < 0.522$), however there was a significant difference between interference values for HF and LF regular words ($p = 0.005$). Earlier t-tests of SOLs indicated that the only source of significant phonologic effect was also LF regular words, which were produced, on average, 5 ms faster in the 300 ms SOA condition than in silence. Four additional t-tests with Bonferroni adjustments necessitating a p-value of 0.0125 for significant indicated that the difference between interference values for HF regular words at the 100 ms SOA and the 300 ms SOA approached significance ($p = 0.05$), whereas interference values at the 100 ms SOA and 300 ms SOAs did not significantly differ for HF irregular words ($p = 0.849$), LF regular words ($p = 0.324$) or LF irregular words ($p = 0.182$).

Potential Contributions of Nuisance Effects

An additional analysis was conducted in light of the potential contributions of nuisance effects. Although initial phoneme had been controlled across all four target word groups during stimulus set preparation, with the removal of erroneous responses and outliers, the balance was not maintained. Figure 12.10 shows mean SOLs for each initial phoneme set. In addition, another potential source of variability is maturation or repetition effects. Each of the 40 target

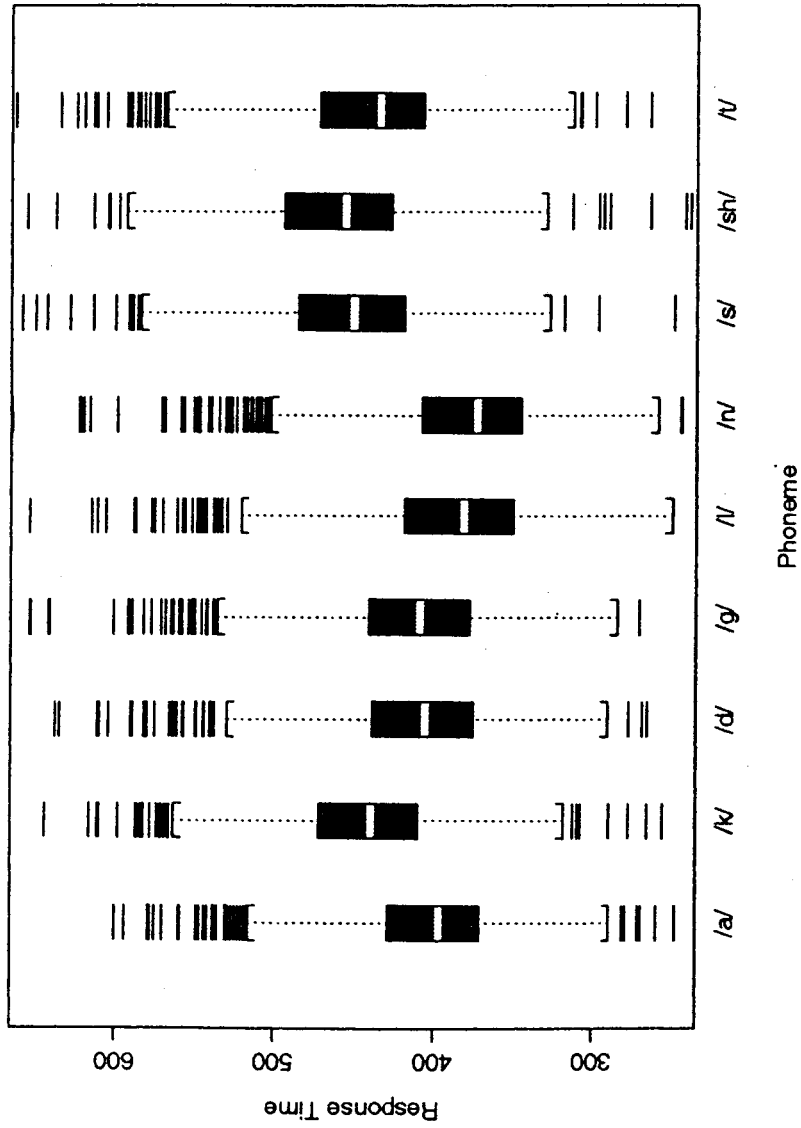


Figure 12.10. Experiment 2. Mean SOLs for each initial phoneme set.

words was repeated 10 times in silence and 5 times at each of the two SOA conditions (i.e., 20 times in total). Participants were given three short breaks during the course of the experiment, thus creating four experimental blocks, or runs. However, as the experiment was not originally designed to investigate effects of repetition, the number of trials for each target type in each SOA condition was not evenly distributed across run, rendering a straightforward analysis of variance uninterpretable. Tables 12.8 and 12.9 show this distribution.

A regression analysis was chosen for its ability to correct for potential nuisance factors due to the uneven distribution of conditions across runs and missing data points. For categorical variables (i.e., variables with a fixed number of distinct levels), the calculations of ANOVA and regression are the same. The test used for significance is called a “likelihood ratio,” and is identical to the ANOVA F-test. The regression framework is appropriate in this case, however, because of its flexibility as compared to the ANOVA. A regression analysis is more conducive to the inclusion of a number of nuisance variables as covariates. The nuisance variables SUBJECT, INITIAL PHONEME and RUN were included as covariates in the regression analysis.

Table 12.8. Experiment 2. Number of trials for each HF target word at each SOA across run for each subject.

HF	irregular	target	Run 1			Run 2			Run 3			Run 4			Grand Total
			SOA			SOA			SOA			SOA			
			0	100	300	0	100	300	0	100	300	0	100	300	
		doubt	3	1	1	1	1	1	2	1	3	4	2	1	20
		eight	2	2	1	1	2	3	1	2	4	4	1	1	20
		guy	2	1	1	3	2	3	1	2	2	2	3		20
		key	4	2	1	1	1	1	1	2	4	4	1	2	20
		knock	3		1	1	1	2	3	2	4	4	1	2	20
		laugh				4	3	5	2	1	1	1		1	20
		shoe	2	1	1	3	3	3	2	1	2	2	2	3	20
		suit	2	2	2	2	1	3	2	1	3	2	2	1	20
		talk	3		1	4	1	2	3	1	1	1	1	1	20
		write	1	1	1	4	2	4	2	1	1	1			20
Total			22	10	8	24	11	28	16	16	26	13	12	200	
	regular	cost	1	2	1	2	3	4	2	2	3			1	20
		drop	4	1	1	4	1	1	2	2	1	2	2		20
		eat	2	2	2	2		3	1	1	3	3	2	2	20
		game	3	1	1	3	2	2	1	2	2	1	1	1	20
		leg	3	1	2	3	1	2	1	1	2	2	2		20
		net	2	1	2	5	1	3	1	1	1	2	2	2	20
		range	2	3	1	2	1	3	1	1	3	1	1	1	20
		shift	3	1	2	2	1	2	2	1	3	1	2	2	20
		song	1	1	1	3	3	4	2	1	2	2	2	3	20
		tend	2		1	3	3	3	2	2	2	2			20
Total			23	12	14	29	13	27	11	13	21	14	12	200	
HF Total			45	22	22	53	24	55	27	29	47	27	24	400	

Table 12.9. Experiment 2. Number of trials for LF target word at each SOA across run for each subject.

LF	irregular	target	Run 1			Run 2			Run 3			Run 4			Grand Total
			0	100	300	0	100	300	0	100	300	0	100	300	
		axe	4		3	2	3	1	2	3	3	2	2	20	
		cough	3			4	1		2	2	3	1	2	20	
		dough	2	2	1	1	1	1	3	1	1	4	1	20	
		ghost	3	2	1	3	1		2	1	1	2	1	20	
		knight	2		3	2		1	3	2	3	3	1	20	
		limb	2	2		2	1	2	3	1	3	1	1	20	
		sheaf	4	1	2	1	2		1	1	4	1	2	20	
		sigh	3		2	2	2	2	2	2	3	1	1	20	
		tomb	2	2	2	3	2	1	3		2	1	1	20	
		writhe	3		1	2	1	2	3	2	2	2	2	20	
Total			28	9	15	22	14	9	23	14	12	27	13	14	200
	regular	crib	4	2	1	3	1		1	2	2	2	2	20	
		dime	2	2	1	3	1	2	3	1	1	2	1	20	
		elm	4		1	4	1	1	1	2	1	1	2	20	
		gag	4	1	1	3	1	1	1	1	2	2	1	20	
		lane	3	1	3	2	2	1	2	1	3	1	1	20	
		nest	3	1		4	1	1	2	2	1	2	2	20	
		reek	4	1	2	2	1	1	1	1	3	2	1	20	
		sag	3	2	2	4	1		2	1	1	1	3	20	
		shine	3	1	1	4	2	1	2	1	2	1	1	20	
		tilt	2	3	1	3	1	2	3	1	1	2	1	20	
Total			32	14	13	32	11	10	18	10	12	18	15	15	200
LF Total			60	23	28	54	25	19	41	24	24	45	28	29	400

Regression Analysis Results

The regression analysis indicated significant main effects for both frequency ($p < 0.001$) and regularity ($p < 0.001$). All interactions failed to reach significance. These results are summarized on Table 12.10.

Table 12.10. Experiment 2: Regression analysis with the inclusion of SUBJECT, INITIAL PHONEME and RUN as covariates.

Effect	DF	Line Item	Significance (p-value)		
				Effect Size (ms)	95% CI (ms)
Frequency	1		6.2E-05		
Regularity	1		<1E-10	3.2	(0.4,6.1)
Regularity: Frequency interaction	1		0.86	5.2	(2.4,8.1)
SOA	2	100 vs. 0	0.99	-0.5	(-4.5,3.6)
SOA: Frequency Interaction	2	300 vs. 0	0.17	-1.8	(-5.3,1.7)
		100: frequency		0.6	(-2.9,4.1)
SOA: Regularity Interaction	2	300: frequency	0.73	2.7	(-2.3,7.7)
		100: regularity		-2.4	(-7.4,2.5)
3-way Interaction	2	300: regularity	0.81	1.7	(-3.2,6.7)
		100:regularity: frequency		1.0	(-3.9,6.0)
Residual Standard Error	42.7 ms	300:regularity: frequency		-1.8	(-8.9,5.2)
				0.7	(-6.3,7.7)
Residual DF			13668		

CHAPTER 13: EXPERIMENT II. DISCUSSION

Frequency and Regularity Main Effects

In both the repeated measures ANOVA and regression results, the effects of word frequency were significant. These results are in agreement with a number of other studies that have found significant effects of word frequency in the word reading (pronunciation) task (e.g., Balota & Chumbley, 1984; Grainger et al., 2000; Hino & Lupker, 1996; Huttenlocher & Kubicek, 1983; Lupker et al., 1997; Ostergaard, 1998; Schilling et al., 1998). Similarly, the effects of spelling regularity were significant in both analyses. These results are in agreement with a number of other studies that have found significant regularity effects in word reading (e.g., Baron & Strawson, 1976; Berndt et al., 1987; Stanovich & Bauer, 1978).

The Frequency x Regularity x SOA Interaction

Results of the repeated measures ANOVA indicated that the three-way interaction was significant. This interaction was analyzed further with regard to the specific predicted results. Results of the regression analysis indicated that the

three-way interaction was not significant when the analysis was adjusted for nuisance effects.⁹

Prediction 1 Summary

Prediction 1 for Experiment 2 stated that the regularity effect for HF words should be greater in conditions of interference than in silence. To investigate this prediction, in the primary analysis, *regularity effect values* were calculated for both HF and LF words in the silence, 100 ms SOA and 300 ms SOA conditions by subtracting the mean SOLs for regular words from the mean SOLs for irregular word by subject, by run. While the mean regularity effect values were larger for HF words in the 100 ms SOA (8.1 ms) and in the 300 ms SOA (6.4 ms) interference SOA as compared to the silence condition (5.9 ms), the analysis of regularity effect values indicated that none of these differences were significant. This result is consistent with the lack of a significant regularity x SOA interaction in both the repeated measures ANOVA ($p < 0.342$) and the regression analysis ($p < 0.74$). This finding is inconsistent with the predicted results.

⁹ This discrepant result will be discussed in the section “Null Results and the Interference-Induced Assembly Hypothesis.”

Prediction 2 Summary

Prediction 2 stated that for irregular words, greater interference effects should be observed for HF words than for LF words. To investigate this prediction, *interference values* were calculated for HF and LF words by subtracting the mean SOLs for the silence condition from the mean SOLs for the 100 ms and 300 ms SOAs for each subject. Results indicated that at the 100 ms SOA, magnitude of interference was not sensitive to either word frequency or regularity. Furthermore, analyses of SOL indicated that there were no significant interference effects at any SOA. However, at the 300 ms SOA, significant facilitation was observed for LF regular words only. These findings are also inconsistent with the predicted results.

Implications of Experiment 2 Findings

Prediction 1 Results

Null results were obtained for both predictions. Although the trend in the regularity effect values indicated that the size of the regularity effect for HF words was larger in conditions of interference than in the silence condition, these differences were not statistically significant. This prediction was based on the frequency x regularity interaction obtained in a number of studies (e.g.,

Brown et al., 1994; Hino & Lupker, 1996; Monsell, 1991; Paap & Noel, 1991) that has been modeled within the dual route model for reading. This interaction is based on the assumption that retrieval of HF forms from the orthographic representation from the orthographic lexicon is not sensitive to regularity, or that, even if it does take longer to retrieve the representations of irregularly spelled words, processing along the lexical-semantic route proceeds more quickly than processing via the GPC route. Thus a smaller or absent regularity effect is predicted for HF words than for LF words since even if the retrieval of the representation of words is sensitive to regularity, the correct output generated by the lexical-semantic route will be produced before the GPC route can output an erroneous pronunciation. In the present experiment, however, regularity effects were equally large for both HF and LF words.¹⁰ Furthermore, a similar trend was observed for LF words as was predicted for HF words, the size of the regularity effect for LF words increased from 6.2 ms in silence to 6.3 ms at the 100 ms SOA and 7.8 ms at the 300 ms SOA, although none of these differences were significant.

¹⁰ Similar findings indicating significant regularity effects for HF words have been obtained when stimuli are controlled for spelling consistency. This issue will be addressed in more detail in the section, "Additional Implications, the Frequency x Regularity Interaction."

Lack of Support for the Dual Route and Interference-Induced Assembly Hypotheses

These findings are not consistent with either the dual route hypothesis for pre-motor encoding or the interference-induced assembly hypothesis. In the absence of any interaction with magnitude of the regularity effect with word frequency, there is no support for the notion that processing for HF and LF words differs.

This is the central tenet of the dual route pre-motor encoding model.

Furthermore, although for HF words, in accord with Prediction 1, the trend in the size of the regularity effect suggested that it was larger in both the 100 ms and 300 ms SOA that in silence, these differences were far from significant.

Thus the results predicted by the interference-induced assembly hypothesis were not obtained.

Prediction 2 Results

Prediction 2 and Support for the Dual Route Hypothesis

Null results were also obtained for the prediction that the greatest phonologic interference effects would be obtained for HF irregular words. This prediction was made based on the assumption that phonologic interference effects would be induced in the reading task. However, unexpected facilitative effects were

obtained. This unexpected finding does, however, have relevance to the dual route pre-motor encoding model. There are three points of support for the dual route model.

First, the significant FREQUENCY X REGULARITY X SOA interaction, the source of which was traced to significant facilitative effects induced only in LF regular words, supports the notion that the processing of LF and HF frequency words and regularly and irregularly spelled words differ in some way. This significant interaction supports the dual route pre-motor encoding hypothesis. If processing proceeded in the same manner for HF and LF words and for regularly and irregularly spelled words, it would be expected that the phonologic interfering stimulus would affect all stimulus groups in the same way. This was clearly not the case, as at the 300 ms SOA, LF regular words were the singular case of significant phonologic effects.

Second, the trend in SOLs shows that at the 100 ms SOA, HF regular words also tended to be facilitated by the phonologic auditory stimulus. The asynchronicity of these trends for HF and LF words – that facilitative effects are observed for HF regular words at the 100 ms SOA while facilitative effects for LF words are not observed until the 300 ms SOA – further underscores the notion that LF and HF words are processed differently, even when regularity is held constant. In

particular, this pattern lends further support to the notion that the time course of processing for HF and LF words differ; specifically that the time course of LF words lags that of HF words.

Third, when SOLs are averaged across regularity, the trend in the data suggests a frequency x SOA interaction; while interference values for both HF and LF words at the 100 ms SOA tended toward facilitation, at the 300 ms SOA, the interference values for HF words tended toward interference. Thus the significant three-way interaction, and specific trends in the patterns of facilitation for LF and HF words support the notion of dual routes of pre-motor encoding for HF versus LF words.

Prediction 2 and Support for the Interference-Induced Assembly Hypothesis

The interference-induced assembly hypothesis predicted that greater interference effects would be observed for HF words than for LF words. Although no significant interference effects were obtained for words of either frequency, the aforementioned trend toward the frequency x SOA interaction suggests that, at the 300 ms SOA, HF words were more susceptible to interference than were LF words. The mean interference value for LF frequency words at the 300 ms SOA was -1.76 ms while the mean value for HF words was 0.48 . This is the first

point of support for the interference-induced assembly hypothesis. A second point of support is found in the present data when an adjustment is made in the relative speed of processing assumption.

The relative speed of processing assumption and support for the interference – induced assembly hypothesis

Prediction 2 for the present experiment specifically predicted that, based on the interference-induced assembly hypothesis, the greatest phonologic interference effects would be observed for HF irregular words. However, no significant interference or facilitative effects were obtained for irregular words of either frequency. Thus the auditory stimulus was shown to have no significant effect on irregularly spelled words despite the robust main effect of regularity.

Although contrary to Prediction 2 for Experiment 2, this finding supports the notion that spelling regularity affects a level of processing that is distinct from the level at which phonologically related auditory stimuli affect processing; spelling regularity is modeled as being relevant at the early stage of the retrieval of an orthographic representation while the auditory stimulus is modeled as affecting the later stages of pre-motor encoding.

The time course of pre-motor encoding for regular vs. irregular words

The regularity effect expected from Prediction 2 was based on the relative speed of processing assumption; greater interference effects were predicted for HF *irregular* words rather than HF *regular* words because, within the dual route model for reading, regularity effects are accounted for by the notion that irregular words require additional time to resolve the conflicting outputs of the lexical-semantic and GPC routes. This account, and the prediction for Experiment 2, hinges on the assumption that the conflicting outputs of the lexical-semantic and GPC routes become available at the same time, and thus processing time along both routes is assumed to be equal. Under conditions of interference, however, it may be the case that processing along the inherently slower GPC route is slowed to such an extent that its output is produced much later than the output of the lexical-semantic route whether the word be regular or irregular. Given that the GPC route is analogous to controlled processing, it would be likely that it would be extremely prone to interference effects (Carroll, 1999; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). If it were the case that the GPC is slowed to such an extent, then any regularity effects observed in conditions of interference would be due solely to the processing involved in the retrieval of the orthographic representation. As the onset of pre-motor encoding depends on the retrieval of the orthographic representation, the time course of pre-motor encoding for regular or irregular words would differ; pre-motor

encoding would begin for regular words before pre-motor encoding for irregular words. Thus, differences in the time course of pre-motor encoding for regular versus irregular words may account for the lack of the predicted effects for irregular words.

There is support for this modified account of the relative speed of processing assumption in the present data. Shifts from phonologic facilitation to phonologic interference effects within cross-modal interference paradigms are interpreted as evidence for the onset of pre-motor encoding (Rogers, Belleville et al., 1999; Rogers & Storkel, 1998; Schriefers et al., 1990). The trend in the SOL data shows that although HF regular words tended to be facilitated at the 100 ms SOA (interference value of -3.44 ms), but at the later 300 ms SOA, the trend shifts in the direction of interference (interference value of 1.55 ms). T-tests determined that this shift in mean interference value for HF regular words from facilitation at the 100 ms SOA toward interference at the 300 ms SOA was significant ($p=0.05$). In contrast, HF irregular words do not show a similar trend. Although HF irregular words shift from an interference value of -1.30 ms at the 100 ms SOA to a value of -0.59 ms at the 300 ms SOA, the amount of change between the SOAs is far from significant ($p=0.849$). Thus, while, for HF regular words, the presentation of the auditory stimulus at the 100 ms and 300 ms SOAs tended to induce phonologic facilitation and followed by phonologic

interference, these SOAs fail to produce a similar pattern for HF irregular words, or for LF regular or irregular words. These trends support the notion that there is a difference in the time course of processing for regular and irregular words.¹¹ Furthermore, with an adjustment in Prediction 2 based on the modified relative speed of processing assumption, the trend toward interference for HF regular words provides preliminary support for the interference-induced assembly.

Prediction 2 and the time course of pre-motor encoding for LF vs. HF words

The findings that suggest that regular and irregular words have a different time course of pre-motor encoding have an additional implication. Although LF regular words show no effect of the auditory stimulus at the 100 ms SOA, significant facilitative effects are obtained at the 300 ms SOA. Facilitative effects for HF regular words were observed at the earlier 100 ms SOA. That facilitative effects for LF regular words are observed at a later SOA suggests that there is an asynchronous time course of lexicalization for high frequency and low frequency words as well, a finding that has found some support in the literature (e.g., Levelt et al., 1998; Rogers, Belleville et al., 1999). It would be predicted, then, that in a pattern analogous to that of HF regular words, interference effects for LF regular words would be observed at a later SOA.

¹¹ This suggestion of time course differences will be addressed again in the section, “Additional Implications.”

Additional Implications of Experiment 2 Findings

The frequency x regularity interaction

The dual route model for the processing of written words predicts an interaction between spelling regularity and word frequency. When words are named in the absence of interference, the regularity effect is typically smaller or absent for HF words than for LF words. No such interaction was found in the silence or interference conditions of the present experiment in either the repeated measures ANOVA or the regression analysis. Although this interaction has been found to be significant in a number of studies (e.g., Brown et al., 1994; Hino & Lupker, 1996; Monsell, 1991; Paap & Noel, 1991), it has been challenged recently by findings obtained by Jared (1997, 2002).

Jared (1997; 2002) proposes that the finding that irregular words are responded to more slowly than regular words cannot be fully accounted for by appealing to the tacit knowledge of spelling-to-sound correspondence rules which suggest that the protracted processing of irregular words is directly related to the degree to which the pronunciation of such words conforms to those rules. Rather, Jared focuses on spelling *consistency*, the degree to which the pronunciation of a

given word with a given spelling pattern is shared by other words with the same spelling pattern. Consistent words are defined as words with letter patterns that are always pronounced the same way whenever they appear in a word (e.g., -ust in *dust*). Inconsistent words are defined as words with letter patterns that are pronounced differently in different words (e.g., -ost in *cost* and *host*). Thus the regularity effect is recast as a *consistency effect*, which lies along a continuum; the less typical the pronunciation in the inconsistent word, the greater the difficulty with which it will be produced.

Jared (2002) noted that when the stimuli used in a number of studies that found little or no effect of regularity in HF words were re-categorized, taking into account the degree of consistency, consistency effects that were likely to be statistically significant were obtained for HF words. Results from a series of experiments conducted by Jared (1997; 2002) suggest that when spelling consistency is manipulated a reliable effect can be induced in HF words.

In Experiment 1, for example, Jared (1997) investigated the consistency effect by analyzing response times to both HF and LF consistent and inconsistent words. Spelling-sound consistency was determined on the basis of word bodies, the medial vowel(s) and final consonant(s) of a word (e.g., -eak for *steak*). Consistent and inconsistent words were matched for neighborhood density

characteristics. Results indicated significant main effects for both word frequency and consistency. There was no frequency x consistency interaction; the consistency effect was 30 ms for HF and 40 ms for LF words.

The results obtained in Experiment 2 are consistent with Jared's (1997, 2002) findings. This lack of a significant frequency x regularity interaction may be attributed to the method of stimulus selection. Degree of spelling regularity was determined through the calculation of a *regularity index* based on the percentages for each grapheme-phoneme correspondence in a word as reported in the frequency and percentage tabulations reported by Hanna et al. (1966). The concept of spelling consistency is inherent in the percentage tabulations because calculations represent the percentage of the time a given grapheme or grapheme group (such as *ght* in the word *night*) represents a given phoneme. Higher percentages correspond to a greater degree of consistency in that when a grapheme corresponds to a particular phoneme a large percentage of the time, the number of words containing that exact grapheme-phoneme correspondence is large and the number of words containing that grapheme when it corresponds to a different phoneme is small. Words with a high regularity index are words in which the specific grapheme-phoneme correspondences across the onset, nucleus and coda occur with the greatest consistency. Words with a low regularity index, then, are words in which the specific grapheme-phoneme

correspondences do not occur consistently. Thus the significant regularity effect obtained in Experiment 2 may be attributed to effects of spelling consistency as reflected by the regularity indexes of the target stimuli.¹²

Picture Naming versus Reading

A comparison of mean SOLs for the naming task in Experiment 1 and the word reading task in Experiment 2 indicates that mean SOLs for the reading task were faster than mean SOLs for picture naming. This finding can be accounted for by the task analysis presented by Indefrey and Levelt (2001).¹³ Based on data obtained from a number of investigations, lead-in and core processes for both picture naming and reading are presented, and those tasks believed to be involved in each are indicated. For picture naming and reading tasks, lead-in processes involve visual object recognition and visual word recognition, respectively. Both tasks are modeled as involving the core processes associated with phonologic code retrieval, phonologic encoding, phonetic encoding and articulation. In the picture naming task, however, both conceptual preparation and lexical selection are listed as obligatory. The data are unclear as to whether these processes are necessary in the reading task, and, if they are relevant, to

¹² See Chapter 11 for a more in-depth discussion of stimulus selection methods and see Appendices B-E for regularity indexes for each target word.

¹³ See Table 7.1 in Chapter 7.

what extent processing at these levels are analogous in both tasks. Thus, differences in response times in these two tasks may be attributed to differences in the time course of stages that depend on specific stimulus characteristics¹⁴, or on differences in the number of core processes involved.

Given these potentially fundamental differences in processing across tasks, however, greater phonologic effects, both facilitative and interference were obtained in the reading task using orthographic stimuli than in the picture-naming task. These findings are contrary to those of Smith and Magee (1980), who found that greater interference effects were obtained in picture naming tasks than word pronunciation. An explanation for this finding is not obvious. As auditory interfering stimuli with shared rimes were used in both tasks, this finding cannot be attributed to difference in the type of prime. This finding may be attributable to the relative strength of activation of the stimulus word in the auditory versus the visual modality, or related to the differing time courses of processing in picture naming versus reading. It may be that the direct orthographic input in the reading tasks produces stronger activation within the lexical network. It may also be that the SOAs at which the auditory interfering stimulus is presented in the reading task influences processing of the phonologic

¹⁴ See "Prediction 2 Results" in the current chapter.

representation at a point in processing that is more susceptible to facilitative or interference effects.

A third alternative is that the auditory stimulus is priming different types of representations in each task. As mentioned in Chapter 5, the model of spoken language production proposed by Levelt and colleagues (e.g., Levelt, 1989; Levelt et al., 1999b; Levelt & Wheeldon, 1994) includes not only a stage of phonologic assembly, but it also differentiates between the generation of abstract phonologic representation, and the generation of a phonetic and motor plan. Thus, it is possible that the auditory stimuli in the present experiment facilitated the generation of one of these latter representations in the reading task while in picture naming, a different representation is being affected.

The Time Course of Pre-Motor Encoding in Reading

Based on the findings of Whatmough, Arguin and Bub (1999), who found that a congruent auditory input introduced 16 ms after the word/nonword pairs in a lexical decision task induced significant interference effects, it was expected that the introduction of phonologically related interfering stimuli would induce interference effects in a reading task. At SOAs of 100 ms and 300 ms, however, in the present experiment, although there was a trend toward interference effects

for HF regular words at the 300 ms SOA, no statistically significant interference effects were obtained. To the contrary, a significant effect of facilitation was found for LF regular words, but only in the 300 ms SOA condition, and no other significant facilitative effects were obtained for any other word types at the 300 ms or the 100 ms SOA. That neither significant facilitative nor interference effects were obtained at the 100 ms SOA suggests that perhaps this earlier SOA did not successfully tap into the time course of phonologic encoding in the reading task. The trend in the data, however, as discussed earlier, suggests that there may have been a tendency toward facilitative effects for HF regular words at this earlier SOA.

Facilitative effects of a phonologically related prime are typically accounted for within a spreading activation framework in the following manner. When a phonologically related auditory stimulus is presented enough in advance of the processes of pre-motor encoding of a primary target, the corresponding nodes of the auditory stimulus within the lexical network are excited, thus facilitating the selection of the nodes shared by the target word during the pre-motor encoding of its word form for production (e.g., (Dell, 1986). Thus the trend toward facilitative effect for HF regular words at the 100 ms SOA, and the significant facilitative effects for LF regular words at the 300 ms SOA in the reading task of Experiment 2, suggests that the onset of pre-motor encoding of HF regular

words precedes the onset of pre-motor encoding for LF words, a notion that is supported by Rogers, et al. (1999) who found a lag between the parameters of interference for LF versus HF words in a picture naming task.

However, the longest mean SOLs for LF words in interference is 423 ms, which occurred at the 100 ms SOA. It seems unlikely, even for LF words, that the onset of pre-motor encoding occurs after 300 ms, since production occurs, on average, within 123 ms of that SOA. Thus it is not likely that, in the case of LF words, the observed facilitative effects of the phonologically related auditory stimuli resulted from activation of lexical nodes by the auditory stimulus *before* the onset of pre-motor encoding. It is more likely that, for LF words, the onset of pre-motor encoding occurs shortly before the auditory stimulus is presented at the 300 ms SOA and that selection of the appropriate nodes within the lexical network, which have already been excited by the stimulus word in the early stages of pre-motor encoding, is facilitated by the additional activation caused by the phonologically related auditory stimulus.

Considering both accounts for the facilitative phonologic effects, however, the onset of pre-motor encoding for LF regular words is likely to be occurring within the 100 to 300 ms time frame. In the case of HF regular words, the longest mean SOL is 420 ms at the 300 ms SOA. Again, it seems unlikely that

the onset of pre-motor encoding occurs after 300 ms, and the lack of significant facilitation at 300 supports this. It can be inferred, then, that for HF regular words the onset of pre-motor encoding occurs before 300 ms, and perhaps even before 100 ms.

The possibility remains, however, that pre-motor encoding could occur as late as 400 ms (Indefrey & Levelt, 2000; Levelt et al., 1998; Samelin, Service, Kiesila, Uutela, & Salonen, 1996). Thus an alternative account is that the auditory stimulus may be priming something other than a phonologic representation. As mentioned in Chapter 5, and in the previous section, although the model of spoken language production proposed by Levelt and colleagues (e.g., Levelt, 1989; Levelt et al., 1999b; Levelt & Wheeldon, 1994) includes a stage of phonologic assembly, it differentiates between the generation of abstract phonologic representation, and the generation of a phonetic and motor plan. Thus, it is possible that the auditory stimuli in the present experiment facilitated the generation of one of these latter representations.

Null Results and the Dual Route Hypothesis

Experimental evidence for dual routes of processing during pre-motor encoding derives primarily from the results of syllable frequency and duration

investigations (e.g., Levelt & Wheeldon, 1994) which have shown that naming latencies and durations for high frequency syllables were consistently faster than latencies and durations for low frequency syllables when phoneme frequency was controlled, and from the robust word frequency effect (e.g., Grainger et al., 2000; Hino & Lupker, 1996; La Heij et al., 1999; Rogers, Belleville et al., 1999). Varley and Whiteside (1998, 2000) use the phenomenon of word and syllable frequency effects as the foundation for their conceptualization of a dual route theory in which whole phonologic/motor programming representations for high frequency monosyllabic words, high frequency multisyllabic words, or even multi-component clauses are retrieved as wholes during pre-motor encoding while representation of such units that are used with low frequency must be assembled afresh for each production. Observational data from the characteristics of the speech of individuals with apraxia of speech (AOS), such as loss of speech automaticity and reduced and variable coarticulation, are also interpreted as providing support for the notion of dual routes; AOS is seen as a disruption of the direct route and a subsequent reliance on the less efficient indirect assembly route for pre-motor encoding and production. Thus this theory, as it stands, is wholly explanatory; frequency effects and the speech disruptions in AOS in production are explained by means of the dual processing routes.

In an investigation designed to test the dual route pre-motor encoding hypothesis, Varley, Whiteside and Luff (1999) predicted that null results for the AOS group would provide support for their hypothesis. Production latencies and utterance durations for high frequency and low frequency words were measured for speakers with AOS and matched brain-damaged and non-brain-damaged controls. The authors predicted that the hypothesized disruption in the direct route of whole word retrieval in speakers with AOS would result in the *absence* of frequency effects in the duration measures of the output of such speakers since all words would have to be produced by means of the indirect, sublexical assembly route. A null result was obtained for the response latencies and durations of the AOS group. The authors interpreted this null effect as support for both the notion of dual routes of encoding, and also as evidence of a direct route deficiency in speakers with apraxia of speech (Varley et al., 1999).

It is difficult, however, to interpret a null result as strong support for any hypothesis. Upon detailed consideration of the data, a number of additional factors may be identified that may potentially explain the null results by other accounts, and consequently that may, as in the case with the present experiment,

suggest the need for more refined investigations.¹⁵ Additionally, there may be factors related to experimental design or analysis methodology that could lead to the confounding of effects.

In the case of the null effects obtained by Varley and Whiteside (1999), for example, when participants repeated the stimulus word after the investigator, each word was preceded by either the article “a” or the article “the.” It is unclear whether the whole word movement gestalts proposed by the authors are assumed to include an article, and whether, if an article is included, a definite or indefinite article would be involved. Thus the use of differing articles may have affected the results. Furthermore, the analysis was based on only ten data points for HF and ten for LF words produced by only four individuals with AOS, and the standard deviation of the reported data (1260 ms) far exceeded the mean (1125 ms) in the high frequency word condition.

The null result with such a small sample and with such high variability obtained by Varley and Whiteside (1999) does not provide a strong empirical base for the dual route hypothesis. Additionally, the empirical foundation of the Varley and Whiteside dual route hypothesis is further undermined by recent experiments conducted by Levelt and Meyer (as reported by Levelt et al., 1999b) in which

¹⁵ See “Future Directions.”

neither syllable nor segment frequency effects were obtained when a large number of possible confounding factors were controlled.¹⁶

Null Results and the Interference-Induced Assembly Hypothesis

The null results obtained for the present experiment are equivocal with regard to both the dual route theory and the interference-induced assembly hypothesis. On one account, the null results of Experiment 2 could be interpreted as unreserved *support* for a dual route theory in which there are fundamental differences in the nature of pre-motor processing for HF and LF words since statistically significant frequency-based differences were observed. However, as was discussed in the preceding section, null results do not form a strong means of support for any theory. Similarly, too, on another account, these null results cannot be used as a solid basis for the unqualified *rejection* of the interference-induced assembly hypothesis. As has been discussed in the preceding sections, there are alternative explanations relating to the time course of pre-motor encoding that could potentially account for reasons why the desired result was *not* obtained.

¹⁶ These factors were not described by the authors.

An additional variable that appears to have contributed to the null results that has not been discussed as of yet is the lack of agreement between the results obtained by means of the repeated measures ANOVA and the regression analysis statistical analyses. Although initial phoneme had been controlled across the four target word groups during stimulus set preparation, with the removal of erroneous responses and outliers, that balance was not maintained. In addition, participants produced each target word 20 times during the course of the experiment, and participants were given three short breaks during the course of the experiment, thus creating four runs. As the experiment was not originally designed to investigate the effects of maturation/repetition, the distribution of target types and SOA condition across each run was uneven. The regression analysis was chosen for its ability to correct for these potential nuisance factors. When these factors were taken into effect, however, only the main effects of word frequency and spelling regularity were statistically significant. The corrections for maturation and/or repetition effects in the regression model were based on the division of the data by run. It is unclear from this analysis, however, whether the null effects in the regression analysis stem from the effects of initial phoneme, effects of repetition on individual target words, or from effects of maturation stemming from the fact that participants were engaged in the same task over a period of time.

CHAPTER 14: FUTURE DIRECTIONS AND CONCLUSIONS

The findings obtained in Experiment 2, despite the statistically null effects, do suggest a number of trends that have strong implications. For example, there are implications with regard to experimental paradigms and design. In comparing the data from Experiments 1 and 2, for example, it is evident that the use of orthographic stimuli in the reading paradigm yielded greater phonologic effects than those obtained by means of picture naming. This suggests that a word reading paradigm presents a fruitful alternative to picture naming when a comparison of magnitude of interference is of primary experimental interest. Furthermore, the regression analysis suggests that effects of repetition and/or maturation may have significant effects on pre-motor encoding.

There are also strong implications for both the dual route and interference-induced assembly hypotheses, as well as for the time course of pre-motor encoding and models for reading. Results suggest, for example, that there are differences in the time course of pre-motor encoding that are based on both word frequency and spelling regularity. These findings provide limited support for dual route models for both pre-motor encoding and reading and also suggest that the variability in the time course of pre-motor encoding could account for

the statistically null result. There is also some support from trends in the interference values for one of the central predictions of the interference-induced assembly hypothesis – that HF words are indeed more susceptible to interference.

Future Directions

A sound theory, however, cannot be built on trends nor on null results. Thus the experiments presented in this document also provide more of a starting point than an end. The results obtained can be used to guide future investigations of both the dual route hypothesis for pre-motor encoding and the interference-induced assembly hypothesis. There is the suggestion in the present data, for example, that the presentation of a phonologically related auditory stimulus at the 300 ms SOA induces interference effects in HF regular words. It is not possible to determine from the present data, however, when interference effects would be obtained for LF regular words. Thus a direct comparison of magnitude of phonologic interference effects for LF and HF words was not possible. Findings obtained in Experiment 2 suggest that there are differences in the time course of pre-motor encoding. Further research is needed to identify SOAs that will tap into the pre-motor encoding of both HF and LF regular and irregular words and to thus better delineate the time course of pre-motor encoding for these different word types.

Another direction for future investigation involves the effect of mixing different stimulus types (i.e., HF and LF, regular and irregular) in the same experimental block. As discussed in Chapter 9, data obtained in investigations manipulating the context in which reading tasks are performed (i.e., the presence or absence of nonwords) suggests that the nature of the words that are presented together in mixed experimental blocks in reading tasks can affect which route of processing exerts the greatest influence. While the frequency-sensitive lexical-semantic route may be a preferred route for processing during reading, for example, when nonwords are present in the experimental block, frequency effects are not observed, a finding that suggests that the presence of nonwords, which can only be successfully produced via the frequency-insensitive GPC route, biases readers to rely more on the GPC route (Baluch & Besner, 1991; Lupker et al., 1997; Monsell, 1991).

These finding suggests that in Experiment 2, the presence of both HF, LF and regular and irregular words in the experiment may have had significant effects on response times. Trials involving regular and irregular words were randomly mixed throughout the experiment. The presence of irregular words may have influenced response times to regular words because when irregular words are randomly included in the experimental block, an expectancy that the GPC route

will produce an erroneous output and hence the need for conflict resolution is created. With the elimination of irregular words in future experiments, this expectancy would also be eliminated. If target stimuli in Experiment 2 had consisted solely of regular words, it is possible that baseline response times in the silence condition would have been faster. Consequently, interference values, which are calculated based on the mean SOLs in silence, may have potentially been much larger, and thus may have reached statistical significance.

Conclusions

At the base of the investigations reported in this document is the intent to understand whether pre-motor encoding proceeds in a singular manner or whether there may be two or more routes by which the processes of phonologic encoding through motor programming might proceed. Throughout this document various sources of evidence have been described that support the singular route (i.e., the obligatory assembly hypothesis) as well as evidence supporting the multiple route model (i.e., the dual routes of pre-motor encoding). The evidence supporting the obligatory assembly hypothesis (Rogers & Storkel, 1998) is derived from obtaining an effect that suggests assembly, the phonologic similarity effect, in a context that should maximize the likelihood of whole word retrieval (i.e., HF words selected from a limited cohort). Within the

current experimental design, cross-modal priming, it is not apparent how support for a singular route could be obtained. For example, the dual route hypothesis would have been supported if HF words had exhibited greater interference effects than LF words because those results could have been interpreted as evidence that the processing route for HF words had been shifted by the presence of interference. However, without positive findings, it is difficult to conclude that the failure to obtain predicted results supports the alternative hypothesis (i.e., that there is only one route, namely, obligatory assembly). Thus there is a methodological dilemma that needs to be made explicit and directly concerns the design of future experiments intended to test questions concerning *one* versus *many* routes. To argue that there is only one route, one must demonstrate in a rather exhaustive manner that there is never evidence of two routes. The results of such experiments necessitate proving the null, an enterprise recognized for its impossibility, as one can never test all possible reasons why a null effect has been obtained. Thus, if future experiments that are designed to obtain evidence of two or more routes of processing obtain such evidence, then one can conclude with confidence that the *one route theory* must be wrong. However, if such evidence is not obtained, one cannot conclude with confidence that only one route exists. This is the dilemma faced in such controversies that pit one of anything against two or more of anything. Thus relative to the present studies, the failure to support the dual route theory of pre-

motor encoding cannot be interpreted to either affirm or disconfirm the obligatory assembly hypothesis. The question remains unresolved.

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Appendix A. Experiment 1 Stimuli

HF Targets >20/million			LF Targets <7/million		
Target	Semantic IS	Phonologic IS	Target	Semantic IS	Phonologic IS
star	sky	bar	stump	tree	lump
tongue	mouth	rung	torch	flame	porch
hand	glove	sand	harp	pluck	tarp
tooth	gum	youth	tongs	ice	songs
moon	space	noon	mop	broom	pop
wheel	round	peel	wig	hair	jig
clock	time	block	clam	shell	slam
ring	gem	string	raft	boat	craft
leg	thigh	beg	leash	dog	quiche
knife	fork	wife	noose	hang	juice
skirt	dress	flirt	skull	head	dull
door	knob	core	dart	aim	cart
rose	bud	hose	mask	face	task
match	strike	patch	scroll	book	stroll

Appendix B. Experiment 2 Stimuli: High Frequency, Regular Words
 IS= interfering stimulus, V=verb, Adj=adjective, N=noun (part of speech determined by Francis & Kucera, 1982)

Regular words = greater than 80% regularity index									
HF words > 150/million									
Target Words					Interfering Stimuli				
word	frequency count	regularity index	# of letters	part of speech	IS	frequency count	part of speech	IS	frequency count
drop	159	93.9	4	V	lop	1	V	lop	1
game	180	83.7	4	N	lame	2	Adj	lame	2
cost	349	91.3	4	N	lost	49	Adj	lost	49
net	80	92.4	3	N	bet	18	V	bet	18
leg	126	85.9	3	N	keg	3	N	keg	3
shift	47	88.1	5	V	sift	3	V	sift	3
song	129	82.9	4	N	wrong	117	Adj	wrong	117
tend	104	94.8	4	V	bend	50	V	bend	50
range	152	78.4	5	N	grange	1	N	grange	1
eat	122	80.7	3	V	heat	91	N	heat	91
Mean	145	87.2	4		Mean	34		Mean	34

Appendix C. Experiment 2 Stimuli: High Frequency, Irregular Words
 IS= interfering stimulus, V=verb, Adj=adjective, N=noun (part of speech determined by Francis & Kucera, 1982)

Irregular words = less than 60% regularity index									
HF words > 150/million									
Target Words					Interfering Stimuli				
word	frequency count	regularity index	# of letters	part of speech	IS	frequency count	part of speech	IS	frequency count
doubt	115	53.4	5	N	route	48	N	route	48
guy	66	48.4	3	N	wry	5	Adj	wry	5
key	71	3.3	3	N	ski	7	N	ski	7
knock	47	37.5	5	V	frock	2	N	frock	2
laugh	98	38.0	5	V	graft	1	N	graft	1
shoe	58	2.1	4	N	brew	2	V	brew	2
suit	64	57.9	4	N	fruit	49	N	fruit	49
talk	275	33.4	4	V	balk	4	V	balk	4
write	561	53.6	5	V	tight	22	Adj	tight	22
eight	104	47.1	5	N	late	132	Adj	late	132
Mean	146	37.4	4		Mean	27		Mean	27

Appendix D. Experiment 2 Stimuli: Low Frequency, Regular Words
 IS= interfering stimulus, V=verb, Adj=adjective, N=noun (part of speech determined by Francis & Kucera, 1982)

Regular words = greater than 80% regularity index							
LF words <30/million							
Target Words				Interfering Stimuli			
word	frequency count	regularity index	# of letters	part of speech	IS	frequency count	
				speech		part of speech	
dime	11	85.1	4	N	lime	13	N
gag	6	87.9	3	N	lag	5	V
crib	8	85.9	4	N	lib	1	N
nest	22	92.4	4	N	best	51	Adj
lane	24	85.2	4	N	cane	13	N
shine	32	81.1	5	V	sign	142	N
sag	11	81.8	3	V	rag	17	N
tilt	17	91.8	4	V	built	81	Adj
reek	3	87.8	4	N	greek	46	V
elm	4	92.5	3	N	helm	3	N
Mean	14	87.1	4		Mean	37	

Appendix E. Experiment 2 Stimuli: Low Frequency, Irregular Words
 IS= interfering stimulus, V=verb, Adj=adjective, N=noun (part of speech determined by Francis & Kucera, 1982)

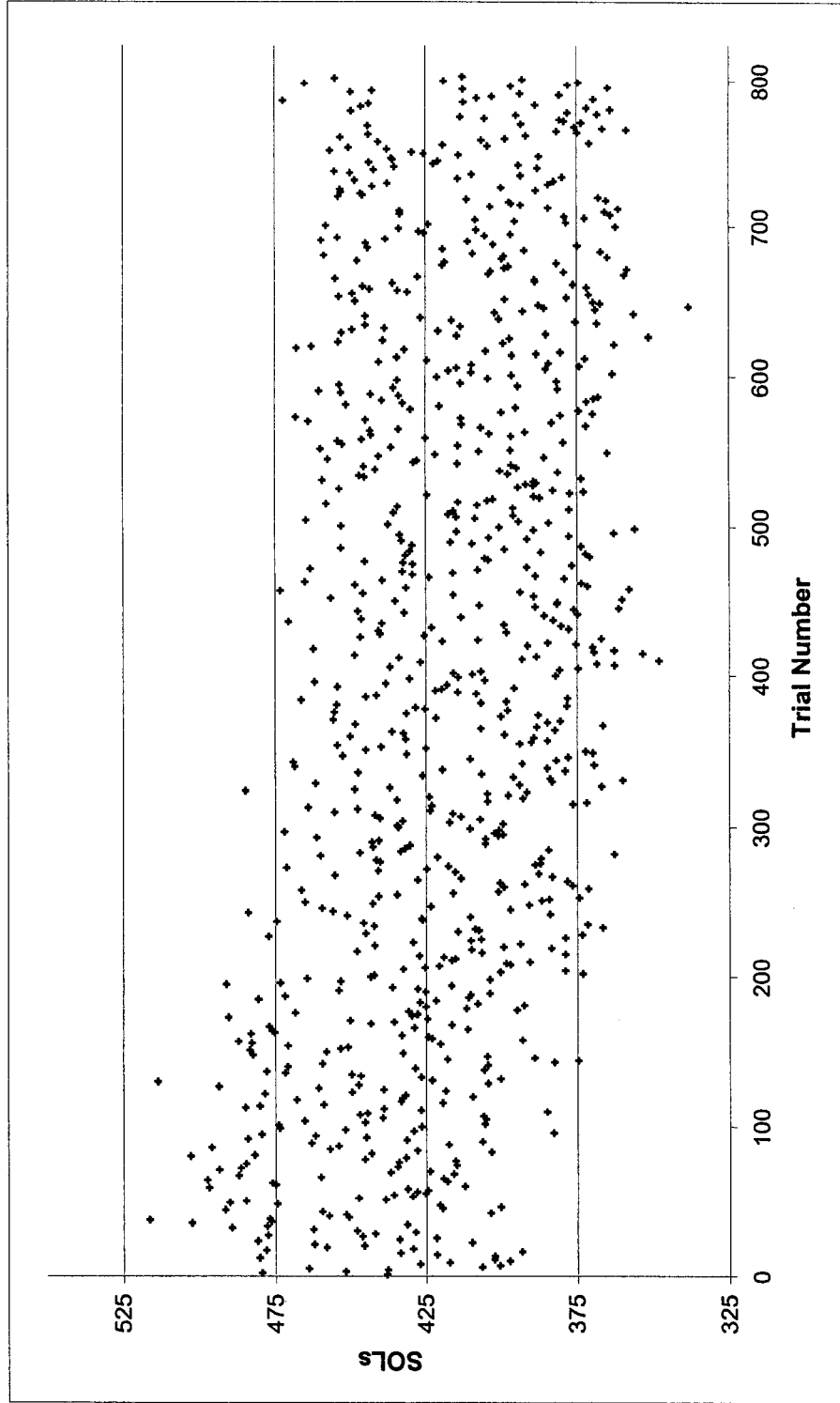
Irregular words = less than 60% regularity index						
Target Words				Interfering Stimuli		
word	frequency count	regularity index	# of letters	part of speech	IS	frequency count
dough	13	50.0	5	N	row	48
ghost	16	41.8	5	N	roast	8
cough	8	30.0	5	V	scoff	3
knight	25	35.5	5	N	fright	2
limb	10	59.3	4	N	grim	14
sheaf	3	37.9	5	N	brief	64
sigh	28	38.9	4	V	fry	8
tomb	13	35.7	4	N	boom	8
writhe	8	55.8	6	V	tithe	1
axe	19	2.4	3	N	lax	3
Mean	14	38.7	5		Mean	16

Appendix G. Experiment 2: Error Report for Irregular Words

Irregular High Frequency	Target	Run 1			Run 2			Run 3			Run 4		
		0	100	300	0	100	300	0	100	300	0	100	300
doubt		56	20		18	19	19	38	17	56	79	39	21
eight		40	39		19	20	38	60	19	40	79	21	19
guy		41	18	21	59	41	41	57	21	40	42	61	
key		72	36		18	20	21	21	21	36	75	18	35
knock		61			21	20	20	41	57	37	80	20	37
laugh				37	81	52	18	98	39	21	18	18	16
shoe		35	17	19	61	20	17	60	39	19	39	36	53
suit		36	38	33	39	20	42	39	60	20	58	38	17
talk		58	21	82	82	21	42	39	60	20	19	20	21
write		18	20	18	77	41	61	75	38	19	20	20	21
HF Irregular Total Observations.		417	188	149	475	213	277	548	311	306	509	253	219
Expected Total Observations		462	210	168	504	231	294	588	336	336	546	273	252
% missing		9.74%	10.48%	11.31%	5.75%	7.79%	5.78%	6.80%	7.44%	8.93%	6.78%	7.33%	13.10%
Row Totals, All Runs													
		3865										4200	7.98%

Irregular Low Frequency	Target	Run 1			Run 2			Run 3			Run 4		
		0	100	300	0	100	300	0	100	300	0	100	300
axe		81		60	42	60		21	39		60		40
cough		52			76	20		40	36	56	18	31	38
dough		33	40	19	13	17	19	48	16	19	70	21	35
ghost		60	40	20	56	18		36	19	17	36	18	58
knight		40	40	63	40	40	19	61	41	60	60	58	17
limb		35	40		38	18	37	58	20	35	60	18	21
sheaf		70	16	39	19	37	18	18	21	21	75	18	41
sigh		59		35	37	41	35	37	34	17	59	19	19
tomb		39	37	38	60	41	21	51	51	21	40	19	18
writhe		40		12	24	13	25	41	27	28	29	29	
LF Irregular Total Observations		509	173	286	405	265	156	411	253	214	507	231	268
Expected Total Observations		588	189	315	462	294	189	483	294	252	587	273	294
% missing		13.44%	8.47%	9.21%	12.34%	9.86%	17.46%	14.91%	13.95%	15.08%	10.58%	15.38%	8.84%
Row Totals, All Runs													
		3678										4200	12.43%

Appendix H. Experiment 2: Scatterplot of Raw Data (SOLs) by trial number



VITA

Camilla Leilani Calkins, daughter of Ronald Anderson and Miriam Necula, was born March 22, 1973, in Philadelphia, PA. At the age of three, she moved with her family to St. Petersburg, FL. After graduating with an International Baccalaureate Diploma from St. Petersburg High School, she attended the University of Miami, and spent her sophomore year studying at the Università dell'Aquila in L'Aquila, Italy and traveling throughout Europe. She earned a Bachelor of Arts degree in Comparative Education at Eckerd College, and a Master of Arts in Linguistics from Florida International University. In 1997, she moved to Seattle, which she now calls home. On June 27, 2003, she married James Calkins. Six months later, she earned her Doctor of Philosophy at the University of Washington in Speech and Hearing Sciences.