EXAMINING SKILLED READING PROCESSES

A Thesis Submitted to the College of
Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in the Department of Psychology
University of Saskatchewan
Saskatoon

by
William J. Owen
Fall, 2002

PERMISSION TO USE

In presenting this thesis in partial fulfilment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Department of Psychology
Arts Building
University of Saskatchewan
9 Campus Drive
Saskatoon, Saskatchewan
S7N 5A5

Abstract

Skilled reading often occurs with little effort. However, when basic reading processes are analyzed in detail, the illusion of simplicity is removed. The present research focuses on the proficiency with which a skilled reader can successfully access lexical (i.e., whole-word) and sublexical (i.e., sub-word) levels of orthographic and phonological knowledge. In particular, I will address questions pertaining to: (1) the nature of the connections between sub-processes of basic visual word recognition, (2) the degree to which context affects whole-word versus sub-word processing, and (3) whether there are neuroanatomical correlates that correspond to the sub-processes of basic visual word recognition. The findings presented in this set of experiments support: (1) facilitation-dominant connections from orthography to phonology, (2) context related whole-word and sub-word processing, and (3) lexical and sublexical neuroanatomical correlates of basic reading processes. The findings are discussed with respect to the issue of whether there is a single processing route from orthography to phonology or if there are two processing routes from orthography to phonology.

Acknowledgements

I wish to thank my supervisor, Dr. Ron Borowsky, his commitment, enthusiasm, dedicated support, and friendship over the past five years. You have been a great mentor, and I will ensure that my future students receive the same support and commitment that you gave me. I also wish to thank the members of my dissertation committee, Dr. Scott Bell, Dr. Jamie Campbell, Dr. Jim Cheesman, Dr. Gordon Sarty, and my external examiner, Dr. Chris Westbury, for the thorough and insightful considerations of my work. I would also like to extend my appreciation to the whole *Cognitive NeuroScience Research Group* for allowing me to develop and promote my areas of research. Jonathan Fugelsang and Thomas Phenix were especially helpful in terms of the many critical discussions we entertained over the years.

I would like to make special mention of my parents, Linda and Owen J. Owen, for their continued support over the many years of university training. I have been inspired by your dedication and work ethic. I would also like to thank my Grandma, Olive Mutch, for her continued support in my pursuit of an academic career. Also, I thank Elizabete Rocha, whose love and support is always much appreciated.

Finally, I would like to acknowledge the National Science and Engineering Research Council of Canada for their financial support of my research. Thank you all!

Table of Contents

List of Tables

Introduction

Experiments 1-4

Experiment 5

Experiment 6

List of Figures

Introduction

Experiments 1-4

Experiment 5

Experiment 7

List of Appendices

EXAMINING SKILLED READING PROCESSES

Formal writing systems, and therefore formal reading systems, are approximately 3000 years old (Gelb, 1963). The function of a formal writing system is to capture phonographic (i.e., sound-to-print) relationships so that writers can interpret the past, describe the present, and anticipate the future. However, writing would be senseless without formal reading skills that could transform written words back into (new) meaningful thoughts. For most of us reading is an effortless process, although occasionally the meaning and/or pronunciation of a written word may elude us. As a recent human development, reading processes probably procured areas of the brain already dedicated to language processing (Kolb & Whishaw, 1990), suggesting that the establishment of language is important for the later emergence of basic reading skills (Hanson, 1989; Perfetti & Sandak, 2000).

Evidence is available to support the hypothesis that children exposed to a spoken or signed language have better productive reading skills (i.e., able to read at or better than a grade six level) than children who are not exposed to a formal language, or who experience delayed exposure to language (Hanson, 1989; Paul & Quigley, 1994). For example, it is known that ninety percent of children born deaf are born into hearing families (Goldin-Meadow & Mylander, 1990). Furthermore, Conrad (1979) reported that of 22,000 children who were known to have been born deaf, less than half were diagnosed before the age of three. Such findings indicate that the majority of children born deaf experience early linguistic impoverishment due to the fact that they are not identified as being unable to experience spoken language. As such, these children are often introduced to language three to four years later than their hearing peers (Conrad, 1979). Delayed linguistic input has negative consequences for higher-level language processes (e.g., reading) that exploit established linguistic knowledge.[1] For example, 16-year-old high school students who are deaf, and who were often introduced to language after age three, read at a level commensurate with 11-year-old hearing students (Conrad, 1979). Thus, Conrad's poignant statement that, "The education of children born deaf is essentially a war against cognitive poverty." (p. xi) is well taken. One avenue of attack against this "cognitive poverty" is to improve the productive reading skills of children who are born deaf in order that they can access common information via newspapers or text-based Internet sites. However, the pedagogy of reading for all children should be informed by our understanding of basic reading processes. The primary questions that have preoccupied basic visual word recognition researchers have focused upon the issues of how readers represent and relate the orthographic (i.e., printed representations), phonological (i.e., spoken word representations), and semantic (i.e., meaning) codes for written words (e.g., Frost, 1998; Henderson, 1982; Huey, 1908).

The proficiency with which a skilled reader can successfully access lexical (i.e., whole-word) and sublexical (i.e., sub-word) levels of orthographic and phonological knowledge is central to the present research. The general issue to be addressed relates to how readers convert printed words into phonological and/or semantic knowledge representations. Specifically, I will address questions pertaining

---

[1] In the developmental dyslexia literature, it is considered important to distinguish between poor reading skills that are a result of deviant versus delayed reading processing. However, both deviant and delayed reading processes present functional deficits. That is, a person who has either deviant or delayed reading processes and cannot read the words on a street sign or in a newspaper is equally disadvantaged. With respect to children born deaf, it is not the case that a 3-4 year delay in language acquisition results in a simple delay in language mastery (Conrad, 1979). Developmental childhood language delays often affect adult language and/or reading performance (Leong, 1999).

to: (1) the nature of the connections between sub-processes of basic visual word recognition, (2) the degree to which context affects whole-word versus sub-word processing, and (3) whether there are stable neuroanatomical correlates that correspond to the sub-processes of basic visual word recognition. Other linguistic structural information concerning syntax, pragmatics, and discourse also constrain reading processes (e.g., Dell, Schwartz, Martin, Saffran and Gagnon, 1997; Singer & Remillard, 2001); however, these processes are beyond the scope of this research.

Overview

The study of basic reading processes involves many levels of theoretical and analytical descriptions. First, it is important to discuss two classes of models that have been developed to account for basic visual and spoken word recognition. The differences between the two classes of models provide distinct hypotheses that will be examined in this dissertation. Second, indices of word recognition, in particular the word frequency, orthographic length, and list context effects, will be discussed as these indices are used in many of the experiments reported here. Third, it is important to introduce the different stimulus types that are manipulated in word recognition research. Fourth, converging evidence from neuroimaging studies of basic reading processes will be examined. Fifth, the questions of interest and the pertinent experiments will be elucidated in three chapters of research. Finally, the results of the present experiments will be integrated and discussed with respect to how the different classes of word recognition models should be constrained to account for the data.

Models of Visual Word Recognition

There are several competing models of visual word recognition; however, most of the models can be broadly classified as either dual- or single-route models. Several groups of researchers have posited that two non-semantic reading processes are necessary in order to describe basic skilled and impaired reading performance (e.g., Bernstein & Carr, 1996; Coltheart, Curtis, Atkins, & Haller, 1993; Monsell, Patterson, Graham, Hughes &Milroy, 1992; Paap & Noel, 1991; Zorzi, Houghton, & Butterworth, 1998). In contrast, other researchers have argued that only one non-semantic reading process is necessary to describe basic skilled and impaired reading performance (e.g., Carello, Lukatela & Turvey, 1994; Harm & Seidenberg, 1999; Henderson, 1982; Kwantes & Mewhort, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Despite the differences in the number of non-semantic routes for mapping orthography onto phonology, both groups of dual- and single-route model researchers posit that an additional semantic route is necessary to describe how context and meaning affects reading. Figure 1 illustrates the Owen and Borowsky (2002a) framework for studying basic reading and speech perception processes, which is useful for comparing dual- and single-route models of visual word recognition.

Dual-route models. The traditional dual-route model of visual word recognition distinguishes between lexical and sub-lexical sources of phonology (e.g., Baron & Strawson, 1976; Coltheart, 1978). Borowsky, Owen, and Fonos (1999) referred to the two processing routes as *sight vocabulary* (SV; i.e., lexical or addressed

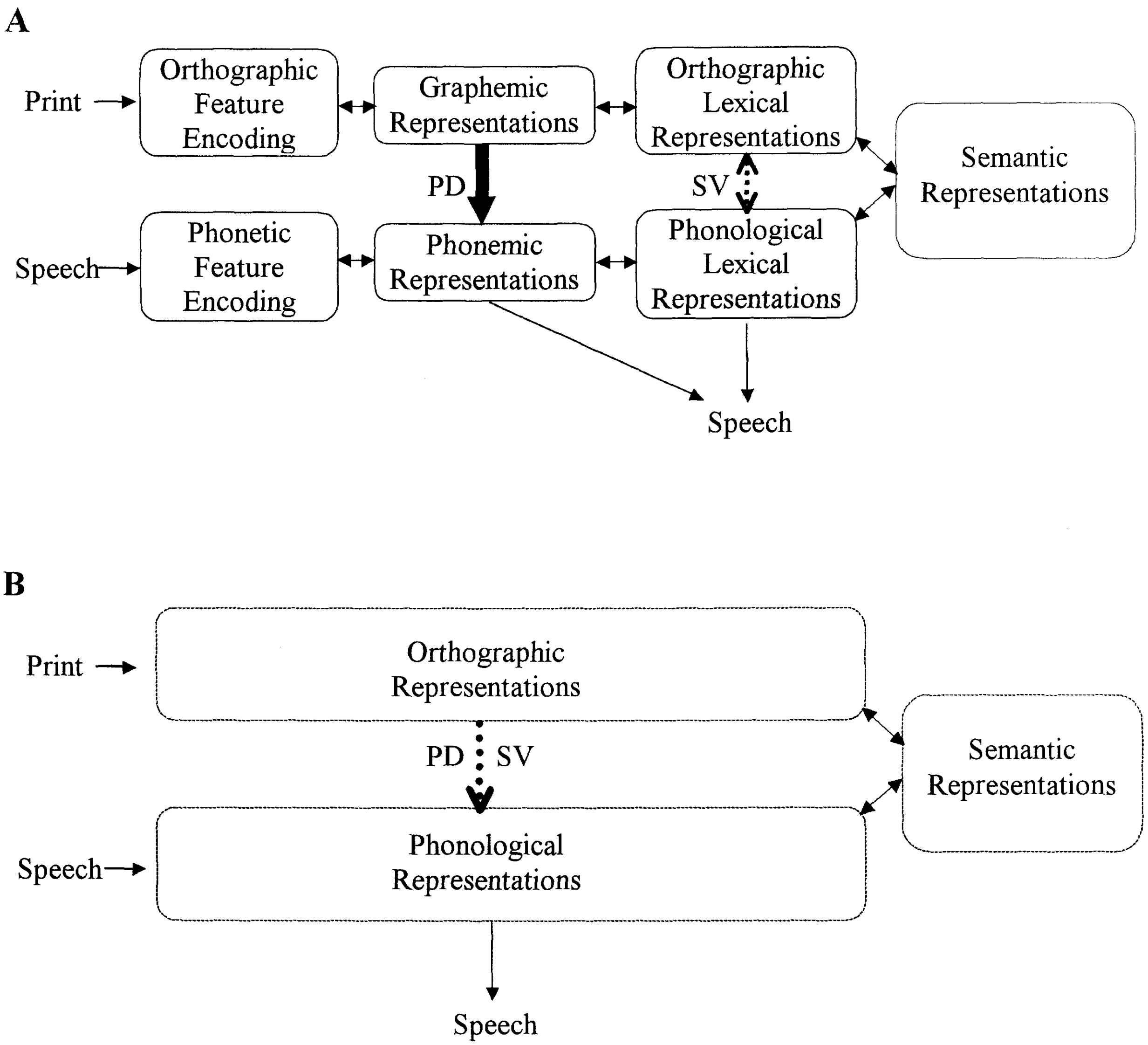


Figure 1. A framework for comparing dual- and single-route models of visual word recognition (see Owen & Borowsky 2002a): A. Dual-route model, B. Single-route model. Connections that have been corroborated by experiments are shown in bold, and the connections to be corroborated in Experiments 1-4 of this dissertation are illustrated by dotted arrows. PD = phonetic decoding (i.e., sublexical, assembled phonology) route, SV = sight vocabulary (i.e., lexical, addressed phonology) route.

phonology) and *phonetic decoding* (PD; i.e., sub-lexical or assembled phonology). Figure 1A illustrates the sub-processing systems involved in a dual-route account of basic reading.

Printed orthographic stimuli are first encoded based upon elementary feature analyses (e.g., lines, angles, curves; McClelland & Rumelhart, 1981). In the Coltheart (Coltheart et al., 1993, Coltheart, Rastle, Perry, Langdon & Zeigler, 2001) and McClelland and Rumelhart (1981) models, feature analysis information feeds forward to the letter-level. The letter-level is not represented in the Owen and Borowsky (2002a) framework because it is assumed that letters are redundant within the graphemic-level of representation. Graphemes are letters or letter units (e.g., *t* and *th*). Graphemic information can follow one of two processing routes, hence the name dual-route models. In particular, the graphemic information cascades in parallel to both the orthographic lexical level of representation (i.e., the SV route) and the phonemic level of representation (i.e., the PD route). The SV route maps whole-word orthographic representations directly onto whole-word phonological representations. In contrast, the PD route maps the graphemes onto phonemes (minimal, linguistic primitives). Traditionally, it has been assumed that with respect to English the graphemes are mapped onto phonemes by applying spelling-sound rules in a serial left-to-right manner (Coltheart, 1978; Coltheart et al., 1993; Coltheart et al., 2001; cf. Zorzi, 2000). The phonemes are assembled to produce a phonological output.

Despite the considerable agreement that two non-semantic processing routes are necessary to adequately describe reading behaviours, there are considerable differences between dual-route models in how lexical and sub-lexical knowledge is represented. The most influential model has been Coltheart and colleagues' (Coltheart et al., 1993; Coltheart et al., 2001) *dual-route cascade model*. In the dual-route cascade model, the subsystems of the SV route, the orthographic and phonological lexicons, were implemented using a localist (i.e., relevant units are stored as complete nodes), interactive activation (i.e., activation between adjacent sub-components is bi-directional) network consisting of whole-word units. The subsystems of the PD route, the graphemic and phonemic representations, consist of graphemes, phonemes, and a set of rules for mapping graphemes to phonemes. Coltheart et al. (1993) described how the spelling-sound rules can be inferred from a training set of about 3000 monosyllabic word spelling patterns and their phonetic transcriptions. Their rule-learning algorithm was applied to single-letter spelling-sound correspondences (e.g., *m* → /m/), multiple-letter spelling-sound correspondences (e.g., *ee* in the word eel), and context sensitive spelling-sound correspondences (e.g., *c* in the words cost and cell). A set of hierarchical operation rules governed how the derived spelling-sound correspondences were to be applied.

Dual-route models do not have to subscribe to localist SV and rule-based PD representations. For example, Zorzi et al. (1998) have implemented a connectionist dual-route model. The orthographic units consist of a set of distributed position-specific input units corresponding to the *onsets* (i.e., initial consonant or consonant cluster) and *rimes* (i.e., vowel and final consonants) of words. The orthographic units are connected to a set of hidden units, which are connected to a set of phonological units. The phonological units also correspond to the onsets and rimes of words. Because the hidden units connect the orthographic to phonological units, Zorzi et al.

have termed this route the *mediated route*. The mediated route is akin to the SV route because the hidden units are able to extract lexical properties, which facilitates whole-word naming (see also Monsell, 1991; cf. Plaut et al., 1996). Zorzi et al.'s dual-route connectionist model also contains direct connections between the orthographic units and the phonological units. The *direct route* is akin to the PD route because it maps sub-lexical orthography to sub-lexical phonology. An important distinction between the dual-route connectionist and the dual-route cascade models is that the dual-route connectionist model does not contain explicitly stated spelling-sound rules to map sub-lexical orthography onto sub-lexical phonology, rather this knowledge is stored (implicitly) in the connection weights between the orthographic and phonological systems.

In both the dual-route cascade and the dual-route connectionist models, the SV and PD processing routes are considered to be non-semantic. Semantics, or meaning, is represented by a separate subsystem within the dual-route model, and is assumed to interact with orthographic lexical and phonological lexical representational subsystems (Coltheart et al., 2001). Although no current computational dual-route model has implemented the semantic subsystem, Coltheart et al. (2001) posited that the semantic system may be best represented by an interactive activation network of conceptual units similar to the lexical-semantic access model proposed by Dell et al. (1997). The semantic subsystem is implicated in certain contextual effects that influence orthographic lexical and phonological lexical processing (e.g., ambiguity resolution; Borowsky & Masson, 1996a; Swinney, 1979).

Single-route models. The distinction between dual- and single-route models lies in the number of non-semantic pathways relating orthography to phonology. The difference is a consequence of whether the basic components of visual word recognition are integrated (Borowsky et al. 1999; see Figure 1B). By grouping orthographic feature, graphemic, and orthographic lexical representations together, and by grouping phonetic feature, phonemic, and phonological lexical representations together, only one non-semantic route is available to relate orthography to phonology.

Owen and Borowsky (2002a) describe three types of single-route models, which differ in the degree of emphasis given to lexical and/or sub-lexical representations. *Analogy models* (e.g., Glushko, 1979; Kwantes & Mewhort, 1999) emphasize the lexical level of representation. This class of single-route model assumes that the pronunciations of words are produced by mapping whole-word orthographic representations directly to whole-word phonological representations. In order to account for how readers pronounce novel words and nonwords (e.g., CHTHONIC or PRANE, respectively), it is assumed that pronunciations for unfamiliar items are based upon orthographically similar lexical entries (e.g., SONIC and CANE, respectively). It is clear that analogy models only explicitly represent the SV route. *Phonological mediation models* (e.g., Carello et al., 1994) assume that fast sub-lexical phonemic access is obligatory in skilled reading. As such, the PD route subsumes SV processing. *Single-route connectionist architectures* (e.g., Harm & Seidenberg, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) explicitly specify sub-lexical representations, and, due to the architecture of the model, implicitly specify lexical representations. It has been argued that the hidden units in such models, which mediate sub-lexical orthographic and sub-lexical phonological processing, capture lexical-level representations (e.g., Besner, Twilley, McCann & Seergobin, 1990; Monsell, 1991; Zorzi et al., 1998; cf. Plaut et al., 1996). Thus, the SV and PD routes are inseparable in single-route connectionist architectures.

Single-route connectionist architectures have featured prominently in the extant literature. The original Seidenberg and McClelland (1989) single-route connectionist model demonstrated that explicit lexical representations and explicit spelling-sound rules did not have to be pre-specified in a model of visual word recognition. The original model was composed of distributed orthographic, hidden, and phonological units. The 400 orthographic units represented *Wickelfeatures*, which are three-letter units. For example, the word *word* consists of the Wickelfeatures _WO, WOR, ORD, and RD_. The orthographic units are connected to a set of one to two hundred hidden units. The purpose of the hidden units is to increase the computational power or processing capacity of the model (McLeod, Plunkett & Rolls, 1998). The hidden units mediate the connections between the orthographic and phonological output units. The phonological units consisted of *Wickelphones*, which are three-phoneme units. The connections between the orthographic units, hidden units, and phonological units adhere to the principle of bi-directional interactive connections. Each connection has: (1) *graded*, rather than all-or-none, (2) *adjustable*, and (3) *non-linear* (i.e., a logistic function) weights. Therefore, information regarding frequency of occurrence and context-sensitivity of phonemes, among other structural properties, is captured in the weighted connections between processing units and not at the units themselves (see also, Borowsky & Besner, 1993; Borowsky, Owen &

Masson, in press; McCann & Besner, 1987). The back propagation learning algorithm, which is an offline, supervised error-correction learning mechanism (Simpson, 1990), modifies the strength of the connection weights. Plaut et al.'s (1996) recent version of the Seidenberg and McClelland single-route model has abandoned the Wicklefeature representations in favour of more psychologically plausible representations such as *onsets*, *vowels*, and *codas* (i.e., final consonant cluster).

As the label for this class of models implies, there is only one non-semantic route specified to map orthographic representations onto phonological representations. Plaut et al. (1996) have argued that the single-route connectionist model does provide an existence proof that two routes/mechanisms are not necessary to describe reading behaviours. Nevertheless, they have also had to argue that the implementation of a semantically mediated processing route may be necessary to capture specific subtleties in human reading performance. Recently, Harm and Seidenberg (2001) have implemented the semantic route. Semantic representations were based upon semantic features of words, and were derived by determining [is-a] relationships (e.g., a bird *is an* animal that flies and has wings). Over 1,900 semantic features were generated based upon a corpus of 6,103 words. Semantic categories emerged due to the fact that words that shared common sets of features tended to be organized closer in semantic space than words that were unrelated.

Summary. Models of visual word recognition differ in the number and type of processing routes to compute speech output from printed words. These differences have allowed for researchers to generate testable hypotheses in order to further examine the basic visual word recognition processes of SV and PD. One important question that must be addressed concerns how researchers index SV and PD processing.

Indices of Word Recognition

Are there indices of SV and PD processing that can be readily identified? Can encouraging readers to rely differentially on SV and PD processing modulate measures of these indices? The extant literature offers some insight into these questions. In particular, the word frequency and orthographic length effects have been interpreted as indices of SV and PD processing, respectively, whereas list context effects suggest that readers can modulate their reliance upon SV and PD processing. Each of these three effects will be discussed in turn, along with how dual- and single-route models can account for these effects.

Word frequency effect. The *word frequency effect* refers to the robust finding that words appearing frequently in printed material are named faster and more accurately than words appearing less often (Forster & Chambers, 1973; Frederiksen & Kroll, 1976; Scarborough, Cortese & Scarborough, 1977). The type of words, tasks, and list contexts used to investigate word frequency all influence the magnitude of the word frequency effect (see Table 1). Monsell (1991) stated that the word frequency effect is *greater* for exception words (i.e., words that do not follow typical spelling-sound correspondences; e.g., YACHT) than regular words (i.e., words that follow typical spelling-sound correspondences; e.g., BLACK). This *word frequency by regularity interaction* is ubiquitous in word recognition research (e.g., Hino & Lupker, 2000; Seidenberg, 1985). The word frequency effect is also larger in lexical decision tasks (i.e., decide whether the stimulus is a real word) than in word naming or rhyming

Table 1

Effect Sizes of the Word Frequency and Orthographic Length Effects

Study	Word Frequency Effect High	Low	Δ Response Latency
Seidenberg (1985) Experiment 2 Naming Task			
Exception words	541	583	42
Regular words	540	556	16
Seidenberg et al., (1984) Experiment 3 Naming Task			
Exception words	590	639	49
Regular words	588	610	22
Seidenberg et al., (1984) Experiment 3 Lexical Decision Task			
Exception words	530	604	74
Regular words	533	601	68
Monsell et al., (1992) Experiment 2 Naming Task (with nonword context)			
Exception words alone	422	474	52
Exception words + nonwords	437	479	42

Study	Orthographic Length Effect Short	Long	Δ Response Latency
Weekes (1997) Experiment 1 Naming Task*			
High frequency words	538	548	10
Low frequency words	555	585	30
Nonwords	575	650	75

Note: High = high frequency, Low = low frequency, Short = three letter words, Long = 6 letter words, * mean response latencies were extrapolated from a graph.

tasks (i.e., decide whether two words and/or nonwords "sound" the same; e.g., Balota & Spieler, 1999; Monsell, 1991). Furthermore, Monsell et al. (1992) have shown that list context can minimize the word frequency effect. When exception words are presented amongst nonwords, the word frequency effect for exception words is smaller (see also Baluch & Besner, 1991; Zevin & Balota, 2000). Given that exception words cannot be correctly pronounced using PD processing (e.g., YACHT would be pronounced as "yatched"), it is assumed that exception word naming reflects SV processing. Thus, the word frequency effect has generally been interpreted to mean that orthographic lexical organization is frequency sensitive (e.g., Forster, 1985; Paap, McDonald, Schvaneveldt & Noel, 1987), or that the connections between the basic visual word processing sub-systems are frequency sensitive (e.g., Borowsky & Besner, 1991, 1993; McCann & Besner, 1987; Seidenberg & McClelland, 1989).

In the dual-route cascade model the localist orthographic lexical representations are frequency sensitive (Coltheart et al., 2001). In particular, lexical representations for higher frequency words have a constant baseline activity level that is greater than the constant baseline level for low frequency words. Thus, it takes less activation for high frequency orthographic representations to exceed a specific threshold. These same principles also apply to the phonological lexicon. In contrast, dual-route models by Besner (1999) and Zorzi et al. (1998) assume that the connections between the orthographic and phonological representations are frequency sensitive. Specifically, the more times a particular connection has been used, the more efficient and stronger the connection between the orthographic and phonological representations.

The Seidenberg and McClelland (1989) single-route connectionist model also captures the word frequency effect that is observed in the behavioural data. After 150,000 learning trials, in which high frequency words were presented more often than low frequency words, the Seidenberg and McClelland single-route connectionist model was evaluated by assessing the phonological error score (i.e., the summed squared discrepancy between the correct phonological output and the obtained phonological output pattern). These authors showed that words that were presented more often to the model had lower phonological error scores than words that were presented less often. Since this model does not have any explicitly defined lexical representations in which frequency information can be stored, it must be the case that the knowledge about a word's frequency was carried by the strength of the connections between orthographic and phonological representations (see also Zorzi et al., 1998). When the connections between the orthographic and phonological representations were stronger, the resultant phonological error score was lower.

Orthographic length effect. The *orthographic length effect* refers to the finding that items with fewer letters are named faster, and more accurately, than items with more letters (Balota & Chumbley, 1985; Frederikson & Kroll, 1976; Weekes, 1997). Developmentally, children learn shorter words prior to learning longer, more complex words. Correspondingly, Weekes (1997) has demonstrated that the orthographic length effect is greater for nonwords than for low frequency words, whereas no orthographic length effect was observed for high frequency words (see Table 1).

Weekes (1997) interpreted this pattern of data as being consistent with the dual-route cascade model of visual word recognition. Specifically, the naming of familiar and high frequency words relies on the SV route because such words have well-established mental lexical representations, whereas the naming of nonwords and less familiar, low frequency words relies on the PD route. As the SV route computes whole-word phonology, length is not a factor for high frequency words. According to Coltheart et al. (1993), the PD route operates by serially applying spelling-to-sound correspondences, thus, the longer the orthographic stimulus the more spelling-sound correspondences need to be assembled before a phonological output can be generated.

The orthographic length effect would appear to pose a problem for models of visual word recognition that assume parallel processing. However, Zorzi (2000) has argued that length effects do not necessarily imply that spelling-sound correspondences are generated serially. The Zorzi et al. (1998) dual-route model does not contain explicitly stated rules for mapping sound onto spelling in a serial manner. Despite the lack of rules that are to be applied in a serial, letter-by-letter fashion, parallel-processing models can also account for the orthographic length effect (Plaut et al., 1996; Zorzi, 2000). Two explanations have been put forth. First, dual-route parallel processing models produce larger phonological error scores for stimuli with more letters because such items activate added competing phonological output units. Second, Plaut et al. (1996) have argued that the degree of parallel processing is dependent upon the reader's experience and, therefore, high frequency words should be computed using parallel processes, whereas low frequency words and nonwords should be computed using more sequential processes. It follows that the orthographic length effect should be larger for nonwords than low frequency words, which should be larger than for high frequency words. Note, however, that this suggestion is essentially a dual-mechanism account of the orthographic length effect and, thus, is similar to the dual-route model explanation of the orthographic length effect.

List context effect. The *list context effect* refers to the set of findings that behavioural performance for a particular stimulus type can be influenced by whether other stimulus types are included in the list (e.g., performance on exception word naming is influenced by whether nonwords are included in the list; Monsell et al., 1992; see Table 1). Zevin and Balota (2000) used a priming procedure to facilitate optimal SV or PD route use. Their basic design was to precede a particular target stimulus type (e.g., an exception word, which, theoretically, must be pronounced via SV processing) with five stimuli from another stimulus type category (e.g., nonwords, which, theoretically, must be pronounced via PD processing). In general, the prime type influenced the target stimulus pronunciation. The list context in which different stimuli are presented modulates the word frequency. For example, the word frequency effect was larger when regular words were preceded by low frequency exception words than when they were preceded by nonwords. It has also been shown that pseudohomophone base-word frequency effects are present when pseudohomophones are presented in pure lists but not in mixed pseudohomophone-nonword lists (Borowsky et al., in press).

The fact that word frequency effects are context specific (e.g., the frequency effect observed for exception word naming is often diminished when exception words are presented amidst a list of nonwords; Monsell et al., 1992) has been interpreted to indicate that the reader has strategic control of the relative contribution of the SV and PD routes (Davelaar, Coltheart, Besner & Jonasson, 1978; Hawkins, Reicher, Rogers

& Peterson, 1976; cf. Dennis & Newstead, 1981; Lupker, Brown & Colombo, 1997). Although the term "strategic control" implies a conscious effort to switch processing strategies, it is only meant to convey the notion that the reliance on the lexical and sublexical phonological processes is flexible. As such, it is probably better to discuss list context effects in terms of *strategic reliance* rather than strategic control.

Dual-route models are inherently more flexible than single-route models due to the explicit representation of both sublexical and lexical phonological processing routes (Borowsky et al., 1999). As such, dual-route models can easily account for list context effects by assuming that different context stimuli prime either the SV or PD routes, and that selective priming of one route or another increases a reader's reliance upon that pathway. That is, list context influences the strategic reliance on PD and SV processing in order to optimize speed and accuracy of visual word recognition. Since nonwords would have no lexical representations, it is optimal if a list containing many nonwords is read via PD processing in order to decrease the influence of attempting to access whole-word representations.

Single-route connectionist models have not been able to account for list context effects so parsimoniously. Strain, Patterson, and Seidenberg (1995; see also Harm & Seidenberg, 1999; Plaut et al., 1996) have argued that list context effects reflect a division of labour between non-semantic processing and semantically mediated processing. That is, semantic processing facilitates visual word recognition of stimuli that are processed relatively slowly by the orthography-to-phonology route. Essentially the Strain et al. (1995) argument regarding the division of labour hypothesis reduces down to a dual-route account of basic visual reading processing, with the notable exception that one route is semantic in nature.

Summary. Researchers have often assumed that SV access is indexed by the word frequency effect and, that PD access is indexed by orthographic length effect. Interestingly, both dual- and single-route models have been shown to be able to account for these two basic effects. Furthermore, studies have shown that skilled readers can strategically adjust their reliance upon SV and/or PD processing due to contextual demands in order to facilitate reading performance (in terms of speed and accuracy). The list context effects, which often modulate the word frequency and orthographic length effects, have been most easily accommodated by the dual-route theories of visual word recognition. These list context effects are due to the different combinations of stimuli that can be utilized in word recognition studies.

Stimulus Types

All models of visual word recognition must address the issue of how skilled and impaired readers name different orthographic letter-strings. In particular, English contains four classes of real words, which includes regular, regular-inconsistent, exception, and strange words (Seidenberg, Waters, Barnes & Tanenhaus, 1984; see also Glushko, 1979; Taraban & McClelland, 1987). Researchers have also created novel nonwords, which vary in their degree of similarity to the four classes of real words, in order to investigate how skilled readers learn or generalize their phonological knowledge to novel words (Laxon, Smith & Masterson, 1995).

Regular words are words that follow typical spelling-sound correspondences (e.g., BLACK). Furthermore, the pronunciations of all other "body" neighbours (e.g., other _ACK words) are also pronounced following typical spelling-sound correspondences. Regular words are named faster and more accurately than the other stimulus types (Seidenberg et al., 1984). *Regular-inconsistent* words follow typical spelling-sound correspondences (e.g., SAVE, GAVE) but have one or more body neighbours that are pronounced according to exceptional spelling-sound correspondences (e.g., HAVE). Glushko (1979) originally demonstrated that regular-inconsistent words were named slower and less accurately than regular words, however, Taraban and McClelland (1987) reported no difference for naming latencies or error rates between regular and regular-inconsistent words. Jared, McRae and Seidenberg (1990) provided a thorough examination of the inconsistency effect for regular words. Jared et al. tested whether the inconsistency effect for regular words was due to the orthographic or phonological properties of the words. They argued that the lexical decision task relies on processing orthographic properties of stimuli, whereas the naming task includes processing the phonological properties of the stimuli. The conclusion reached in this study was that the inconsistency effect was due to phonological properties of the words because the inconsistency effect only arose in naming tasks, which must involve phonology, and not in the lexical decision tasks. Moreover, the inconsistency effect depended on the frequency of the regular-inconsistent words' orthographic friends (i.e., body neighbours that are pronounced similarly to the regular-inconsistent word; e.g., WAVE, SAVE, GAVE) and enemies (i.e., body neighbours that are pronounced differently from the regular-inconsistent word; e.g., HAVE). Robust inconsistency effects were found for low frequency words with a "weak" neighbourhood of friends (i.e., a low summed neighbourhood frequency value) and a "strong" neighbourhood of enemies (i.e., a high summed neighbourhood frequency value). Jared (1997) has also extended this finding to high frequency regular-inconsistent words with a weak neighbourhood of friends and a strong neighbourhood of enemies.

Exception words are words that follow atypical spelling-sound correspondences, and are pronounced differently from the majority of their body neighbours (e.g., HAVE). Seidenberg et al. (1984) restricted their use of the term "exception" to words with typical spelling patterns (e.g., _AVE) and atypical spelling-sound correspondences. If an exception word is pronounced using the typical spelling-sound correspondences, a regularization error will result (e.g., HAVE → "hāv"). It has been demonstrated that exception words tend to be pronounced slower and less accurately than regular words (Glusko, 1978; Jared, 1997). *Strange* words are words that have both atypical spelling-sound correspondences and atypical spelling patterns (e.g., aisle). Seidenberg et al. (1984) have shown that the inclusion of strange words amongst lists of exception words exacerbates or inflates effects purportedly attributable to atypical spelling-sound correspondences alone (e.g., the regularity effect, whereby regular words are named faster than exception words).

Researchers interested in the question of how readers generalize their knowledge of word naming to novel words utilize nonwords in their studies (e.g., Besner et al., 1990; Castles & Coltheart, 1993; Glushko, 1979; Seidenberg, Plaut, Petersen, McClelland & McRae, 1994). It has been demonstrated that nonwords are named slower and less accurately than real words (e.g., Frederiksen & Kroll, 1976; Lupker et al., 1997). By creating nonwords that resemble real regular and exception words at an orthographic level, nonwords can vary in their degree of regularity (e.g., Glushko, 1979). However, Coltheart et al. (2001) have argued that the concept of regularity cannot apply to nonwords. In Coltheart et al.'s terms, regularity is defined with respect to whether a pronunciation based upon typical spelling-sound correspondences matches a dictionary pronunciation. The use of this particular definition of regularity is questionable because dictionary pronunciations may vary between sources and as a function of local dialects. Nonwords, though, can be defined as more-or-less consistent with their real-word orthographic neighbours.

The use of nonwords has raised some concerns. For example, Borowsky, McDougall, MacKinnon, and Hymel (2002; see also Seidenberg et al., 1994; Zorzi et al., 1998) have argued that nonword naming is exigent. First, researchers must decide how to score a nonword pronunciation. Borowsky, McDougall et al. (2002) illustrated that the nonword GEAD may be pronounced four different ways (e.g., with a hard or soft 'g', and to rhyme with "bead" or "bread"). The experimenter has to decide which pronunciation is "correct". Second, it has been my experience in research that some children and adults will refuse to name nonwords. Such difficulties may arise because nonword naming is an atypical task that may require additional attention and processing demands.

An alternative to using nonwords has been to study pseudohomophones (i.e., nonwords that sound like real words; e.g., BRANE). The majority of studies have shown that a pseudohomophone naming advantage occurs over nonword naming. That is, pseudohomophones are named faster and more accurately than nonwords (e.g., Grainger, Spinelli & Ferrand, 2000; Herdman, LeFevre & Greenham, 1996; McCann

& Besner, 1987; Seidenberg, Petersen, MacDonald & Plaut, 1996). However, recent experiments have shown that the pseudohomophone naming advantage depends upon whether nonwords are included in the list of stimuli to-be-named (i.e., a list context effect). Borowsky et al. (in press) demonstrated that when nonwords and pseudohomophones were presented in a mixed list format, there was a pseudohomophone naming advantage. In contrast, when a pure block of pseudohomophones was named before a pure block of nonwords, there was a pseudohomophone naming disadvantage (i.e., participants were slower and made more errors to pseudohomophones). However, when a block of nonwords was named before a block of pseudohomophones, no difference was observed. The pseudohomophone naming advantage is consistent with the idea that pseudohomophones can benefit from stored phonological lexical knowledge. In contrast, the pseudohomophone disadvantage is consistent with the idea that once an assembled phonological representation has been generated it can be checked against lexical or semantic representations. Furthermore, this lexical verification strategy can be encouraged due to specific list contexts. Therefore, it is important to examine how skilled readers name both nonwords (i.e., stimuli with unfamiliar orthographic and phonological representations) and pseudohomophones (i.e., stimuli with unfamiliar orthographic but familiar phonological representations) in order to adequately address issues relating to how readers generalize their knowledge of word naming to novel words.

Summary. In general, how skilled and impaired readers name the above stimulus types has provided important constraints upon theories and models of visual word recognition. Stimulus manipulations, as process-pure manipulations of SV and

PD, have also been used to determine the neurological underpinnings of basic reading processes.

Neurological Basis of Visual Word Recognition

Basic visual word recognition is composed of orthographic, phonological, and semantic processing, as well as motor programming and execution. Recently, some researchers have turned to Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) investigations in order to map out the regions involved in each type of processing. The goal of developing neurological models of basic visual word processing is to examine the material basis of word recognition processes, and to gain further insights into the nature of normal reading processes. Other researchers are also attempting to use neurological models of reading to help identify and diagnose persons with reading disabilities in order to provide appropriate remediation (Pugh et al, 2000).

Based upon an initial PET study of silent letter-string naming (i.e., false font, nonwords, real words) by Petersen, Fox, Synder & Raichle (1990), visual feature processing, as indexed by activity during false font blocks of trials, was localized as occurring in the bilateral, lateral extrastriate regions of the occipital cortex. Orthographic processing (i.e., visual word form), as indexed by activity during the word and nonword blocks of trials, was localized as occurring in the left medial extrastriate regions of the occipital cortex. Semantic processing, which could only occur for real words, was localized to the left frontal cortex.[2] Contrary to Petersen et al. (1990), a follow up PET study by Howard et al. (1992) localized the visual word

---

[2] Phonological processing was not assessed in this particular study; however, in a previous study, Petersen, Fox, Posner, Mintun, and Raichle (1988) indicated that phonological processing was assumed to be left-lateralized in the temporoparietal region.

form area to the left posterior superior gyrus of the temporal lobe, closer to the area postulated by early clinical neuroscientists. One difference between the Petersen et al. and Howard et al. studies deals with the issue of stimulus presentation duration, with the latter study using longer stimulus presentation durations (see Price, Wise, Watson, Patterson, Howard & Frackowiak, 1994; Pugh et al., 2000). Price et al. (1994) suggested that shorter presentation durations activate more automatic, memory-based word (SV) representations, whereas longer presentation durations allow for more effortful, rule-based (PD) processing.

Using fMRI, Small, Noll, Perfetti, Hlustic, Wellington, and Schneider (1996) replicated the Howard et al. (1992) PET study. In the active condition, participants named *aloud* a list of words, which was compared to pronouncing the word "range" in response to false font stimuli. To minimize head motion associated with naming aloud, a dental bite bar was used to immobilize the head while still allowing for articulation. The results indicated that the visual word form area (i.e., orthographic processing) was located in the left posterior superior temporal gyrus, which was consistent with the Howard et al. (1992) study.

Similar to the initial PET studies, fMRI studies aimed at identifying where orthographic processing occurs have produced equivocal results. Pugh et al. (1996) replicated the basic findings of Petersen et al. (1990) using a hierarchical decision task design instead of a naming task. Specifically, Pugh et al. had participants make same/different judgments on pairs of stimuli. The stimuli were theoretically derived to tap visual-spatial, orthographic, phonological, and semantic processing. Line judgments (e.g., //\\ //\\ – same; ///\ //\\ – different), which should employ visual-spatial processing, served as the baseline task. Case judgments (e.g., bBTb bBTb – same; bTTB bBTb – different) minus line judgments, which should subtract out visual-spatial processing from letter-level processing, engaged the lateral extrastriate occipital cortex. The rhyme judgments (e.g., lete jeat – same; meap jeat – different) using nonwords activated the left medial extrastriate occipital lobe. Furthermore, the left medial extrastriate occipital lobe was activated more when real words were presented in the semantic judgments task (e.g., corn rice – same; bike rice – different) as compared to when nonwords were presented in the rhyme task, suggesting that this region is part of the visual word form area. This finding is consistent with the Petersen et al. (1990) study. The rhyme task, a phonologically based task, produced increased activity in the inferior frontal gyrus, prefrontal dorsolateral, middle and superior temporal gyri regions. The semantic categorization task produced increased activity in the middle and superior temporal regions. Overall, the Pugh et al. (1996) study provided a comprehensive examination of the different brain regions involved in subcomponents of basic visual word recognition.

Some neurological models are consistent with a dual-route approach to the study of basic reading processes. In particular, recent reviews of the functional magnetic resonance imaging literature have identified several isolable brain regions that appear to be differentially involved in sub-components of basic visual word recognition (see Binder & Price, 2001; Demb, Poldrack & Gabrieli, 1999; Posner & Raichle, 1994). For example, Pugh et al. (2000) suggest that a *dorsal pathway* aides beginning readers as they establish lexical-semantic representations. This pathway includes the angular gyrus, supramarginal gyrus, and the posterior aspect of the superior temporal gyrus, which are areas in the temporal-parietal region. The dorsal pathway is hypothesized to support rule-based analyses of words and nonwords, and is therefore akin to the PD process described in cognitive models of visual word recognition. The properties of this pathway include a relatively late hemodynamic response function (i.e., cerebral blood flow as a function of time from stimulus onset) that is minimized when presentation rates and reading skill increase, and when real words are presented. In contrast, skilled readers tend to rely on a faster, lexical-based pathway once words are established in memory. The *ventral pathway* of the occipital-temporal region is hypothesized to support lexically based reading. It includes the lateral extrastriate and the left inferior occipito-temporal regions. The ventral pathway is hypothesized to support a memory-based word form system, and is therefore akin to the SV process.

Summary. Recent advances in MRI technology have allowed researchers to non-invasively investigate which regions of the brain are engaged during basic reading processing (see Binder & Price, 2001; Demb et al., 1999). Consistent with several cognitive models of visual word recognition, it appears that the basic sub-components of reading (i.e., orthography, phonology and semantics) are located in isolable brain regions. In particular, specific areas of the brain appear to engage in lexical-level, or SV, processing, whereas other distinct areas of the brain appear to be engaged in sublexical-level, or PD, processing. Furthermore, researchers are attempting to connect their neurological models of basic reading processes back to cognitive models. Regardless of the level of description (i.e., neurological or cognitive), several important questions remain regarding the relationship between SV and PD. The series of experiments described in the next three chapters serve to examine three particular issues related to SV and PD processing.

The Current Empirical Issues

The empirical issues to be addressed in the series of experiments that follow concern: (1) defining a general framework of SV and PD processing that captures both single- and dual-route models in order to highlight the similarities and differences between single- and dual-route models, (2) extending the research on list context effects to examine strategic reliance on PD and SV processes, and (3) determining whether neurological models of basic reading processes reflect the SV and PD distinction as indexed by word frequency effects.

The research presented in this dissertation focuses on examining the dual- and single-route debate concerning the number of non-semantic reading processes available to skilled reading. In particular, chapter one will examine whether the nature of the connection at the lexical level of representation (i.e., the SV route) differs from the type of connection at the sublexical level (i.e., the PD route), as suggested by numerous dual-route models (e.g., Coltheart et al., 2001). Chapter two focuses on the degree to which context influences reliance upon SV and PD processes. Chapter three will examine if there are neuroanatomical correlates of SV and PD processing. As three different methodologies were used to address each question, the series of experiments pertaining to each question will be introduced, presented, and discussed in a modular fashion. Following the three research chapters, the current experiments will be discussed with respect to how they constrain models of visual word recognition.

Chapter 1

THE INTERACTIVITY OF ORTHOGRAPHIC AND PHONOLOGICAL LEXICAL ACCESS: A GENERAL FRAMEWORK FOR SINGLE- AND DUAL-ROUTE MODELS

The identification of spoken and written words involves the integration of the target stimulus and relevant contextual sources of information from the environment. It has been demonstrated that listeners integrate both auditory and visual sources of information during auditory perception. The classic "McGurk effect" (e.g., MacDonald & McGurk, 1978; McGurk & MacDonald, 1976) illustrates that when listeners are presented with an auditory stimulus (e.g., /ba-ba/) that does not match visually presented vocal gestures (e.g., mouth movements for /ga-ga/), the auditory and visual information are integrated during auditory perception (e.g., the listener hears "da-da"). People are often presented with concurrent spoken and printed stimuli (e.g., we are often asked to attend to overhead notes while a lecturer reads the overhead notes aloud, and to read storybooks to children while they follow the printed words). Thus, how concurrent visual and auditory stimuli are integrated has been an important issue for models of language processing (e.g., Borowsky et al., 1999; Fowler & Deckle, 1991; Frost & Katz, 1989; MacDonald & McGurk, 1978; Massaro, Cohen & Thompson, 1988; McGurk & MacDonald, 1976).

Models of visual word recognition differ in the number and type of non-semantic connections between orthographic and phonological representations. The connections between orthographic and phonological representations allow for these processing subsystems to communicate with one another. The types of communication proposed to exist between processing subsystems may be predominantly *facilitative* (i.e., information from one subsystem has the overall effect of facilitating or benefiting processing in another subsystem), predominantly *inhibitory* (i.e., information from one subsystem has the overall effect of inhibiting or costing processing in another subsystem), or a balanced combination of the two (i.e., equal facilitation and inhibition, or in other words, equal benefits and costs). The communication from one subsystem to another may also be unidirectional or bi-directional. For example, the dual-route cascade model has facilitation-dominant connections that map graphemes onto phonemes, and excitatory bi-directional connections that map orthographic lexical representations onto phonological lexical representations (Coltheart et al., 2001). In contrast, the single-route connectionist models of Seidenberg and colleagues (Harm & Seidenberg, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) have one set of fully recurrent connections between orthographic and phonological units. As such, single-route models typically group together the orthographic levels of representation (e.g., orthographic features, graphemes, and orthographic lexical representations), and, similarly, group together the phonological levels of representation (e.g., phonetic features, phonemes, and phonological lexical representations). Figure 1 illustrates these differences, and provides a framework for comparing dual- and single-route models of visual word recognition, including the types of connections for communicating between processing subsystems that are corroborated in the present experiments.

As illustrated in Figure 1A, dual-route models process printed words by first analyzing the printed words into orthographic features (e.g., curves, lines, angles), which have bi-directional connections with the graphemic level of representation (e.g., *b*). Graphemic information can follow one of two processing routes, hence the name dual-route models. The sublexical (i.e., PD) processing route maps graphemes onto phonemes. Once the phonemes have been assembled and synthesized, they can be used to produce speech output. Assembled phonology can also be checked against stored phonological lexical representations (e.g., Borowsky et al., in press, discuss several criteria for maximizing phonological lexical access when forced to rely on assembled phonology). Alternatively, the graphemes can be synthesized and mapped onto complete orthographic lexical representations. To produce spoken output via this route, orthographic lexical representations are then mapped onto phonological lexical representations (i.e., SV). Coltheart et al. (2001) assumed that the set of connections from the orthographic lexical to the phonological lexical level are facilitative, an assumption that is evaluated in the current set of experiments. It should be noted that both the orthographic lexical and phonological lexical representations may also be influenced by connections with the semantic system.

Speech input is analyzed into phonetic features (e.g., place, manner, and voicing) that are connected to a phonemic level of representation. Again, the phonemes can be assembled to produce speech output or to activate phonological lexical representations. The phonological lexical representations may be used to produce speech or to activate orthographic lexical representations. Coltheart et al. (2001) assumed that the set of connections from the phonological lexical to the orthographic lexical level was facilitative. This assumption is also evaluated in the current set of experiments.

As illustrated in Figure 1B, single-route models process printed words by analyzing the printed words into orthographic representations (e.g., Wicklefeatures; Seidenberg & McClelland, 1989). The orthographic representations are mapped onto corresponding phonological representations via a single set of connections between the orthographic level and the phonological level of representation. Speech input is analyzed into phonological representations; however, they are not considered to be represented separately at the level of features, phonemes and words as in the dual route class of models. That is, SV and PD processes are considered to be redundant within each other.

The present research examines the nature of the connections between orthographic lexical and phonological lexical SV representations by utilizing a recent variant of a two-alternative, forced-choice (2AFC) paradigm (Borowsky et al., 1999; Ratcliff & McKoon, 1997). The experiments reported here involved presenting a "context" stimulus (e.g., saw: *cap*) simultaneously with a target stimulus in a different modality that was congruent (e.g., heard: /cap/), incongruent, or irrelevant to the context (i.e., a baseline; see Table 2). In the congruent condition, the visual context matched the auditory target stimulus, and was followed by a response probe that included the target and another alternative. In the incongruent and irrelevant conditions, the context and target items did not match. For these two conditions, the 2AFC probe presented to the participant determined the distinction between the incongruent and irrelevant conditions. For example, in the incongruent condition, the participant may have seen the visual context *cap* simultaneously with the auditory target /rap/, followed by the visual 2AFC probe containing the misleading context and

Table 2

Example Stimuli as a Function of Congruent, Irrelevant, and Incongruent Conditions

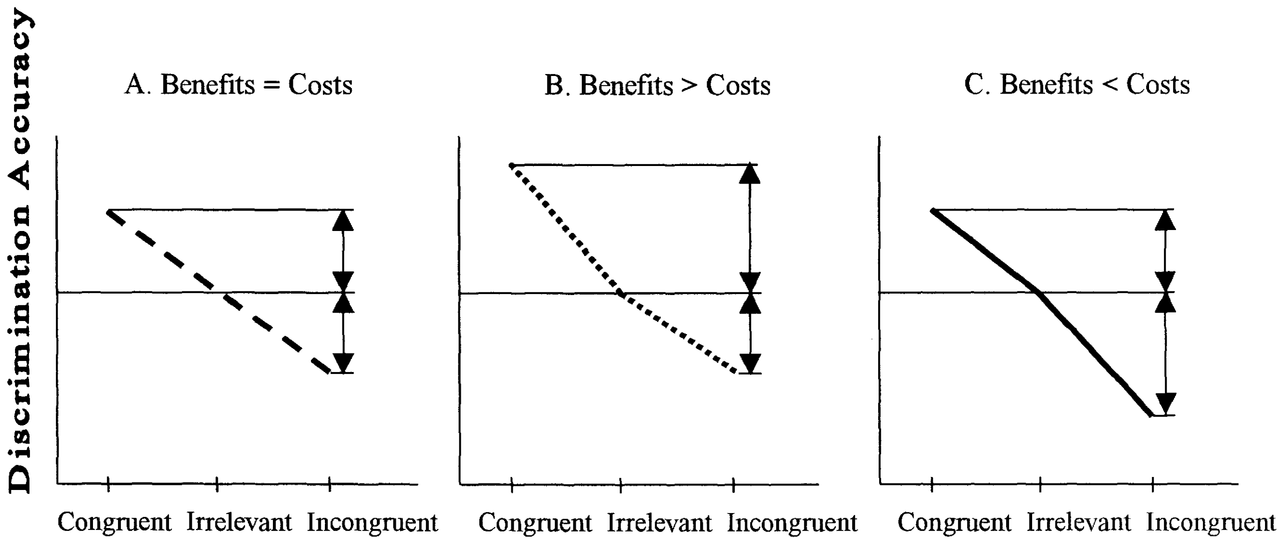
	Conditions		
	Congruent	Irrelevant	Incongruent
Visual Context	cap	map	rap
Auditory Target	/cap/	/cap/	/cap/
Probe	"/cap/ or /rap/"	"/cap/ or /rap/"	"/cap/ or rap/"

the correct target (e.g., heard /cap/ or heard /rap/). In the irrelevant condition, the participant may have also seen the visual context *cap* simultaneously with the auditory target /rap/, however, the visual 2AFC probe contained a non-presented item and the correct target (e.g., heard /map/ or heard /rap/).

The 2AFC paradigm can be used to distinguish bias from sensitivity effects. As described later, *bias effects* occur when the context benefits accurate target discriminations in the congruent condition to the same degree as the context costs target discrimination performance in the incongruent condition (see Figure 2A). In contrast, *sensitivity (or encoding/activation) effects* occur when there is a significant difference between the benefits and costs conveyed by the context in the congruent and incongruent conditions, respectively (see Figures 2B and 2C; see also Massaro, 1989; Masson & Borowsky, 1998; Paap, Johansen, Chun & Vonnahme, 2000; Ratcliff and McKoon, 1997).

Bias Effects versus Equal Facilitation and Inhibition.

If the context stimulus simply serves to bias a participant's willingness to choose a response probe alternative, then the difference between the congruent and the irrelevant conditions would equal the difference between the irrelevant and the incongruent conditions (i.e., the context provides equal benefits and costs; see Borowsky et al., 1999). Ratcliff and McKoon (1997) had proposed that a symmetrical effect of the context upon target discriminations may be interpreted as simple bias (i.e., the participant's selection of a probe stimulus is influenced by the context stimulus if the context stimulus is included in the response probe). This simple bias account implies that there are no direct connections from the context modality to the



e.g., Conditions:	Congruent	Irrelevant	Incongruent
Visual Word Context:	cap	map	rap
Spoken Word Target:	/cap/	/cap/	/cap/
Probe:	cap rap	cap rap	cap rap

Figure 2. Hypothetical effects of the context stimulus upon target discrimination. Bias effects (A) produce equal benefits (congruent minus irrelevant accuracy scores) and costs (irrelevant minus incongruent accuracy scores). Sensitivity effects produce a significant difference between benefits and costs, whereby facilitation-dominant effects (B) produce greater benefits than costs, and inhibition-dominant effects (C) produce greater costs than benefits.

target modality. However, Borowsky et al. (1999) have pointed out that a symmetrical effect of the context on target discriminations could also represent equal facilitative and inhibitory connections between processing subsystems. If the context produces equal benefits and costs it may also be assumed that there must be equal facilitative and inhibitory connections between the context and target modalities. If the context produces equal benefits and costs it is reasonable to assume that there are either equally facilitative and inhibitory connections between the context and target modalities, or no direct connections at all and only simple bias effects instead. Thus, a symmetrical effect of the context on target discriminations can be accommodated by either: (1) a bias effect with no direct connections from the context to the target modality, or (2) equally weighted excitatory and inhibitory connections from the context to the target modality.

Sensitivity Effects: Facilitation versus Inhibition Dominance.

If the context modality differentially affects congruent and incongruent target discriminations, the effect of the context on target discriminations will deviate significantly from a symmetrical effect of the context on 2AFC accuracy. Borowsky et al. (1999) had proposed that asymmetrical effects of the context upon target discriminations are more definitive than bias effects in informing word recognition modelers about the nature of the connection between the context and target modalities. Specifically, if the context stimulus benefits the congruent target discriminations more than it costs the incongruent target discriminations (see Figure 2B), it is reasonable to argue that *facilitation-dominant* connections exist between processing subsystems. That is, in order for the benefits of the congruent context to exceed the costs of the incongruent context, the facilitative connections from the context modality to the target modality must outweigh (i.e., carry more influence than) the inhibitory connections. Thus, when the context is congruent with the target stimulus, the communication between the context and target modalities must be predominantly excitatory in order to produce an added benefit for accuracy in the congruent condition over and above the absolute value of the cost of the context in the incongruent condition. Alternatively, if the context costs the incongruent target discriminations more than it benefits the congruent target discriminations (see Figure 2C), it is reasonable to argue that *inhibitory-dominant* connections exist between processing subsystems. That is, in order for the costs of the incongruent context to exceed the benefits of the congruent context, the inhibitory connections from the context modality to the target modality must outweigh the facilitative connections.

To summarize, a sensitivity effect (facilitation dominance or inhibition dominance of the context modality on the target modality) is evidence for a connection from the context modality to the target modality. Facilitation dominance suggests that the facilitative connections must outweigh the inhibitory connections, whereas inhibition dominance suggests that the inhibitory connections must outweigh the facilitative ones. In this sense, a sensitivity effect is always one of two asymmetrical patterns of the context modality influencing target modality discrimination accuracy, and thus can be interpreted as existing over and above any simple bias effect whereby the participant bases their response on the clearly perceptible context stimulus (which would yield a symmetrical effect of context on target discrimination accuracy), or alternatively, over and above equally facilitative and inhibitory connections from the context modality to the target modality.

Borowsky et al. (1999) have previously used this logic to investigate the nature of the connections between sublexical orthographic (i.e., grapheme) and sublexical phonological (i.e., phoneme) processing systems. Extending Ratcliff and McKoon's (1997) 2AFC paradigm for assessing prime sensitivity effects, Borowsky et al. presented participants with three congruency conditions. A sublexical target stimulus (e.g., spoken /ta/) was presented simultaneously with a context stimulus from a different modality that was congruent (e.g., printed *ta*, probes "heard ta" and "heard da"), irrelevant (e.g., printed *na*, probes "heard ta" and "heard da"), or incongruent (e.g., printed *da*, probes "heard ta" and "heard da") to the target. For the phoneme discrimination experiments, a grapheme provided the context and the phoneme was considered the target, whereas in the grapheme discrimination experiments, a phoneme provided the context and the grapheme was considered the target.

For the phoneme discrimination experiments, Borowsky et al. (1999) showed that grapheme contexts had a facilitation-dominant effect on target phoneme discrimination. That is, the benefits of the context grapheme exceeded the costs. For the grapheme discrimination experiments, they also showed that a phoneme context had a symmetrical effect on congruent and incongruent condition performance compared to the irrelevant baseline condition. The authors interpreted these findings to suggest that there are facilitation–dominant connections from the grapheme system to the phoneme system, and either no direct connections in the opposite direction (i.e., the simple bias interpretation), or equally facilitative and inhibitory connections in the opposite direction.

As single-route models only have one set of non-semantic connections between orthographic and phonological representations, these models predict that the same pattern of results observed for sublexical stimuli (e.g., graphemes, phonemes) would be obtained with lexical stimuli (i.e., words). Because the Borowsky et al. (1999) study showed that the connection from *sublexical* orthographic representations to *sublexical* phonological representations was facilitation dominant, single route models must predict that orthographic *lexical* contexts will facilitate phonological *lexical* discrimination accuracy. Furthermore, because the Borowsky et al. study showed that the connection from *sublexical* phonological representations to *sublexical* orthographic representations is either non-existent (i.e., the simple bias account), or equally facilitative and inhibitory, single route models must predict a symmetrical effect of phonological *lexical* contexts on orthographic *lexical* discrimination accuracy.

As dual-route models (e.g., Coltheart et al., 2001; Zorzi et al., 1998) have two sets of non-semantic connections at the lexical and sublexical levels of representation, these models do not have to predict that the same pattern of results would be obtained for lexical and sublexical stimuli. In fact, the recent Coltheart et al., (2001) dual-route model utilizes facilitation-dominant connections from orthographic sublexical representations to phonological sublexical representations (i.e., graphemes to phonemes), and excitatory, bi-directional connections at the lexical representational level. Based upon these sets of connections, it was hypothesized that orthographic lexical contexts will have a facilitation-dominant effect on phonological lexical discrimination accuracy, and, similarly, it was hypothesized that phonological lexical contexts will have a facilitation-dominant effect on orthographic lexical discrimination accuracy. Moreover, Kay, Lesser & Coltheart (1996) have stated that little is known about the nature and type of the connections between processing subsystems. Because the connections between processing subsystems allow for the different subsystems to communicate with one another, it is important to examine the nature of these connections. The current experiments sought to empirically determine the nature of the connections at the lexical level in order to better inform models of visual and spoken word recognition, and provide a framework for what follows.

Experiments 1 and 2

Experiments 1 and 2 investigated the influence of an orthographic lexical context upon spoken word discrimination. Experiment 1 was designed to be a relatively difficult spoken word discrimination task, whereas in Experiment 2 the spoken word discrimination was made easier by increasing the audibility of the spoken word targets. Experiment 2 served to evaluate whether the pattern of results would change as a function of location on the accuracy scale, which might implicate a scaling artefact, or some form of additional bias that depends on the discriminability of the target.

Method

Participants. Thirty-two University of Saskatchewan students participated in Experiment 1 for partial credit in an introductory psychology class, and another 24 students were paid $5 for participating in Experiment 2. Each participant gave informed written consent as approved by the University of Saskatchewan Behavioral Sciences Ethics Committee (see Appendix A). All reported English as their first language and normal (or corrected-to-normal) vision.

Apparatus. An IBM-compatible computer with Micro-Experimental Laboratories (MEL) software controlled the timing of events and recording of the data. Orthographic stimuli were presented in white on a black background using a NEC colour monitor (model JC-15W1VMA). A pair of Altec Lansing ACS5 speakers, placed on either side of the monitor, was used to present the auditory stimuli via a Creative Lab Sound Blaster-compatible 16-bit audio card. The "1" and "2" keys on the numeric keypad were used to collect participants' responses.

Materials and design. Five three-letter word triplets were used for the set of experiments reported here (see Appendix B). Within each triplet set, the items were matched for rhyme and whether the initial letter was an ascender (e.g., d), descender (e.g., p), or x-height (e.g., m). Creative WaveStudio (version 2) was used to record the spoken words (spoken by a male). Each triplet was constructed such that each initial onset was added to the same rhyme. All spoken stimuli were recorded in 16-bit mono, at a sampling frequency of 22KHz, and were 500ms in duration. Each spoken stimulus was presented simultaneously with white-noise (the MEL white-noise level was set to 88% maximum output for Experiment 1, and reduced to 86% maximum output for Experiment 2). MEL code specification for the white-noise output was AUDIO_SET_VOLUME(4, 0, 88) and AUDIO_SET_VOLUME(4, 0, 86) for Experiments 1 and 2, respectively, which effectively masked the spoken words.

Three congruency conditions were created based on the match of the orthographic lexical context to the spoken word target and the response probe (see Table 2). The orthographic stimulus was presented simultaneously with the spoken word target and was congruent, incongruent, or irrelevant to the target. In the *congruent* condition, the orthographic context matched the spoken word target, and the visually presented response probe for this condition contained the target and one of the other two stimuli from the same triplet set (e.g., orthographic context *cap* and spoken word target /cap/, probed with *heard cap* or *heard rap*). In the *irrelevant* condition, the orthographic context did not match the spoken word target, and the visually presented response probe contained the target and the irrelevant remaining stimulus from the triplet set (e.g., orthographic context *map* and spoken word target /cap/, probed with *heard cap* or *heard rap*). In the *incongruent* condition, the orthographic context did not match the spoken word target, and the visually presented response probe contained both the context and target stimuli (e.g., orthographic context *rap* and spoken word target /cap/, probed with *heard cap* or *heard rap*). The three spoken words from each triplet and corresponding orthographic stimuli appeared in each of the congruent, incongruent, and irrelevant conditions equally often, and the correct alternative of the response probe appeared equally often on the right- or left-hand side, creating 36 trial conditions per triplet set. The experiment consisted of 15 practice trials, followed by two continuous blocks of 180 randomized trial conditions for a total of 360 experimental trials.

Procedure. Participants were instructed, both verbally and in writing, that they would see a printed word (e.g., *cap*, *map*, or *rap*) in the middle of the computer screen and, at the same time, they would hear a spoken word presented in white-noise. They were told to pay attention to both what they saw and what they heard (and that sometimes the two would match, sometimes not), but to respond to what they heard, selecting from a two-alternative response, as quickly and accurately as possible, with an emphasis placed upon accuracy of responding. If the participant was unsure of what they heard, they were told to guess. The sequence of events was: (1) a fixation mark appeared in the centre of the screen, (2) the participant pressed the space-bar to initiate each trial, (3) after a 100 ms interstimulus interval (ISI), a clearly visible orthographic stimulus appeared in the centre of the screen simultaneously with the degraded spoken word target, both for a total of 500 ms, and (4) after a 100 ms ISI, a two alternative response probe was presented visually, in bright text, a couple of lines below where the context orthographic stimulus was presented (e.g., *heard cap* [*press 1*], *heard rap* [*press 2*]). The procedure was approximately 25 minutes in duration, during which time the experimenter remained in the laboratory.

Results

Experiment 1. Overall mean response accuracy for the congruent, irrelevant, and incongruent conditions is presented in Figure 3A. A repeated measures analysis of variance (ANOVA) of condition (congruent, irrelevant, and incongruent) on accuracy was significant, $F(2,62) = 68.85$, $MSE = 126.92$, $p < .001$. Dependant t-tests showed that the mean accuracy for the congruent condition was significantly greater than that for the irrelevant condition, $t(31) = 8.716$, $SE = 2.12$, $p < .001$, and the irrelevant condition mean accuracy was significantly greater than the incongruent condition mean accuracy, $t(31) = 6.77$, $SE = 2.14$, $p < .001$. The test of the difference of the

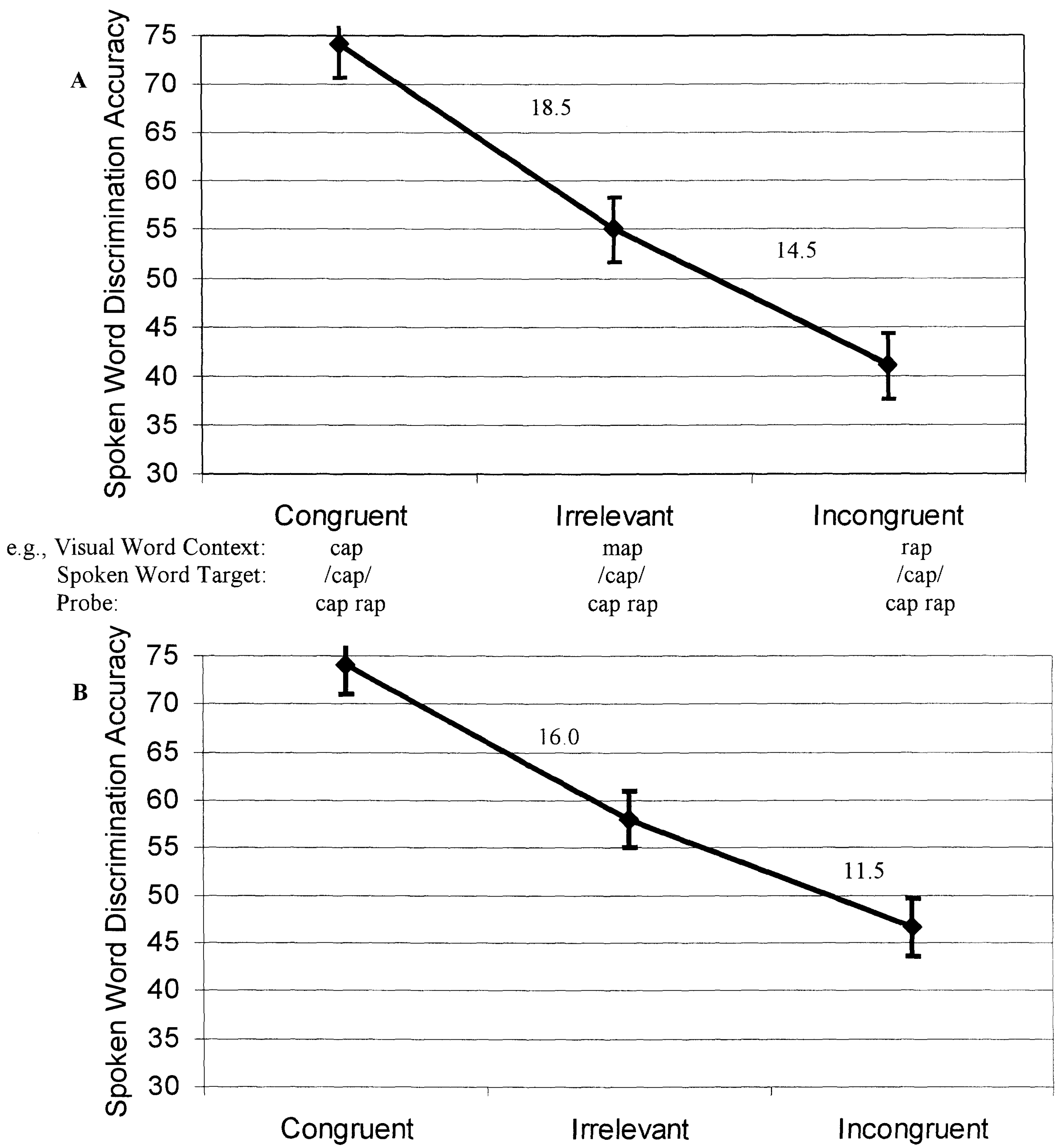


Figure 3. Mean spoken word discrimination accuracy (in percent) as a function of orthographic and phonological lexical congruency for: (A) Experiment 1, and (B) Experiment 2. Confidence intervals were calculated using the formula for a with-in subjects design as outlined in Loftus and Masson (1994).

congruent condition mean accuracy minus the irrelevant condition mean accuracy (18.5%) and the irrelevant condition mean accuracy minus the incongruent mean accuracy (14.5%) was significant, *t*(31) = 2.17, *SE* = 1.85, *p* < .05.

Experiment 2. Overall mean response accuracy for the congruent, irrelevant, and incongruent conditions is presented in Figure 3B. A repeated measures ANOVA of condition on accuracy was significant, *F*(2,46) = 59.65, *MSE* = 76.59, *p* < .001. Dependant t-tests showed that the mean accuracy for the congruent condition was significantly greater than that for the irrelevant condition, *t*(23) = 8.795, *SE* = 1.82, *p* < .001, and the irrelevant condition mean accuracy was significantly greater than the incongruent condition mean accuracy, *t*(23) = 5.47, *SE* = 2.09, *p* < .001. The test of the difference of the congruent condition mean accuracy minus the irrelevant condition mean accuracy (16.0%) and the irrelevant condition mean accuracy minus the incongruent mean accuracy (11.5%) was significant, *t*(23) = 2.33, *SE* = 1.99, *p* < .05.

Experiment 2 was conducted to determine if increasing the response accuracy level would alter the facilitation-dominance effect found in Experiment 1. A one-tailed independent samples t-test was conducted to determine if the baseline (i.e., irrelevant) condition in Experiment 2 was significantly greater than that observed in Experiment 1. The difference between the baseline conditions (3%) was significant, *t*(54) = 1.77, *SE* = 1.47, *p* < .05. To determine if the pattern of results differed between Experiments 1 and 2, an ANOVA of condition by experiment was conducted on the accuracy data. There was a main effect of experiment, *F*(1,54) = 5.73, *MSE* = 55.74, *p* < .05, and of condition, *F*(2,108) = 119.52, *MSE* = 105.48, *p* < .001. There was no interaction between experiment and condition in the repeated measures ANOVA (*F*'s < 1.00), and thus Experiment 1 and 2 accuracy data were combined. A one-sampled t-test comparing the difference of the facilitation effect (i.e., the congruent minus irrelevant condition mean accuracy) minus the inhibition effect (i.e., the irrelevant minus incongruent condition mean accuracy) to a mean of zero was conducted. This difference score was significantly greater than zero, $t(55) = 3.17$, $SE = 1.35$, $p < .01$, and the confidence intervals did not include zero (see Table 3). This facilitation dominance effect was also supported by a significant quadratic trend among the condition means, $F(1,55) = 10.07$, $MSE = 16.90$, $p < .01$.

Discussion

Experiments 1 and 2 provided evidence of facilitation-dominant connections from orthographic lexical representations to phonological lexical representations. As the same pattern held for both levels of phonological discriminability, the facilitation-dominance result was not compromised by a scaling effect on overall accuracy, nor any form of additional bias due to the discriminability of the target. A scaling account would suggest that the non-linear function observed in Experiment 1 was due to a floor effect that limits poor performance in the incongruent condition, and that by increasing the target discriminability the non-linear function would become more linear. An additional bias account would suggest that as the discriminability of the target increased, the shape of the non-linear function would change according to how this bias influences the participant's judgment (see Borowsky et al., 1999). However,

Table 3

Mean Difference Between Facilitation and Inhibition (in percent), and the 95% Confidence Intervals as a Function of Discrimination Task

	Facilitation Minus Inhibition	95% Confidence Interval	
Discrimination Task	Mean Effect	Lower Bound	Upper Bound
Spoken Word Discrimination (Experiments 1 and 2)	+ 4.27	+ 1.57	+ 6.97
Written Word Discrimination (Experiments 3 and 4)	- 0.72	- 3.53	+ 2.09

the scaling and additional bias accounts can be ruled out as plausible alternatives because the shape of the function did not change as a result of increasing the target discriminability. Thus, the results of Experiments 1 and 2, which demonstrated that orthographic contexts benefit congruent accuracy more than they cost incongruent accuracy, are concordant with facilitation-dominant connections from orthographic lexical level of representation to phonological lexical level of representation. Experiments 3 and 4 examined the influence of phonological lexical contexts on orthographic lexical discriminations.

Experiments 3 and 4

Experiments 3 and 4 investigated the influence of a spoken word context upon orthographic word discrimination. Experiment 3 was designed to be a relatively difficult orthographic word discrimination task, whereas in Experiment 4 the orthographic word discrimination was made easier by increasing the visibility of the orthographic word targets. Experiment 4 served to evaluate whether the pattern of results would change as a function of location on the accuracy scale.

Method

Participants. Thirty-two University of Saskatchewan students participated in Experiment 3 for partial credit in an introductory psychology class, while 24 different students participated in Experiment 4. All reported English as their first language and normal (or corrected-to-normal) vision.

Apparatus. The same apparatus as in the previous experiments was used.

Materials and design. The same materials and design as in the previous experiments were used for Experiments 3 and 4. The only differences were that clearly audible words (i.e., without any white-noise) now provided the context, and the orthographic words were degraded by contrast reduction and presented as targets. MEL code specification for the specific level of the contribution of red, green, and blue for dark gray was SET_PALETTE_VGA(8,5,5,6) and SET_PALETTE_VGA(8,6,6,6) in Experiments 3 and 4, respectively. Although contrast reduction is arguably different from the addition of white-noise used in Experiments 1 and 2, Borowsky and Besner (1991; 1993) have shown that contrast reduction is suitable for demonstrating both facilitation and inhibition priming effects in the lexical decision task.

Procedure. The procedure was similar to that in Experiments 1 and 2 except that participants were to discriminate between target orthographic words. In order to obtain similar mean response accuracy for the baseline (i.e., irrelevant) conditions in the orthographic discrimination tasks as was observed for the same condition in the spoken word discrimination tasks, the visually degraded orthographic presentation was reduced to 150 ms.

The procedure was similar to Experiments 1 and 2, except participants were instructed to respond to what they saw. The sequence of events was: (1) a fixation mark appeared in the centre of the screen, (2) the participant pressed the space-bar to initiate each trial, (3) after a 100 ms ISI, a degraded orthographic stimulus appeared in the centre of the screen for 150 ms during the simultaneous presentation of a clearly audible spoken word target for 500 ms, and (4) after a 100 ms ISI, a two alternative response probe was presented visually, in bright text, a couple of lines below where the target orthographic stimulus was presented (e.g., *saw cap* [*press 1*], *saw rap* [*press*

2]. The procedure was approximately 35 minutes in duration, during which time the experimenter remained in the laboratory.

Results

Experiment 3. Overall mean response accuracy for the congruent, irrelevant, and incongruent conditions is presented in Figure 4A. A repeated measures ANOVA of condition (congruent, irrelevant, and incongruent) on accuracy was significant, $F(2,62) = 40.72$, $MSE = 249.69$, $p < .001$. Dependant t-tests showed that the mean accuracy for the congruent condition was significantly greater than that for the irrelevant condition, $t(31) = 6.01$, $SE = 2.97$, $p < .01$, and the irrelevant condition mean accuracy was significantly greater than the incongruent condition mean accuracy, $t(31) = 6.29$, $SE = 2.82$, $p < .001$. The test of the difference of the congruent condition mean accuracy minus the irrelevant condition mean accuracy (17.5%) and the irrelevant condition mean accuracy minus the incongruent mean accuracy (17.5%) was not significant, $t(31) = 0.04$, $SE = 1.91$, $p = .968$.

Experiment 4. Overall mean response accuracy for the congruent, irrelevant, and incongruent conditions is presented in Figure 4B. A repeated measures ANOVA of condition on accuracy was significant, $F(2,46) = 16.59$, $MSE = 124.29$, $p < .001$. Dependant t-tests showed that the mean accuracy for the congruent condition was significantly greater than that for the irrelevant condition, $t(23) = 3.39$, $SE = 2.46$, $p < .01$, and the irrelevant condition mean accuracy was significantly greater than the incongruent condition mean accuracy, $t(23) = 4.23$, $SE = 2.40$, $p < .01$. Again the test

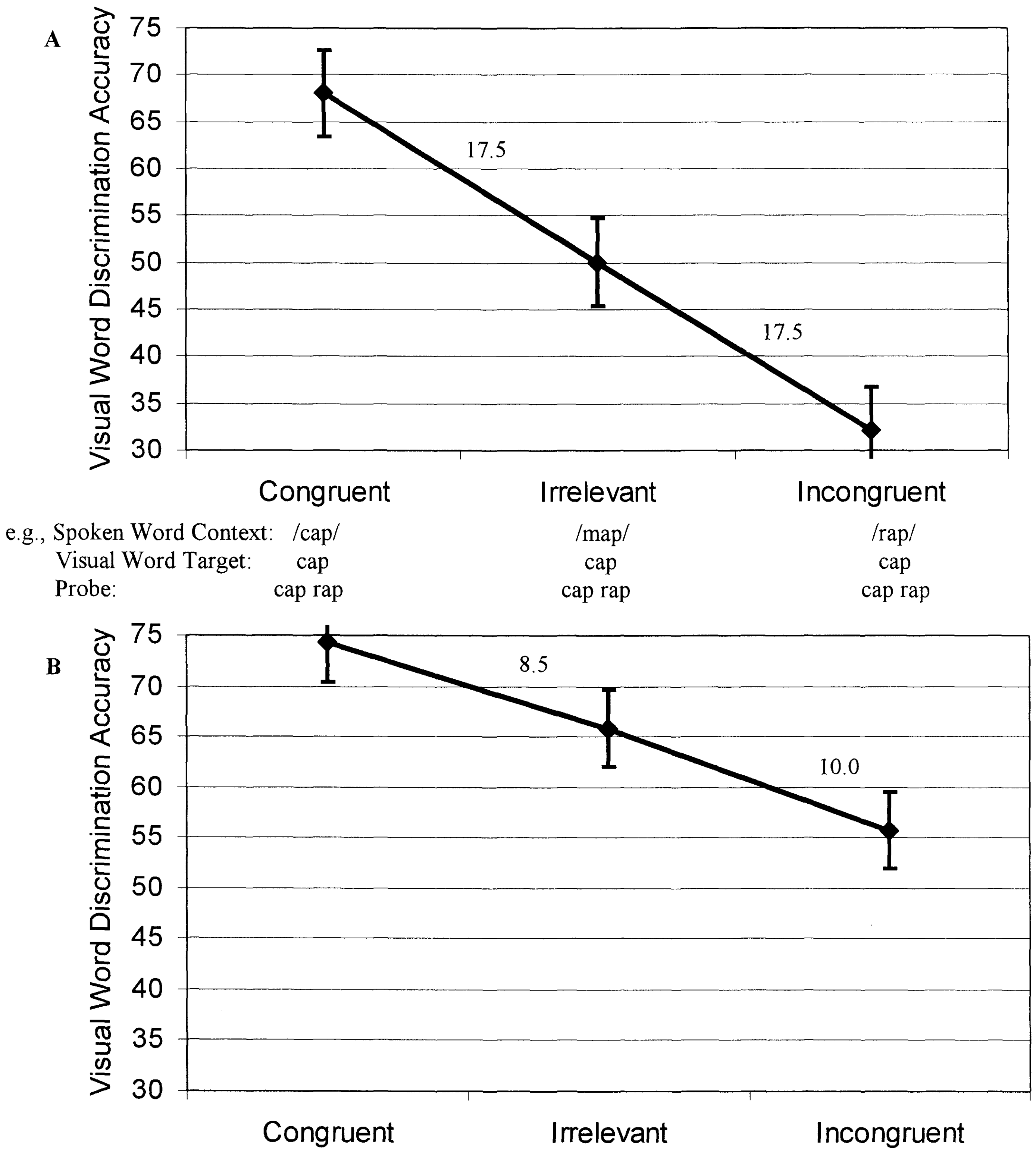


Figure 4. Mean written word discrimination accuracy (in percent) as a function of orthographic and phonological lexical congruency for: (A) Experiment 3, and (B) Experiment 4. Confidence intervals were calculated using the formula for a with-in subjects design as outlined in Loftus and Masson (1994).

of the difference of the congruent condition mean accuracy minus the irrelevant condition mean accuracy (8.5%) and the irrelevant condition mean accuracy minus the incongruent mean accuracy (10.0%) was not significant, $t(23) = -0.85$, $SE = 2.09$, $p = .405$.

Since the purpose of Experiment 4 was to determine if an increase in response accuracy would alter the symmetrical effect found in Experiment 3, a one-tailed independent samples t-test was conducted to confirm that the response accuracy for the baseline (i.e., irrelevant) condition in Experiment 4 was significantly greater than that observed for Experiment 3. There was a significant difference between the baseline conditions for the two experiments, $t(28.1) = 5.56$, $SE = 2.86$, $p < .001$. To determine if the pattern of results differed between Experiments 3 and 4, an ANOVA of condition by experiment was conducted on the accuracy data. There was a main effect of experiment, $F(1,54) = 50.15$, $MSE = 191.93$, $p < .001$, and of condition, $F(2,108) = 51.25$, $MSE = 196.28$, $p < .001$. There was also a significant interaction between experiment and condition, $F(2,108) = 5.15$, $MSE = 196.28$, $p < .01$. However, the test of the quadratic trend, which is equivalent to comparing the facilitation and inhibition effects, did not indicate any interaction between experiment and condition, $F(1,54) = 0.42$, $MSE = 18.58$, $p = .519$, and thus Experiment 3 and 4 accuracy data were combined. A one-sampled t-test comparing the difference of the facilitation effect (i.e., the congruent minus irrelevant condition mean accuracy) minus the inhibition effect (i.e., the irrelevant minus incongruent condition mean accuracy) to a mean of zero was conducted. This difference score was not significantly different from zero, $t(55) = -0.51$, $SE = 1.40$, $p = .613$, and the confidence intervals did include zero (see Table 3). The test for the quadratic trend supported the difference of differences analysis in that there was no significant deviation from a linear function, $F(1,55) = 0.26$, $MSE = 18.39$, $p = .613$. To examine if there was a difference in the quadratic trend amongst the condition means between the phonological discrimination tasks (i.e., Experiments 1 and 2) and the orthographic discrimination tasks (i.e., Experiments 3 and 4), a condition (congruent, irrelevant, incongruent) by discrimination task (phonological and orthographic) quadratic trend test was conducted. The interaction between condition and discrimination task was significant, $F(1, 110) = 6.57$, $MSE = 17.64$, $p < .05$, suggesting that the pattern of results differed as a function of the discrimination tasks.

Discussion

Experiments 3 and 4 provided evidence of a symmetrical effect of phonological lexical contexts on orthographic lexical discriminations. As the same pattern held for both levels of orthographic discriminability, this symmetrical effect is not compromised by a scaling artefact on overall accuracy, nor any form of additional bias due to the target discriminability. Inspection of the confidence intervals from Experiments 1 and 2, and Experiments 3 and 4 reveal that they do marginally overlap, and thus it could be argued that they do not provide unambiguous support that the pattern of results from Experiments 3 and 4 differed from Experiments 1 and 2. However, when analyzed from a different perspective, the data are more suggestive of a difference between the experiments. Specifically, the highest order trend for Experiments 1 and 2 combined was quadratic, whereas for Experiments 3 and 4 combined the highest order trend was linear. Furthermore, the test of the quadratic trend interaction between condition and discrimination task was significant. Taken together, these results do suggest that the pattern of results did change as a function of the discrimination task. The pattern of results for Experiments 3 and 4, which demonstrated that phonological contexts benefit congruent condition accuracy as much as they cost incongruent condition accuracy, could thus be accommodated by either: (1) equally weighted facilitative and inhibitory connections, or (2) a simple bias account with no direct connections between the two lexical subsystems.

Semantic and/or Sublexical Involvement. A concern that deserves some consideration is whether target discriminations could have been made at the semantic level or at the sublexical level instead of at the lexical level. Given that the experiments all used five, three-letter word triplets, which were repeated several times in counterbalancing, it seems unlikely that the stimuli were being semantically processed. Alternatively, it could be argued that the high repetition of the word triplets may have promoted the participants to eventually rely on a sublexical strategy whereby the participant would focus their attention to the onset of the target stimuli. An analysis of the first 90 trials (i.e., the first 25% of the experimental trials) for each experiment suggests that this is not the case, as the same symmetrical and asymmetrical effects are observed as reported for the full experiments (with the exception that there was only a trend for a 6.7% facilitation dominant sensitivity effect in Experiment 2, $t(23) = 1.540$, $SE = .043$, $p = .137$, but note that the pattern was in the correct direction).

Conclusions (Experiments 1-4)

The present set of experiments extended the Borowsky et al. (1999) findings to examine the type of connections involved at the lexical or SV-level of orthographic and phonological representations. Single-route models predict that the same type of connections must exist for both sublexical and lexical levels of representation, whereas dual-route models can allow for different types of connections along the two routes (e.g., Coltheart et al., 2001). As previously discussed, if the context manipulation produces a *symmetrical* effect on target discriminations, as indicated by the context benefiting congruent condition performance to the same degree as the context costs incongruent condition performance, it is reasonable to argue that: (1) there are no direct connections between the context and target modalities (i.e., a simple response bias effect has occurred), or (2) there are equally weighted excitatory and inhibitory connections from the context modality to the target modalities. A more informative outcome, however, is when the context manipulation produces an *asymmetrical* effect on target discriminations, as indicated by costs *not* equaling benefits. This type of result suggests that a directionally-weighted sensitivity effect has occurred. Specifically, if the context benefits the congruent condition performance more than it costs the incongruent condition performance, it is reasonable to argue that the facilitative connections from the context modality to the target modality must outweigh (i.e., carry more influence than) the inhibitory connections. If, on the other hand, the context costs the incongruent condition performance more than it benefits the congruent condition performance, it is reasonable to argue that the inhibitory connections from the context modality to the target modality must outweigh the facilitative connections. The present results indicated that facilitation-dominant connections exist from the orthographic lexical processing subsystem to the phonological lexical processing subsystem. Borowsky et al. (1999) also obtained this pattern for the level of connections that map graphemes onto phonemes. Although both dual- and single-route models can account for both Borowsky et al.'s results in conjunction with the present set of results, such findings are important for constraining the types of connections necessary for models of visual word recognition and speech perception (see Figure 5).

Many current speech perception models that describe both orthographic and phonological processing cannot account for the present set of results (see also Borowsky et al, 1999). For example, Fowler and Deckle's (1991) Direct Realist Theory (developed from Liberman and Mattingly's, 1985, Motor Theory) states that orthographic processing will not influence phonological processing because orthography does not emanate from the same common causal source (i.e., vocal tract gestures). Accordingly, it predicts that there should have been no influence of orthographic lexical processing on phonological lexical processing (i.e., no sensitivity effects across the modalities of orthographic and phonological processing). Massaro et al.'s (1988; Massaro & Cohen, 1993) Fuzzy Logical Model of Perception consists of three operations involved in perception, those of feature evaluation, feature integration, and decision. The feature evaluation of the orthographic information is assumed to be independent of the phonological information. Only at the level of feature integration can orthographic and phonological information interact. As such, Massaro's (1989, pp. 402, 404; see also, Massaro et al, 1988) Fuzzy Logical Model of

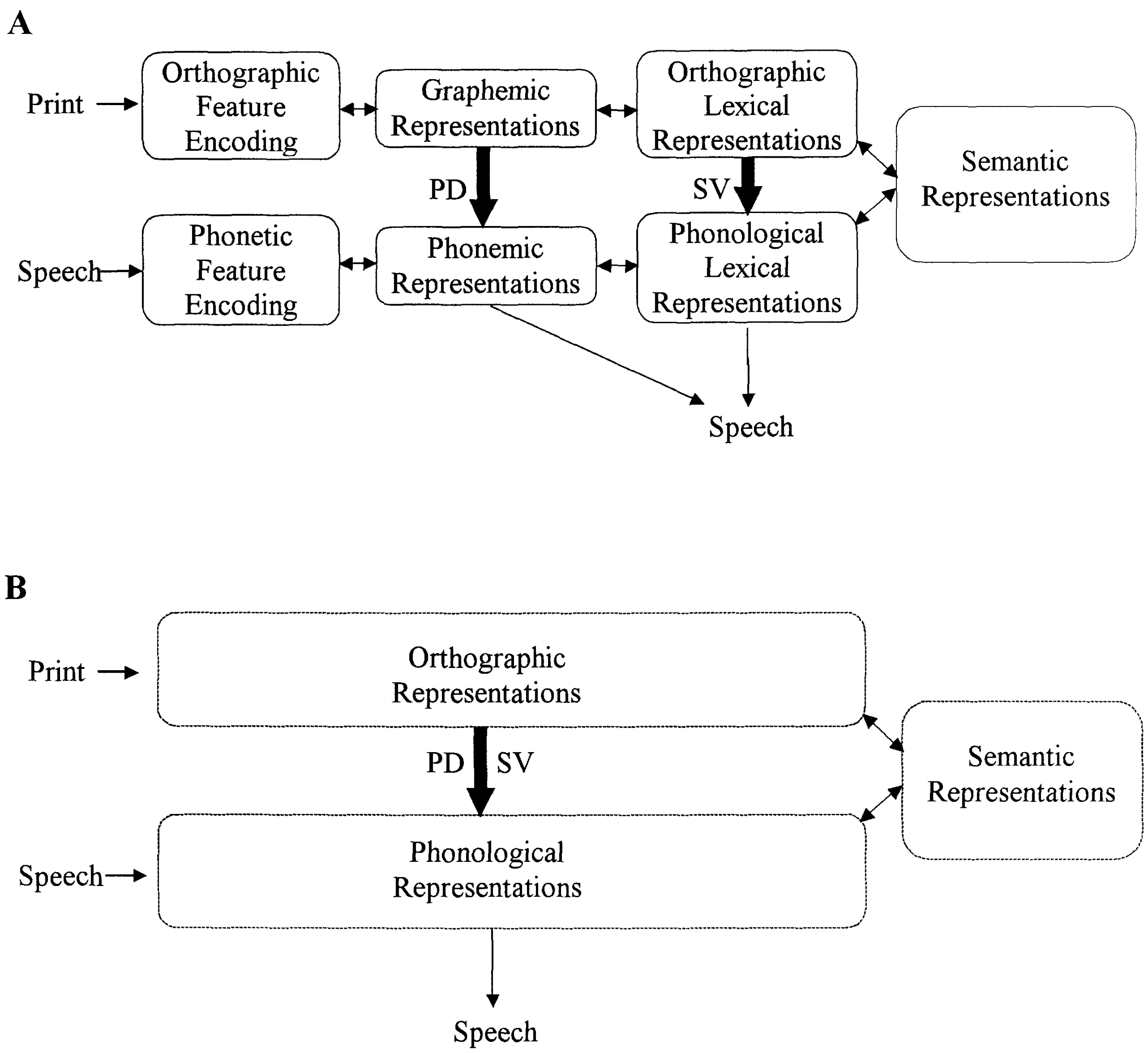


Figure 5. A modified framework for comparing dual- and single-route models of visual word recognition (see Owen & Borowsky 2002a): A. Dual-route model, B. Single-route model. Connections that have been corroborated by experiments are shown in bold. PD = phonetic decoding route, SV = sight vocabulary route.

Perception clearly predicts that cross-modal orthographic and phonological processing effects would be limited to bias effects (i.e., in the present design, the context manipulation should only produce a symmetrical effect on target discrimination accuracy). Both Borowsky et al.'s results and the present results clearly indicated that orthography does facilitate phonological discrimination sensitivity (i.e., at both phonemic and spoken word levels).

Some models of visual word recognition appear to be better able to handle the present set of results. The dual-route cascade model of visual word recognition (Coltheart et al., 2001) has a set of facilitation-dominant connections at the level of mapping graphemes onto phonemes (i.e., the PD route), which is consistent with the Borowsky et al. (1999) findings. At the SV level, Coltheart et al. (2001) have utilized excitatory bi-directional connections. Having excitatory bi-directional connections between the orthographic and phonological lexical representations implies that this architecture would predict facilitation-dominance in both the phonological lexical discrimination tasks (i.e., Experiments 1 and 2) and orthographic lexical discrimination tasks (i.e., Experiments 3 and 4). However, our results suggest that the nature of the SV-level connections needs to reflect a greater facilitative influence of orthographic processing on phonological processing along with equally facilitative and inhibitory influences of phonological processing on orthographic processing (or no connections in this direction, but the dual-route cascade model is clearly implemented to better handle equal interactive activation at this level). As such, Coltheart et al.'s model would require that the amount of orthographic lexical excitatory activation cascading to the phonological lexical level exceeds the amount of orthographic lexical inhibitory activation cascading to the phonological lexical level. In addition, Coltheart et al.'s model would also require that the amount of phonological lexical excitatory and inhibitory activation cascading to the orthographic lexical level be roughly equivalent. Zorzi et al.'s (1998) dual-route connectionist architecture would require that the influence of facilitative connections outweigh the inhibitory connections along both the direct (i.e., PD) and mediated (i.e., SV) routes from orthography to phonology, and that the facilitative and inhibitory feedback from phonology to orthography be roughly equivalent. Single and dual-route models that implement fully recurrent connections (e.g., Jacobs, Rey, Ziegler & Grainger, 1998; Plaut et al., 1996) would also need to be modified to reflect facilitation-dominance from the orthographic to phonological lexical levels of representation. Again, this modification would require that orthographic to phonological facilitative connections outweigh any inhibitory connections, and that phonological to orthographic facilitative and inhibitory connections are equally weighted (if they are to be implemented at all).

The current set of experiments provides an important constraint on the nature of the connections between lexical (i.e., SV) orthographic and phonological representations for models of speech and visual word recognition (see Figure 5). In general, the present results are consistent with the fact that readers have a lot of experience mapping written letters and words onto phonological representations (Borowsky et al., 1999; Frost & Katz, 1989). Future studies could explore whether the opposite pattern of results (in particular, phonological lexical to orthographic lexical facilitation dominance) would be observed for individuals who are highly practiced in mapping spoken words onto orthographic representations (e.g., stenographers).

Another important direction for this research is to explore semantic-mediated target discrimination, and the nature of the connections between the semantic system and the orthographic and phonological subsystems. For example, one could examine a semantic-mediated version of this paradigm whereby the imageability of the targets is manipulated (Strain et al., 1995) or picture contexts are used (Masson & Borowsky, 1998).

Chapter 2

CONTEXTUAL INFLUENCES ON SIGHT VOCABULARY AND PHONETIC DECODING RELIANCE

2.1 The veridicality of the word frequency and orthographic length effects as indices of sight vocabulary and phonetic decoding.

As described in the introduction, a long, often debated issue in basic reading research pertains to the question of how readers compute pronunciations of letter-strings from print (e.g., Huey, 1908). With respect to English, this question is further complicated by the fact that the English language is quasi-regular (i.e., English has both typical and atypical spelling-sound associations). Researchers have therefore tended to dichotomize English words as being either regular or exception. Recall that *regular words* (e.g., mint, cake) can be defined as words with typical spelling-sound correspondences, whereas *exception words* (e.g., pint, yacht) can be defined as words with atypical spelling-sound correspondences. Thus, in order to address the question of how readers compute pronunciations from orthographic patterns, models of visual word recognition must address how skilled readers name these two types of real English words, as well as novel orthographic letter-strings.

To account for the ease with which skilled readers name regular words, exception words, and novel stimuli, one group of researchers has concluded that there are two basic reading processes (e.g., Bernstein & Carr, 1996; Besner, 1999; Coltheart et al., 2001; Paap & Noel, 1991; Zorzi et al., 1998). Recall that the SV route maps whole-word orthographic patterns onto whole-word phonological representations, whereas the PD route parses the orthographic patterns into sub-lexical units (i.e., graphemes), which are mapped onto phonemes, and then assembled to produce a phonological representation. In contrast, another group of researchers have assumed that SV and PD processes are redundant, and, therefore, they only instantiate a single processing route (e.g., Carello et al., 1994; Harm & Seidenberg, 1999; Henderson, 1982; Kwantes & Mewhort, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989). Despite the differences in terms of the number of routes from print to sound, both classes of models have been shown to account for the ubiquitous word frequency effect (i.e., words that occur more frequently in printed material are named faster than words that occur less often in printed material), and the word frequency by regularity interaction (i.e., the word frequency difference is larger for exception words than for regular words).

A major difference between dual- and single-route models is the degree of flexibility with which one can access either sub-lexical or lexical level representations. One obvious question to ask is whether readers can strategically adjust their reliance on SV and PD processes (e.g., Coltheart, 1978; Plaut et al., 1996). Moreover, the degree to which readers can strategically adjust their reliance on SV and PD processes may provide details about the degree to which SV and PD reading processes are controlled or automatic (e.g., Hasher & Zacks, 1979; cf. Logan, 1988). That is, can the concepts of controlled (i.e., voluntary, effortful processes) and automatic (i.e., ballistic, energy efficient processes) processing often discussed in the skills acquisition literature be applied to the concepts of PD and SV reading processes? Studies by Paap and Noel (1991; see also Bernstein & Carr, 1996) and Owen and Borowsky (2002b) seem to address this question.

Paap and Noel (1991; Bernstein & Carr, 1996) tested a counter-intuitive prediction that increasing concurrent processing load (e.g., memory set for 1-5 digits) would free low frequency words from the competing impact of assembled phonological processes (i.e., a release from competition effect), and thus eliminate the word frequency by regularity interaction described in the introduction. Paap and Noel assumed that the PD processing route requires attentional resources. That is, PD is a controlled reading process, and by diverting resources from the PD route to a concurrent memory task, it was predicted that the PD route would not be able to contribute to the phonological output of low frequency exception words. Paap and Noel (1991) found that increased memory loads freed the low frequency exception words from the impact of assembled phonological processing, thus eliminating the word frequency by regularity interaction. This suggests that readers do have some control over PD processing.

In a previous study, Owen and Borowsky (2002b) demonstrated that skilled readers could be forced to increase their reliance on either PD or SV processing. However, Owen and Borowsky utilized a stimulus-driven manipulation to influence SV processing (i.e., stimulus degradation, which has been shown to interact with the effects of automatic spreading activation, Borowsky & Besner, 1993) and an instructional manipulation to influence PD processing (i.e., a manipulation of effortful, controlled processes). In a between-subjects design, one third of the participants named visually degraded words under normal naming instructions, one third of the participants named visually intact words under phonetic decoding instructions, and one third of the participants named visually intact words under normal naming instructions (i.e., a baseline condition). The authors reported that when a list of regular and exception words were visually degraded, participants made selectively more whole-word errors (e.g., pronouncing *one* as "ore"), an index of SV processing. In contrast, when the same items were given to a different group of participants who were instructed to pronounce the items based upon how they looked (i.e., to phonetically decode the items), participants made more nonword errors (e.g., pronouncing *one* as "onnie"), an index of PD processing. Furthermore, nonword errors were slower than whole-word errors, thus providing additional support for the connection between controlled PD and automatic SV processing. It was concluded, based upon this study, that readers could strategically increase their reliance on either SV or PD processing. However, visual degradation and instruction manipulations are fairly deliberate manipulations. A question remains whether readers are sensitive to more subtle manipulations of list context because skilled readers are often exposed to differing list contexts and are rarely exposed to, say, visual word degradation.

Numerous studies have shown that readers have some degree of flexibility over their use of the SV and PD routes (e.g., Baluch & Besner, 1991; Davelaar et al., 1978; Hendriks & Kolk, 1997; Monsell et al., 1992; Zevin & Balota, 2000). For example, Zevin and Balota (2000; Experiment 3) primed either the SV or the PD route by presenting five low frequency exception words or five nonwords, respectively. The primes were followed by a regular word target. As regular words can be named correctly via PD or SV processes, Zevin and Balota argued that the word frequency effect would be modulated as a function of prime-type. Indeed, they showed that when the PD route was primed using nonwords, the word frequency effect for the regular words was smaller than when the SV route was primed using low frequency exception words. Monsell et al. (1992) also showed that the word frequency effect for exception words decreases when the list context also includes nonwords. Moreover, the interaction between word frequency and list context has been extended to other languages. Baluch and Besner (1991) found that in Persian, which has words that contain vowels (i.e., transparent words) and words that do not contain vowels (i.e., opaque words), the inclusion of nonwords minimizes the word frequency effect for the transparent words. The transparent words are akin to regular English words, and can be read via SV or PD processes. The inclusion of nonwords maximizes the reliance on PD processing and, therefore, reduces the word frequency effect. These findings suggest that readers can contextually adjust their reliance on the SV route, as illustrated by either the presence or absence of a word frequency effect. However, the simple presence or absence of a word frequency effect does not allow one to fully investigate the relationship between SV and PD processes. That is, a manipulation that decreases the word frequency effect, signifying a decrease in SV processing, needs to be interpreted in light of how that particular manipulation affects an index of PD processing.

Previous studies have used the orthographic length effect as an index of PD processing (e.g., Weekes, 1997). Recall that the orthographic length effect reflects longer response latencies for orthographic stimuli that contain many letters as opposed to stimuli that contain few letters. Orthographic length effects are larger for nonwords than for words, and larger for low frequency words than high frequency words (e.g., Weekes, 1997).

The question of interest for the present set of experiments is whether list context manipulations that facilitate SV processing, as indexed by an increase in the word frequency effect, would also affect the role of PD processing, as indexed by the orthographic length effect (i.e., whether there is a dissociation between word frequency and orthographic length effects). As single-route models assume that SV and PD processes are redundant (i.e., captured in a single processing route), single-route models must predict that measures of SV and PD processing are not dissociable. However, because dual-route models separate SV from PD processing, dual-route models can account for selective manipulations of SV and PD processing, as measured by word frequency and orthographic length effects, respectively.

Experiment 5 investigated whether list context influences the degree to which readers rely on SV and PD processes. Unlike previous research, this experiment assessed both word frequency and orthographic length effects in order to fully consider the degree to which SV and PD use can be manipulated. Additionally, most previous research has assessed the influence of list context on only one or two stimulus types (e.g., Monsell et al., 1992; Zevin & Balota, 2000). Experiment 5 provided a full factorial design consisting of pure and mixed presentations of regular words, exception words, pseudohomophones, and nonwords (see Table 4). As regular words can be correctly pronounced via a lexical lookup (i.e., SV) procedure or the use of spelling-sound correspondences (i.e., PD processing), these items are considered to be both SV- and PD-reliant stimuli. Exception words, on the other hand, can only be correctly named via a lexical lookup procedure because the application of spelling-sound correspondences would lead to a regularization error. Thus, exception words are

Table 4

Contextual List Conditions

Stimulus Type	Context			
Regular	Alone	+ Exception	+ PH	+ NW
Exception		Alone	+ PH	+ NW
PH			Alone	+ NW
NW				Alone

Note: This design creates 10 unique stimulus list conditions.

considered to be SV-reliant stimuli. As pseudohomophones are novel nonwords and must be named via the use of spelling-sound correspondences, these items are considered to be PD-reliant stimuli (with corresponding phonological lexical representations, akin to hearing a word prior to seeing it in print, which is similar in many respects to reading acquisition). Similarly, nonwords must be named via the use of spelling-sound correspondences, and, therefore, are considered to be PD-reliant stimuli.

Dual-route models of reading can allow for the selective manipulation of word frequency and orthographic length effects due to the fact that SV and PD processes are represented by separate processing routes. However, single-route models cannot allow for the selective manipulation of word frequency and orthographic length effects due to the fact that SV and PD processes are represented by a single processing route. These different assumptions regarding the redundancy of SV and PD processes allowed for several unique predictions. First, it was important that baseline measures of how participants named the regular words, exception words, pseudohomophones, and nonwords in pure list conditions be assessed. It was expected that the exception words would show the largest word frequency effect, followed by the regular words, and then the pseudohomophones (nonwords have no corresponding lexical measure of frequency that can be examined). The only caveat regarding the pseudohomophone frequency effect was that the base-words from which the pseudohomophones were derived also need to be examined to determine if they are capable of producing the word frequency effect in the first place (see Borowsky & Masson, 1999). As both dual- and single-route models have been shown to produce the word frequency by regularity effect, this first prediction served to ensure that this experiment had sufficient power to detect a common word recognition effect. Secondly, when assessing the orthographic length effect in the pure list conditions, it was expected that the nonwords and pseudohomophones would show the largest orthographic length effects, followed by the regular words, and then the exception words. Again, both dual- and single-route models would predict the same pattern of results. If readers can strategically adjust their reliance on the SV or PD routes, and if the word frequency and orthographic length effects are adequate indices of SV and PD processing, respectively, then it should be possible to modulate word frequency and orthographic length effects. Thirdly, it follows from the dual-route perspective that the word frequency effect for stimuli that are typically processed by PD, or by both PD and SV (e.g., pseudohomophones and regular words, respectively), would increase when exception words are included in the list, with little or no consequence to the orthographic length effect. However, single-route models would predict that increased reliance on SV processing, as indexed by a larger word frequency effect, would be accompanied by a decrease in PD processing, as indexed by a smaller orthographic length effect. These effects would suggest that the reader could increase their reliance on SV processing. Fourthly, from a dual-route perspective, the inclusion of PD-reliant stimuli in the list of stimuli should serve to increase the orthographic length effect for SV-reliant, or SV- and PD-reliant, stimuli, with little or no consequence to the word frequency effect for such items. However, single-route models would predict that increased reliance on PD processing, as indexed by a larger orthographic length effect, would be accompanied by a decrease in SV processing, as indexed by a smaller word frequency effect. These effects would suggest an increased reliance on the PD route.

The dual-route model also allows for predictions based upon the assumption that PD processing is controlled or effortful, whereas SV processing is more automatic. As such, one would expect that regular words would show greater modulations of the word frequency and orthographic length effects because, theoretically, such items can be correctly named via PD or SV processing. That is, readers should have more control over the use of PD processing than over the use of SV processing. Furthermore, to the degree that the correct naming of exception words *can only* rely on SV processing, one would expect that the measures of SV and PD processing (i.e., word frequency and orthographic length effects, respectively) would be more resilient to list context modulations (see Zevin & Balota, 2000, for similar arguments). Similarly, to the degree that nonwords can only be named via PD processing, one would expect that the orthographic length effect would be more resilitant to list context modulations. The stability of the word frequency effect for exception words and the stability of the orthographic length effect for nonwords would provide support that these types of stimuli are process pure stimuli.

In summary, if word frequency and orthographic length effects are veridical indices of SV and PD processing, respectively, then according to dual-route models stimuli that are more likely to be read via SV processing should show larger word frequency effects and smaller orthographic length effects than stimuli that are more likely to be read via PD processing. To the extent that the processing of regular words can be influenced by the presence of such stimuli, the magnitude of word frequency and orthographic length effects for regular words themselves should be affected in a direction towards that of the context stimuli.

Experiment 5

Methods

Participants. One hundred and forty University of Saskatchewan students participated in this experiment for partial credit in an introductory psychology course. All participants reported English as their first language and had normal (or corrected-to-normal) vision.

Apparatus. The computer system consisted of an IBM compatible computer with a 15-inch NEC colour monitor (model JC-15W1VMA) to present the stimuli to the participants, and a second monochrome monitor to present the stimuli to the experimenter. Micro Experimental Laboratories software controlled the stimulus displays, timing of events, and recording of responses. Participants initiated each trial by pressing the middle key on the MEL serial response box. A microphone connected to the MEL serial response box detected the response latencies. The experimenter recorded the accuracy of each response using the computer keyboard.

Materials and design. The stimulus list consisted of 126 regular words, exception words, pseudohomophones, and nonwords, for a total of 504 monosyllabic letter-strings (see Appendix C). Regular words, exception words, and the base-words for the pseudohomophones were matched on word frequency (using the Kučera & Francis, 1967, word frequency norms), length, and initial onset. The nonwords were constructed by changing the onsets of the pseudohomophones with an onset of approximately equal or higher frequency of occurrence (see Seidenberg et al., 1996).

The regular words, exception words, pseudohomophones, and corresponding base-words were divided into high, medium, and low frequency words. Table 5 presents the mean word frequency for the high, medium, and low word frequency items. Each of the four stimuli types was presented in either pure (i.e., alone) or mixed blocks consisting of one of the three other word-types (see Table 4). This particular design created 10 unique stimulus lists. The four pure lists were comprised of regular words, exception words, pseudohomophones, or nonwords alone. The mixed lists consisted of: (1) regular and exception words, (2) regular words and pseudohomophones, (3) regular words and nonwords, (4) exception words and pseudohomophones, (5) exception words and nonwords, or (6) pseudohomophones and nonwords. Thus, each stimulus type could be examined under conditions where it was mixed with one of the other three stimulus types.

Procedure. When the participants arrived at the laboratory, they were assigned to one of seven conditions based upon an alternating sequence. Participants named one mixed list or two pure-block lists, with the constraint that they did not name the same type of stimulus twice, thus there were seven conditions instead of 10 (i.e., the number of unique stimulus lists). They were tested individually in a quiet testing room. Participants were instructed, both verbally and in writing, that they would see one letter-string on each trial. The order of stimulus presentation was individually randomized. An additional 10 letter-strings per word-type were used as practice items for each list condition. Participants were informed as to the nature of the letter-strings that they would be presented (i.e., if the letter-strings were real words, nonwords, nonwords that sounded like real words, or some combination of these items). The

Table 5

Mean Word Frequency and Range (in parentheses) for the Different Stimulus Types as a Function of High, Medium, and Low Frequency

	Word Frequency					
	High		Medium		Low	
Stimulus Type	M	(Range)	M	(Range)	M	(Range)
Regular	784.1	(81-7289)	41.6	(11-104)	5.7	(1-16)
Exception	798.8	(84-4393)	41.4	(11-100)	5.0	(1-13)
Base-word/PH	737.6	(72-9816)	36.8	(10-87)	5.0	(1-13)

Note: Word frequency was determined by the Kučera & Francis (1967) word frequency norms; PH = pseudohomophones.

participants were asked to name each letter-string as quickly and accurately as possible.

The sequence of events was as follows: (1) a fixation cross appeared in the centre of the computer screen, (2) the participant initiated the trial by pressing the middle key on the response box, (3) an interstimulus interval of 100 ms preceded the presentation of the stimulus, (4) a letter-string appeared on the screen until the voice key was triggered, (5) the experimenter coded each response as correct, incorrect, or spoiled (i.e., voice failed to trigger the voice key, participant stuttered, or some other noise triggered the voice key). At the end of the experiment, participants were shown a graph of their performance and were debriefed as to the purpose of the experiment. Each participant completed the experiment in an individual session that lasted about 25 minutes.

Results

The correct mean response latencies for the high, medium and low frequency categories of the regular words, exception words, and pseudohomophones are presented in Figure 6. As the stimulus items were matched on word frequency, initial onset and length, the lengths of our items were restricted in range (3-6 letters). As such, there were a greater number of shorter words (3-4 letters) than longer words (5-6 letters), which would compromise any ANOVA that included orthographic length as a factor. Therefore, word frequency and orthographic length effects were examined as continuous variable effects using multiple regression.

Word Frequency and Orthographic Length Regression Analyses. Multiple regression was used to assess the modulation of word frequency and orthographic

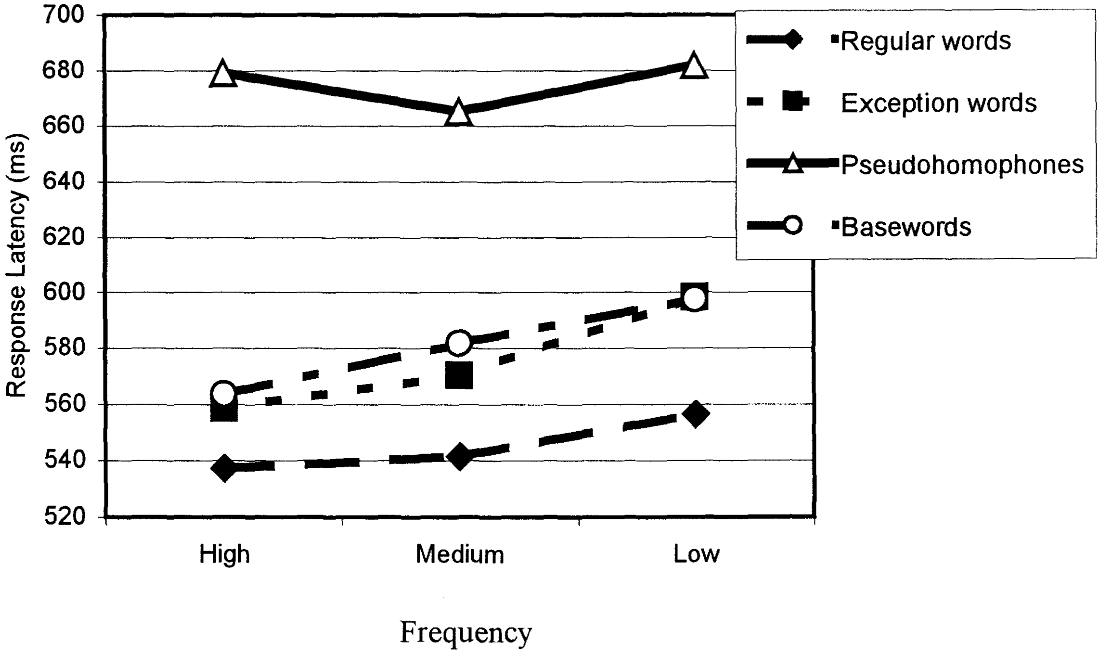


Figure 6. Frequency effects as a function of stimulus type.

length effects. The word frequency for each item was determined from the Kučera and Francis (1967) norms. The norms were log transformed using the following formula: word frequency measure = $\log_{10}$[Kučera and Francis word frequency + 1] (see Balota & Chumbley, 1984; Borowsky & Masson, 1999). Subject-by-item regression analyses, as advocated by Lorch and Myers (1990; see also Borowsky & Masson, 1999; LeFevre, Sadesky & Bisanz, 1996), were used to examine the word frequency and length effects. This method treats each participant's regression coefficient as the unit of analysis (i.e., performing a separate regression of correct item latency on the two independent variables of word frequency and length for each participant and then determining if the average regression coefficients differed from zero using a one-sample t-test).

Significant word frequency effects were observed for regular words alone and exception words alone, whereas orthographic length effects were only observed for the exception words (see Table 6).[3] The nonwords also showed an orthographic length effect. Neither the word frequency nor the orthographic length effect was significant for the pseudohomophones. Given that there were significant word frequency effects for regular and exception words, it was of interest to determine if the word frequency effect was larger for exception words than for regular words.[4] An independent t-test

---

[3] In an initial experiment that only examined naming performance on regular words in the context of the exception words, pseudohomophones, and nonwords, Owen, Blake, and Borowsky (2002) have show that the same regular word items do produce both word frequency and orthographic length effects.

[4] The traditional approach of conducting multiple t-tests only after obtaining a significant F-test was not reported here. As Wilcox (1987) points out the ANOVA is not robust to violations of the homogeneity of varience assumption, as is often assumed. Furthermore, most comparison techniques are *not* designed based upon the criterion of obtaining a significant F-test (with the exception of Fisher's LSD test). However, a very similar pattern of results was obtained when significant F-tests were followed up by Dunnett's multiple comparison procedure, which controls for familywise error rates and allows for multiple comparisons against one baseline condition (i.e., the alone conditions in the present experiment).

Table 6

Summary of the Subject-by-Items Regression Coefficients of Correct Naming Latency on Word Frequency and Length as a Function of Stimulus Type and List Context

List	Stimulus Type						
	Regular		Exception		Pseudohomophone		Nonword
	WF	L	WF	L	WF	L	L
Alone	- 7.8*	2.1	- 21.8*	16.1*	- 0.6	- 1.0	33.1*
+ Context							
+ Reg.	———		- 26.3*	17.0*	4.4	14.9*	30.9*
+ Exc	- 10.4*	14.5*	———		8.9*	2.5	35.7*
+ PH	- 11.4*	9.1*	- 32.3*	12.5*	———		29.1*
+ NW	- 9.5*	12.1*	- 19.5*	25.9*	9.4	6.3	———

Note. WF = word frequency, coefficients represent ms/log unit word frequency (i.e., slope of the regression line); L = orthographic length, coefficients represent ms/letter; * $p < .05$. The base-words for the pseudohomophones did produce word frequency and orthographic length effects (see text).

indicated that there was a larger word frequency effect for the exception words than for the regular words, $t(38) = 2.73, p < .01$, replicating the traditional frequency-by-regularity interaction (e.g., Hino & Lupker, 2000; Seidenberg et al., 1984; Taraban & McClelland, 1987). Independent t-tests also indicated that the length effect was larger for the nonwords than the exception words, $t(38) = 2.36, p < .05$, which was larger than for the regular words, $t(38) = 3.13, p < .01$.

As regular words are the most flexible stimulus items in that they can be read via SV or PD processing, it was of interest to determine if the word frequency and orthographic length effects could be modulated by list context. When exception words were added to the list of regular, there was no significant increase in the word frequency effect; however, contrary to what one would expect, there was an increase in the orthographic length effect, $t(38) = 2.43, p < .05$. Furthermore, when regular words were presented in the context of pseudohomophones, there was no decrease in the word frequency effect, but there was a marginal increase in the orthographic length effect, $t(38) = 1.75, p < .09$. Similarly, when regular words were presented with nonwords there was no modulation of the word frequency effect, however, there was a larger orthographic length effect, $t(38) = 2.21, p < .05$.

As exception words must be read via SV processing, it was important to determine if the word frequency and orthographic length effects would remain stable across list contexts (see also Zevin & Balota, 2000). No difference was observed in the size of the word frequency or orthographic length effects for the exception words alone compared to when the exception words were presented in the context of regular words, $ts < 1.3, ps > .18$. There was a marginal increase in the word frequency effect for exception words when they were presented in the context of pseudohomophones, $t(38) = 1.88$, $p = .069$, but there was no change in the orthographic length effect. In contrast, there was no change in the word frequency effect for the exception words when they were presented in the context of nonwords, but there was a marginal increase in the orthographic length effect, $t(38) = 1.85$, $p = .072$.

As pseudohomophones must be read via PD processing because these are novel stimuli, and because the assembled phonology matches a stored phonological lexical representation, it was relevant to determine if the word frequency would increase in the context of exception words (i.e., SV- reliant stimuli), whereas the orthographic length effects would remain stable across list contexts. In order to properly evaluate the effects involving the pseudohomophones, the base-words were also included in this experiment (see Borowsky & Masson, 1999). Analysis of the base-words for the pseudohomophones indicated that they produced a significant word frequency effect, *M* coefficient = -14.29 ms/log word frequency, $t(19) = -3.97$, $p < .01$, and a significant length effect, *M* coefficient = 12.64 ms/letter, $t(19) = 4.61$, $p < .001$. When pseudohomophones were presented in the context of regular words, there was a marginal increase in the orthographic length effect, $t(38) = 1.87$, $p < .07$. No other modulation effects approached significance.

As nonwords must be read via PD processing, it was of interest to determine if the orthographic length effect could be influenced by different list contexts. The orthographic length effect was not modulated by any of the list contexts, all *t*s > 0.510, all *p*s > .611.

Discussion

Experiment 5 examined the degree to which readers can strategically modulate their reliance on SV and PD reading processes, as indexed by changes in the word frequency and length effects, respectively. There are four findings of particular interest. First, the largest frequency effects were observed for exception words, followed by regular words. Second, nonwords were shown to produce the largest orthographic length effect; however, exception words produced a larger orthographic length effect than regular words. Furthermore, the inclusion of nonwords with exception words increased the orthographic length effect for exception words. Third, the word frequency effect for exception words increased in the context of pseudohomophones. Fourth, regular words increased the length effect for pseudohomophones. Each of these findings and their relevance for visual word recognition models are discussed in turn.

It was shown that the word frequency effect was larger for exception words than for regular words. This finding is concordant with a large body of literature on the word frequency by regularity interaction (Hino & Lupker, 2000; Paap & Noel, 1991; Seidenberg, 1985; Seidenberg et al., 1984; Taraban & McClelland, 1987). Typically, the word frequency by regularity interaction has been interpreted as support for the dual-route model of visual word recognition. In dual-route models, exception words can only be named correctly via SV processing, whereas regular words can be named correctly via either SV or PD processing. As such, exception words should show the largest word frequency effect because exception words have to make contact with frequency sensitive lexical representations (or frequency sensitive lexical connections). However, dual-route accounts would also have to predict that nonwords and pseudohomophones would show the largest orthographic length effects, followed regular words, and then exception words, which was not supported by the present experiments. Owen et al., (2002; Experiment 1) have replicated this same pattern of results.

Single-route models of visual word recognition account for the word frequency by regularity interaction by assuming that, regardless of regularity, all high frequency words have strong orthographic–phonological connections. However, low frequency words have weak connections, and must rely on the degree of consistency of activation in the phonological output units. Regular words would be helped by activation from their consistent word neighbours. On the other hand, exception words would have a greater degree of inconsistent activation at the level of the phonological output units due to competing regularized (incorrect) and atypical (correct) pronunciation. The computational single-route models have also been shown to produce the word frequency by regularity interaction (Plaut et al., 1996; Seidenberg & McClelland, 1989). But because single-route models assume that SV and PD are redundant processes, one would also have to predict that as the word frequency effect changed due to list context, the orthographic length effect would also change. However, this experiment showed that one could selectively modulate either the word frequency effect or the orthographic length effect. Moreover, for regular words (i.e., SV- and PD-reliant stimuli) it appeared that it was easier to manipulate the orthographic length effect, an index of controlled PD processing, than it was to manipulate the word frequency effect, an index of SV processing. These findings are consistent with the idea that PD is a controlled process (see Hasher & Zacks, 1979; Paap & Noel, 1991).

Replicating past research, this experiment showed that nonwords produced the largest orthographic length effects (see also Weekes, 1997). However, exception words surprisingly produced the second largest orthographic length effect, which was greater than the effect for regular words. If exception words can only be named via SV processing, which is assumed to be frequency sensitive, it is inconsistent that such stimuli are also sensitive to a measure of serial PD processing, as indicated by an orthographic length effect that was larger than that obtained for regular words, which can be read by either SV or PD processes. In other words, the overadditive pattern of word-type by length reported here does not follow from dual-route models, which would predict an underadditive pattern of results. However, the assumption that SV and PD routes operate in parallel, which can explain the word frequency by regularity interaction as described above, may also explain why exception words show orthographic length effects. The orthographic length effects for exception words could arise because the latency for a correctly pronounced exception word generated along the SV route is partly influenced by a parallel, regularized pronunciation generated by the serial spelling-sound PD route. For example, the PD output from the serial assembly of an incorrect regularized PD pronunciation (e.g., *pint* to rhyme with *mint*) could influence the correct SV pronunciation of the word *pint*. As the reader would have to resolve the conflicting phonological outputs from the SV and PD routes, the resolution process would allow the correct SV pronunciation response latency to be influenced by the serial PD process.

In order for this explanation to address why exception words showed a larger length effect than regular words, one would need to argue that a phonological output is not produced until both SV and PD processing have generated a phonological representation. The more letters an exception word had, the longer the waiting time for a PD phonological representation to be generated. Furthermore, added processing time would be needed to resolve the conflict between the SV and PD phonological representations. The increase in the length effect for the exception words due to the inclusion of nonwords in the stimulus list, which could further slow the processing of the exception words, would also be consonant with this explanation (see Lupker, Brown & Colombo, 1997, for a similar effect). Unfortunately, this explanation of the length effect compromises the utility of the length effect as a *process-pure* index of PD processing.

The orthographic length effects observed in this experiment do appear to fit with Plaut et al.'s (1996) suggestion that such effects should be observed for stimuli with less well-established representations. Plaut et al. stated that the degree of parallel processing is dependent upon the reader's experience. That is, if frequency can be equated with reader experience, high frequency words should be computed using parallel processes, whereas low frequency words and nonwords should be computed using more sequential processes. It follows that the orthographic length effect should be larger for nonwords than real words. However, can single-route models account for the orthographic length by regularity interaction? Similar to the explanation for the word frequency by regularity interaction, the orthographic length by regularity interaction can be explained by the fact that low frequency exception words, which also tend to be longer words (Zipf, 1935), would have phonological neighbours that would result in conflicting phonological activation that would need to be resolved, whereas the regular words would not be susceptible to conflicting phonological activation. Again, note that Plaut et al.'s suggestion is essentially a dual-mechanism account of the orthographic length effect because it requires the model to shift between parallel and more-serial-like processing. Thus, this explanation is similar to the dual-route model explanation of the orthographic length effect.

Effects involving the pseudohomophone stimuli also provided some support and challenges for dual-route models. In the pseudohomophone-alone naming condition, there was no evidence of a pseudohomophone base-word frequency effect. This could be argued to be consistent with the assumption that pseudohomophones have to be initially processed via the PD route. Further support for this assumption comes from the results that both nonwords and pseudohomophones increased the orthographic length effect for regular words. However, a challenge for the dual-route models comes from the finding that the orthographic length effect for pseudohomophones increased when regular words were also included in the stimulus set. As regular words can be named via SV or PD processes (i.e., regular words are not solely PD-reliant), it would not be expected that regular words would increase the orthographic length effect for pseudohomophones, which are PD-reliant. This finding also compromises the utility of the orthographic length effect. In addition, there was some evidence that the word frequency effect for pseudohomophones could be reversed (i.e., a positive frequency effect) when the SV-reliant exception words were also included in the stimulus list. Another problem for the dual-route model would be how pseudohomophones, which are PD-reliant stimuli, served to increase the word frequency effect for exception words, or SV-reliant stimuli.

The same results that are problematic for dual-route accounts of visual word recognition also appear to be problematic for single-route models. The fact that pseudohomophones selectively increased the word frequency effect for exception words, and did not modulate both the word frequency and orthographic length effects, is not consistent with the single-route account, which assumes redundancy between SV and PD. The results do call into question those models that propose that only one route is necessary to compute phonology for printed words (e.g., the single-route connectionist models; Harm & Seidenberg, 1999, Seidenberg & McClelland, 1989: as well as the single route phonological mediation models; e.g., Carello et al., 1994: and analogy based models; e.g., Glushko, 1979). It is not clear how a single-route, single-mechanism model could account for the selective modulations of (i.e., dissociations between) the word frequency and orthographic length effects shown here. Because of the implicit redundancy between SV and PD processes inherent in all single-route models (see Owen & Borowsky, 2002b), such models would necessarily have to predict that if word frequency were modulated, the length effect would also be modulated (i.e., word frequency and length effects should not dissociate). However, the selective modulation effects that were observed in the present experiments indicated that word frequency and orthographic length are dissociable.

Conclusions (Experiment 5)

Single-route reading models do not differentiate between SV and PD processes and, thus, cannot account for the selective modulations of the word frequency and length effects reported in this study. Dual-route models do differentiate between SV and PD processes and can, therefore, account for the selective modulations of the word frequency and length effects described here. Thus, the balance of evidence seems to support the dual-route cascaded architecture of basic reading processes. Furthermore, the results were consistent with the idea that PD processing is a controlled process and that SV is an automatic process (Hasher & Zacks, 1979; Paap & Noel, 1991). However, word frequency and orthographic length effects did not always serve to clearly index the use of each process, contrary to the typical interpretation of these effects (Baluch & Besner, 1991; Monsell et al., 1992; Weekes, 1997). As such, caution must be taken when interpreting word frequency and orthographic length effects, and it is critical to continue to explore new indices of SV and PD processing (e.g., Borowsky & Besner, 2000; Borowsky, McDougall et al., 2002; Owen & Borowsky, 2002b).

2.2 Identifying phonological lexical processing: When a pseudohomophone naming advantage becomes a naming disadvantage.

Experiment 5 demonstrated that skilled readers can strategically modulate their reliance on SV and PD reading processes due to list context manipulations. It is also important to investigate how list context influences reliance on sublexical and lexical levels of phonology when reading novel words. Furthermore, models of visual word recognition must accommodate how skilled readers can name nonwords in order to account for how novel words are read. Indeed, this issue has defined the two major classes of word recognition models. Given that novel words and nonwords have, by definition, no direct connection from orthography to semantic representation, the focus here is on processing routes between orthographic representations and phonological representations that do not involve semantic mediation. Recall that dual-route models (e.g., Coltheart et al., 2001; Zorzi et al., 1998) have two non-semantic routes between orthographic and phonological representations. One of the routes deals more with novel words by employing sub-lexical spelling-to-sound translation (i.e., the PD route), whereas the other route deals more with familiar words by directly mapping lexical orthographic representations onto lexical phonology representations (i.e., the SV route). As shown in Figure 5, it is assumed that once an assembled phonological representation has been generated via PD processing, the phonological representation can either be used to: (1) produce speech output, or (2) access phonological lexical representations prior to providing speech output. In contrast, single-route models (e.g., Harm & Seidenberg, 1999; Plaut et al., 1996) only contain a single, non-semantic route between orthographic representations and phonological representations (i.e., PD and SV are redundant). Thus, novel words utilize the same route as real words. Of particular interest in this experiment is the comparison of reading orthographically novel words that either do, or do not have phonological lexical representations.

The laboratory equivalent of such orthographically novel, but phonologically familiar, words is the class of nonwords called pseudohomophones (i.e., nonwords that "sound like" real words, e.g., brane). Although these stimuli are potentially useful for examining phonological processes in reading, there have been some difficulties reconciling some commonly reported effects involving pseudohomophones: the standard finding has been a pseudohomophone naming advantage accompanied by a non-significant *base-word-frequency effect* (i.e., no significant relation between pseudohomophone naming latency and the frequency with which their base-words [e.g., brain] are found in print; see Herdman et al., 1996; McCann & Besner, 1987; Seidenberg et al., 1996). Most models of word recognition are better poised to account for the *presence* of a pseudohomophone advantage if it was found to co-occur with a *significant* pseudohomophone base-word frequency effect as this specific pattern of results would serve to indicate that pseudohomophones activated frequency sensitive phonological lexical representations, which benefits pseudohomophone naming but not nonword naming.

Researchers who have reported the standard result have thus made modifications to their models to account for these apparently contradictory findings. For example, the finding of a pseudohomophone advantage but no base-word frequency effect led McCann and Besner (1987) to propose that the phonological lexical system is not itself sensitive to word frequency, whereas Seidenberg et al.

(1996) argued that it necessitated the implementation of a separate set of units for representing phonological articulation. Seidenberg et al. explained that the articulatory units would not be sensitive to word frequency but these units would be sensitive to familiar speech output. However, there have recently been some unchallenged reports of a significant base-word frequency effect in pseudohomophone naming (e.g., Borowsky & Masson, 1996b; Grainger et al., 2000; Marmurek & Kwantes, 1996). In the present experiment, the conditions under which a significant base-word frequency effect is obtainable in pseudohomophone naming are considered, which is relevant to identifying when PD processing results in phonological lexical access.

Pseudohomophone base-word frequency effects in the literature.

Taft and Russell (1992) obtained an overall pseudohomophone advantage on naming latency, and a significant base-word frequency effect that was restricted to an analysis focusing on their slower participants. However, the possibility that participants were treating low-frequency pseudohomophones as nonwords is a potential confound for the significant base-word frequency effect that was obtained. Taft and Russell attempted to ensure that their pseudohomophone stimuli would be recognized as "sounding like" real words by asking participants in an initial experiment to decide whether or not each target stimulus sounds like a real word (i.e., a phonological lexical decision task). Borowsky and Masson (1996b) have argued that this would be a more reasonable safeguard if done for each participant in the naming task. It is also important to note that the ratio of lexical (i.e., pseudohomophone) to nonlexical (i.e., nonword) stimuli in the experiment was 2:1, a different ratio than the 1:1 ratio used by McCann and Besner (1987), and Seidenberg et al. (1996). Thus, one might argue that the presence of a base-word frequency effect may be related to the higher proportion of lexical stimuli in Taft and Russell's experiment. Perhaps the more stimuli in the experiment that can access phonological lexical representations, the greater the probability of finding a base-word frequency effect on naming latency.

In fact, experiments by Marmurek and Kwantes (1996) would appear to support this notion. Using a variety of different stimuli sets and ratios of lexical to nonlexical stimuli, Marmurek and Kwantes did find evidence of base-word frequency effects on pseudohomophone naming latency when the proportion of lexical stimuli was high. For example, Marmurek and Kwantes examined a condition in which participants were presented with a pure block of pseudohomophone stimuli, and they found that base-word frequency effects are obtainable under pure-block pseudohomophone conditions but not under mixed-block conditions (i.e., when pseudohomophones and nonwords are mixed together). Taken together with Taft and Russell's (1992) research, it appears that when using a ratio of lexical to nonlexical stimuli that is 2:1 or greater, base-word frequency effects on pseudohomophone naming latency begin to emerge.[5] Unfortunately, Marmurek and Kwantes did not attempt to exclude poor pseudohomophone items (i.e., pseudohomophones that participants would consider as nonwords) from their analyses, but instead tried to

---

[5] Herdman et al. (1996) used 2:1 ratio (with half of the pseudohomophones containing legal bodies, and half containing illegal bodies) but did not obtain a significant base-word frequency effect. Borowsky and Masson (1999) have pointed out that a speed-accuracy tradeoff appears to compromise Herdman et al.'s results. Also, some mention should be made of the studies that report a reverse base-word frequency effect on pseudohomophone naming latency (e.g., Herdman, LeFerve & Greenham, 1994, Lukatela & Turvey, 1993). It turns out that these studies report reverse frequency effects only in analyses that treat subjects as the random variable, but not in analyses that treat items as the random variable. This analysis issue means that as few as one or two "strange" items can be responsible for the significant "reverse" effect (e.g., a high base-word frequency pseudohomophone that is named very slowly, and/or a low base-word frequency pseudohomophone that is named very quickly) and thus it is of utmost importance that a by-items analysis be conducted to assess this possibility. A more detailed criticism of the Herdman et al. study is provided in Seidenberg et al. (1996).

avoid any potential confound by telling their participants when they were about to be exposed to a pure block of pseudohomophone stimuli.

Based on these findings, Borowsky and Masson (1996b) suggested four criteria that may be important for demonstrating a valid base-word frequency effect on pseudohomophone naming latency: (1) Pseudohomophones and nonwords should be presented in pure blocks of trials; access to frequency sensitive representations or connections should be maximized when all of the stimuli in the experimental block have phonological lexical status, and decreased when nonwords are mixed with the pseudohomophones. Marmurek and Kwantes (1996) did examine pure blocks of pseudohomophones in their experiments, but never included a pure block of nonwords. (2) Inform participants about the nature of the stimuli that they are about to see; if participants have any strategic control over how they will process pseudohomophones and nonwords, they will be more likely to engage in lexical access during pseudohomophone naming if they know about the intended lexical nature of the stimuli that they are about to see (e.g., Marmurek & Kwantes, 1996). (3) Remove any pseudohomophone stimuli (on a subject-by-subject basis) that participants do not consider to "sound like" real English words; the inclusion of response latencies for such stimuli will likely serve to inflate a base-word frequency effect, and thus produce an artefactual effect (i.e., a lexicality effect masking as a base-word frequency effect). (4) The base-word stimuli themselves must be capable of eliciting a frequency effect on base-word naming latency; it should come as no surprise that there is no base-word frequency effect for pseudohomophones that are derived from base-words that are not representative of the population of words that do produce a frequency effect on naming latency (McCann & Besner, 1987). Borowsky and Masson (1999) recently examined the fourth criterion using McCann and Besner's (1987), Seidenberg et al.'s (1996), and Herdman et al.'s (1996) base-word stimuli, and reported that Seidenberg et al.'s base-words failed to produce a significant frequency effect, thus compromising the utility of their pseudohomophone stimuli.

Following some of Borowsky and Masson's (1996b, 1999) suggestions, Grainger, et al. (2000) were able to show significant base-word frequency effects in French pseudohomophone naming. Unfortunately, Grainger et al. did not check for a pseudohomophone advantage in their experiments, nor did they constrain their data analysis on items that participants concurred with as being pseudohomophones.

These critical conditions for demonstrating a base-word frequency effect on pseudohomophone naming latency are utilized in Experiment 6. The issue that was examined in Experiment 6 pertained to whether the pseudohomophone naming advantage and base-word frequency effects are context sensitive. First, it was of interest in this experiment as to whether pure block presentation of pseudohomophones and nonwords (relative to mixed presentation, the standard in the literature), would produce a base-word frequency effect on pseudohomophone naming latency as has been previously reported by Grainger et al. (2000) and Marmurek and Kwantes (1996). Second, it was of particular interest to determine whether a pseudohomophone base-word frequency effect would co-occur with a pseudohomophone naming advantage. To test the generalizability of the context sensitivity effects, this experiment included Herdman et al.'s (1996) items, as well as a new set of pseudohomophone and nonword stimuli.

Experiment 6

Method

Participants. One hundred and twenty University of Saskatchewan students participated in this experiment for partial credit in an introductory psychology course. An additional 25 participants from the same population pool who had not participated in the pseudohomophone naming studies were assigned to name the base-words for the new set of pseudohomophones. All participants reported English as their first language and had normal (or corrected-to-normal) vision.

Apparatus. The experiment was conducted using an IBM compatible computer with two monitors attached, one for the participant, and the other for the experimenter. Micro Experimental Laboratories software was used to control the timing and presentation of events and recording of the responses. A MEL serial response box was used by the participant to initiate each trial. A voice key connected to the serial response box was used to collect response latencies. Response latency was measured from the onset of the target on the screen to onset of pronunciation during the naming task, or the button press during the phonological lexical decision task. The experimenter coded each naming response on the computer keyboard.

Materials and design. Two sets of stimuli were presented separately to participants in this experiment. One set of stimuli consisted of 68 pseudohomophones and 34 nonwords used by Herdman et al. (1996). The pseudohomophones ranged from 0 to 794 counts per million in base-word frequency (i.e., the frequency of occurrence in print for the words from which the pseudohomophones were derived, based on the Kučera & Francis, 1967, corpus). Herdman et al. had originally designed 72 pseudohomophones and 34 nonwords but excluded four pseudohomophones and two nonwords from their analyses due to high error rates. These items were matched in triplets, such that for every nonword there was a high and low frequency pseudohomophone. The other set of stimuli consisted of a new set of 55 pseudohomophones and nonwords. The base-words for the pseudohomophones were matched for word frequency, length, and initial letter to a set of regular and exception words that we have used in other studies (e.g., Borowsky, McDougall et al., 2002; Owen & Borowsky, 2002b). The nonwords were generated from the pseudohomophones by changing one letter. Four pseudohomophones and their corresponding nonwords were not included in this experiment because they also occurred in Herdman et al.'s stimulus set, thus only 51 pseudohomophones and 51 nonwords were presented in this experiment (see Appendix D). The pseudohomophones ranged from 2 to 2332 counts per million in base-word frequency (Kučera & Francis, 1967). The order in which Herdman et al.'s and the new set of stimuli were presented was counter-balanced such that half of the participants named Herdman et al.'s stimuli followed by the new set of stimuli, whereas the other half of the participants named the new set of stimuli followed by Herdman et al.'s stimuli.

The pseudohomophones were presented in pure or mixed lists. Sixty participants were presented the pseudohomophones randomly mixed with the nonwords. In the pure list condition, the order of stimulus presentation was counter-balanced such that 30 participants named a pure list of nonwords followed by the pure pseudohomophone list, whereas the other 30 participants named a pure list of nonwords followed by the pure pseudohomophone list.

Procedure. When the participants arrived at the laboratory, they were assigned to one of three conditions based upon an alternating sequence (i.e., mixed or pure lists, and if assigned to the pure list condition, naming nonwords or pseudohomophones first). They were tested individually in a quiet laboratory. For the naming task, participants were informed as to the nature of the letter-strings that they would be presented (i.e., if the letter-strings were nonwords, pseudohomophones, or both) and were instructed, both verbally and in writing, that they would see one letter-string on each trial.

The sequence of events for the naming task was as follows: (1) a fixation cross appeared in the centre of the computer screen, (2) the participant initiated the trial by pressing the middle key on the response box, (3) an interstimulus interval of 250 ms preceded the presentation of the stimulus, (4) a letter-string appeared on the screen until the voice key was triggered, and (5) the experimenter coded each response as correct, incorrect, or spoiled (i.e., voice failed to trigger the voice key, participant stuttered, or some other noise triggered the voice key). This same procedure was followed for those participants who named the base-words.

After completing the naming task for the first set of pseudohomophones and nonwords, participants immediately performed a phonological lexical decision task (PLDT) so as to individually confirm the phonological lexical status of these items so that we could examine this constraint in our analyses. Participants were not aware of the phonological lexical decision task before they engaged in the naming task. In the phonological lexical decision task, participants were instructed to decide if each letter-string could be pronounced like a word that they knew, and to press the button under their dominant hand to indicate a positive response, or the button under their non-dominant hand to indicate a negative response. The order of stimulus presentation was individually randomized. The sequence for the phonological lexical decision task was as follows: (1) a fixation cross appeared in the center of the screen, (2) the participant initiated the trial by pressing the middle key on the response box, (3) an interstimulus interval of 250 ms preceded the presentation of the stimulus, and (4) a letter-string appeared on the screen until the participant pressed one of the response buttons. Participants then named the second stimulus set, followed by the phonological lexical decision task involving these items. At the end of the experiment, participants were shown a graph of their performance and were debriefed as to the purpose of the experiment. The individual sessions lasted about 25 minutes.

Results

The pseudohomophone advantage (whereby pseudohomophones are responded to faster and/or more accurately than nonwords) was examined using paired samples t-tests in all by-subjects analyses, and also in the by-items analyses with our new stimuli (i.e., each pseudohomophone was individually matched to a nonword). Independent-samples t-tests were used for the by-items analyses of Herdman et al.'s (1996) stimuli (i.e., there was a high and a low base-word frequency pseudohomophone for every nonword, whereas the analyses on base-word frequency that follow will treat frequency as a continuous variable). In order to examine pseudohomophone base-word frequency effects, the word frequency for each item was determined from the Kučera and Francis (1967) norms. These norms were log transformed using the following formula: word frequency measure = $\log_{10}$[Kučera & Francis word frequency + 1] (see

Balota & Chumbley, 1984; Borowsky & Masson, 1999). Two methods of regression analyses were used. First, subject-by-item regression analyses, as advocated by Lorch and Myers (1990; see also Borowsky & Masson, 1999; LeFevre et al., 1996), were used. This analysis method treats each participant's regression coefficient as a unit of analysis (i.e., performing a separate regression of correct item latency on the independent variable of word frequency for each participant and then determining if the average regression coefficient differed from zero using a one-sample t-test). Secondly, the more conventional approach of treating each item as a unit of analysis (i.e., averaging over participants) was used for both response latency and error rate.

Separate regression analyses were performed for: (1) the mixed pseudohomophone-nonword condition (n=60), (2) the nonword-first group (n=30) and (3) the pseudohomophone-first group (n=30). Regression analyses were conducted on pseudohomophone naming latency contingent upon: (1) correct pseudohomophone naming accuracy and (2) correct pseudohomophone naming for which participants also agreed upon the lexical status of the pseudohomophone (i.e., pseudohomophones that "sound like" words on a subject-by-subject basis). Removing pseudohomophones that participants may have pronounced correctly but did not concur that the stimulus "sounded like" a real word serves to eliminate a confound between lexicality and base-word frequency, whereby low frequency pseudohomophones that do not sound like real words to a particular participant yield inflated response latencies. In the tables that follow, the standardized coefficients from each analysis involving base-word frequency are presented. Note that the associated *p* values are the same for unstandardized and standardized coefficients in the item analyses, and that they can differ in the subject regression analyses (where the coefficients are obtained separately for each participant, as described earlier).

The analyses on the new items are presented first, followed by analyses on the Herdman et al. (1996) items. For each set of items, analyses of the pseudohomophone naming advantage are presented first, followed by analyses of the pseudohomophone base-word frequency effects, and finally, an analysis of onset plosivity (i.e., whether the articulatory phonetics of the initial consonant(s) includes completely obstructing the airflow from the lungs for a brief period of time) and practice effects in case these variables contributed to any of the effects.

New Items

Pseudohomophone Naming Advantage. To examine the data for differences between pseudohomophone and nonword median naming latencies, paired-sample t-tests were conducted. The median naming latencies and corresponding error rates are reported in Table 7. In the mixed pseudohomophone-nonword condition the typical pseudohomophone naming advantage was observed by-subjects, $t(59) = -4.241, p < .001$, but not significantly by-items, $t(50) = -1.505, p = .14$. No pseudohomophone error rate advantage was observed by-subjects, $t(59) = -0.357, p = .723$, or by-items, $t(50) = -0.257, p = .798$. In the nonword-first condition, there was no pseudohomophone advantage observed for naming latencies by-subjects or by-items, all ts < 0.889, ps $> .378$. In the nonword-first condition a significant

Table 7

Median Naming Reaction Time (ms) and Error Rates (in percent) for Experiment 6 as a Function of Stimulus List and Presentation Context

	Stimulus List											
	New Items						Herdman et al. Items					
	RT			Errors			RT			Errors		
Context	NWs		PHs	NWs		PHs	NWs		PHs	NWs		PHs
Mixed Lists:												
By-Subjects	807	>	763	12.7		12.4	719	>	702	9.2		8.0
By-Items	750		734	12.7		12.4	673		669	9.2		8.0
Pure Lists: NWs First												
By-Subjects	733		739	9.5	<	12.2	684		698	7.5		7.6
By-Items	719		729	9.5	~	12.2	686		676	7.5		7.6
Pure Lists: PHs First												
By-Subjects	790	<	853	7.7	<	11.9	711	<	749	5.4	<	7.8
By-Items	719	<	797	7.7	<	11.9	656	<	700	5.4		7.8

Note. PH = pseudohomophone; NW = nonword; RT = reaction time; < means $p < .05$; ~ means $p < .10$.

pseudohomophone disadvantage on error rates was revealed by-subjects, $t(59) = 2.177, p < .05$. This effect was marginal by-items, $t(50) = 1.757, p = .085$. In contrast, analyses of naming latencies for the pseudohomophone-first condition revealed a pseudohomophone disadvantage by-subjects, $t(59) = 3.208, p < .01$, and by-items, $t(50) = 5.788, p < .001$. The significant pseudohomophone disadvantage was also reflected in the error rates by-subjects, $t(59) = 5.147, p < .001$, and by-items, $t(50) = 2.403, p < .05$.

To examine the modulation of the pseudohomophone advantage effect, the median response latencies of pseudohomophones in the mixed and pure pseudohomophone-first conditions were compared, as well as the median response latencies of the nonwords in the mixed and pure pseudohomophone-first conditions. The by-subjects analysis revealed no significant differences in response latencies when pseudohomophones and nonwords were named in mixed versus pure lists, ts < 1.49, ps > .145. However, the by-items analysis revealed that pseudohomophones were named significantly faster in the mixed condition than in the pure pseudohomophone-first condition, $t(100) = 3.557, p < .01$, whereas nonwords were named slower in the mixed list condition, $t(100) = -2.241, p < .05$.

Pseudohomophone Base-Word Frequency Effects. Table 8 summarizes the subject-by-item and by-item regression analyses. Following Borowsky and Masson (1999), it was ensured that the base-words from which the pseudohomophones were derived produced a word frequency effect before determining whether the pseudohomophones would reveal similar effects. The correct naming latencies for the base-words were significantly related to frequency of occurrence (see Table 8). For the

Table 8

Summary of the By-Subject and By-Items Regression Analyses on Base-word Frequency for Experiment 6 as a Function of Stimulus List and Presentation Context

Presentation Context And Dependent Variable	Coefficient	Standardized Coefficient	*t*
	New Items		
Subject Regression Analyses			
Mixed Lists			
Naming RT	- 23.34	- 0.06	- 2.53**^{s}
Naming-PLDT RT	- 10.23	- 0.03	- 1.68†
Pure Lists: NWs First			
Naming RT	- 5.44	0.01	- 0.43
Naming-PLDT RT	- 1.63	0.01	- 0.14
Pure Lists: PHs First			
Naming RT	- 46.68	- 0.08	- 3.02**^{s}
Naming-PLDT RT	- 45.01	- 0.07	- 1.94†*^{s}
Base-words:			
Naming RT	- 15.19	- 0.13	- 3.63**^{s}
Item Regression Analyses			
Mixed Lists			
Naming RT	- 14.42	- 0.14	- 0.98
Naming-PLDT RT	- 8.14	- 0.08	- 0.57
Error Rates	- 0.03	- 0.17	- 1.20
Pure Lists: NWs First			
Naming RT	- 8.25	- 0.08	- 0.53
Naming-PLDT RT	- 17.79	- 0.16	- 1.12
Error Rates	0.03	0.19	1.36
Pure Lists: PHs First			
Naming RT	- 41.99	- 0.29	- 2.09*
Naming-PLDT RT	- 47.86	- 0.29	- 2.07*
Error Rates	0.01	0.04	0.31
Base-words:			
Naming RT	- 18.09	- 0.51	- 4.29*
Error Rates	- 0.01	- 0.14	- 1.04
	Herdman et al. items		
Subject Regression Analyses			
Mixed Lists			
Naming RT	6.46	0.01	1.01
Naming-PLDT RT	9.76	0.01	1.46
Pure Lists: NWs First			

Naming RT	- 0.48	- 0.01	- 0.13
Naming-PLDT RT	5.17	0.00	1.15
Pure Lists: PHs First			
Naming RT	- 8.20	- 0.04	- 0.76
Naming-PLDT RT	2.02	- 0.03	0.23
Item Regression Analyses			
Mixed Lists			
Naming RT	- 2.92	- 0.05	- 0.38
Naming-PLDT RT	0.81	0.01	0.11
Error Rates	0.01	0.08	0.66
Pure Lists: NWs First			
Naming RT	- 1.48	- 0.02	- 0.18
Naming-PLDT RT	- 3.81	- 0.05	- 0.44
Error Rates	0.01	0.11	0.93
Pure Lists: PHs First			
Naming RT	- 3.97	- 0.06	- 0.46
Naming-PLDT RT	- 12.22	- 0.12	- 0.99
Error Rates	0.01	0.05	0.39

Note. PH = pseudohomophone; NW = nonword; RT = Reaction Time; Naming-PLDT RT = naming reaction time contingent upon the participant concurring that the pseudohomophone sounded like a real word in the phonological lexical decision task; * $p < .05$; † $p < .10$. Tests of the unstandardized and standardized coefficients are identical for the item regression analyses, but can differ in the subject regression analyses; in these analyses, $*^{s}$ standardized coefficient $p < .05$, $\dagger^{s}$ standardized coefficient $p < .10$. The coefficients represent ms of RT/log unit increase in base-word frequency; the standardized coefficients represent SD of ms of RT/SD of log unit increase in base-word frequency, or equivalently, the correlation (*r*) between RT and log base-word frequency.

mixed pseudohomophone-nonword list condition, a significant pseudohomophone base-word frequency effect was revealed on naming latencies by-subjects, but not by-items. There was a trend for a pseudohomophone base-word frequency effect when correct naming latencies were contingent upon phonological lexical decision accuracy by-subjects (but not when standardized coefficients were analyzed), and not by-items. No pseudohomophone base-word frequency effect was evident with the error rates. A subsequent set of regression analyses examined the pseudohomophone base-word frequency effect for the nonword-first and pseudohomophone-first conditions. For the nonword-first condition, no pseudohomophone base-word frequency effects were observed for naming latencies or error rates. For the pseudohomophone-first condition, significant pseudohomophone base-word frequency effects were revealed by-subjects and by-items for correct naming latencies and by-items for correct naming latencies contingent upon phonological lexical decision accuracy; the corresponding by-subjects analysis revealed a marginal pseudohomophone base-word frequency effect for correct naming latencies contingent upon phonological lexical decision latencies, which was significant when standardized coefficients were analyzed. A by-items regression analysis of the error rates did not reveal a significant pseudohomophone base-word frequency effect. In summary, consistent pseudohomophone base-word frequency effects were only observed in the pseudohomophone-first condition. Interestingly, the significant pseudohomophone base-word frequency effect co-occurred with a pseudohomophone naming disadvantage. In contrast, no consistent pseudohomophone base-word frequency effect was observed in the mixed list condition, yet there was a significant pseudohomophone naming advantage.

Plosivity and Practice Effects. Kawamoto, Kello, Jones & Bame (1998) pointed out that words beginning with plosive consonants (i.e., obstruents and affricatives, consonant sounds that are produced by completely obstructing the airflow from the lungs for a brief period of time; see Carroll, 1999) are problematic for measuring response latency, or the initiation of articulation, because there is a delay between the response latency and the generation of acoustic energy. In comparison, the acoustic energy for nonplosive consonants can be generated immediately after initiation of articulation. Thus, if two sets of stimuli to be compared differ in terms of the number of initial plosive consonants, the set with more plosives should be named slower. Working in opposition to this effect is the sensitivity of a voice key, where hard onsets that are constituted by a majority of plosives, may trigger the voice key over a range of intensities where soft onsets may be less able to do so. To examine whether plosivity and/or practice had any influence on the results reported for the new pseudohomophone and nonword items, six pseudohomophone-nonword pairs that were not matched in terms of plosivity (e.g., feeld-teeld; n=6) were removed. The remaining 45 pairs of pseudohomophone and nonword items were identical in terms of onset (e.g., hoest-hoert; n=37) or they had different onsets that did not change in terms of plosivity (e.g., foart-loart; n=8).

In sum, removing pseudohomophone-nonword pairs that did not match in terms of plosivity, and assessing whether these same effects were stable across the first and second half of the trials did not change the overall pattern of results. In particular, the pseudohomophone naming advantage in the mixed list condition was observed by-subjects for both the first and second halves of the trials, *t*s > -3.63, *p*s ≤ .001. The pseudohomophone naming advantage was also observed by-items during the second half of the trials, *t*(44) = -2.015, *p* = .05. Consistent with the findings reported above, there was no pseudohomophone naming advantage observed for the nonword-first condition, either by-subjects or by-items, *t*s < 1.6, *p*s > .112. A marginal pseudohomophone naming disadvantage was observed in the first half of the trials by-subjects, *t* = 1.76, *p* = .089, which was significant by-items, *t* = 2.50, *p* < .02. Both of these effects were significant in the second half of the trials by-subjects and by-items, *t*s > 3.5, *p*s < .01. No pseudohomophone base-word frequency effect was observed, either by-subjects or by-items, in the mixed list condition for correct naming latencies, *t*s < -1.44, *p*s > .155. The pseudohomophone base-word frequency effect was observed by-subjects for both the first and second half of the trials for the pseudohomophone-first condition, *t*s > -2.21, *p*s < .05. No other significant effects were observed.

Herdman et al. (1996) Items

Pseudohomophone Naming Advantage. To examine the data for differences between pseudohomophone and nonword median naming latencies, by-subjects paired-sample t-tests and by-items two-sampled t-tests were conducted. The median response latencies and corresponding error rates are reported in Table 7. In the mixed pseudohomophone-nonword condition the typical pseudohomophone naming advantage was observed by-subjects, *t*(59) = - 2.707, *p* < .01, but not by-items, *t*(100) = - 0.426, *p* = .67. No pseudohomophone error rate advantage was observed by-subjects, *t*(59) = - 1.585, *p* = .118, or by-items, *t*(100) = - 0.837, *p* = .405. Analysis of list order revealed no pseudohomophone advantages for the nonword-first condition, either by-subjects or by-items, on naming latencies or error rates, all *t*s < 1.05, all *p*s > .29. However, for the pseudohomophone-first condition, significant pseudohomophone naming disadvantages were revealed by-subjects, $t(29) = 2.855$, $p < .01$, and by-items, $t(100) = 4.114$, $p < .001$. Analyses of the error rates showed a significant pseudohomophone disadvantage in the by-subjects analysis, $t(29) = 2.737$, $p = .01$, whereas the by-items analysis was non-significant, $t(100) = 1.35$, $p = .181$.

To examine the modulation of the pseudohomophone advantage effect, the median response latencies of pseudohomophones in the mixed and pure pseudohomophone first conditions were compared, as well as the median response latencies of the nonwords in the mixed and pure pseudohomophone first conditions. The by-subjects analysis revealed no significant differences in response latencies when pseudohomophones and nonwords were named in mixed versus pure lists, *t*s< 1.02, *p*s > .311. However, the by-items analysis revealed that pseudohomophones were named significantly faster in the mixed condition than in the pure pseudohomophone first condition, $t(134) = 3.603$, $p < .001$, and there was a trend for nonwords to be named slower in the mixed list condition, $t(66) = -1.672$, $p = .099$.

Pseudohomophone Base-Word Frequency Effects. Table 8 summarizes the subject-by-item and by-item regression analyses. For all conditions (i.e., mixed list, pure nonword-first, and pure pseudohomophone-first), no pseudohomophone base-word frequency effects were observed for naming latencies or error rates.

Plosivity & Practice Effects. Removing pseudohomophone-nonword triplets that did not match in terms of plosivity would have meant removing 29 out of 34 of the triplets, thus the analyses were restricted to examine potential practice effects. To determine if practice effects contributed to or obscured any effects analyzed above, the correct median pseudohomophone and nonword naming response latencies for the first and second half of the trials were calculated. In sum, there was no evidence that the pseudohomophone naming (dis)advantages or the pseudohomophone base-word frequency effects were influenced by practice. In particular, the pseudohomophone naming advantage in the mixed list condition was evident in the first and second half of the trials by-subjects (ts > - 1.96, ps < .056) but not by-items (ts < - 1.41, ps > .16, similar to what was reported above). There was no evidence of a pseudohomophone naming advantage in the pure nonword-first condition, either by-subjects or by-items, ts< - 1.17, ps > .25. In the pure pseudohomophone-first condition, the pseudohomophone naming disadvantage for the first half of the trials was marginal, ts > 1.79, ps < .085, whereas the effect was significant for the second half of the trials, both by-subjects and by-items, ts > 2.39, ps < .03. No pseudohomophone base-word frequency effects were observed for either the first or second half of the trials in any of the three list conditions, ts < 1.01, ps > .31.

Discussion

Traditionally, the base-word frequency effect on pseudohomophone naming latency has been considered as a fine-grained measure of phonological lexical access, and the comparison of pseudohomophone to nonword naming latencies has been assumed to serve as a coarse measure of the same. As such, these effects have typically been examined together by using mixed-list experiments (e.g., Herdman et al., 1996; McCann & Besner, 1987; Seidenberg et al., 1996; Taft & Russell, 1992).

However, these effects have not typically co-occurred with each other, contrary to predictions by most contemporary models of word recognition. The most common finding has been a null base-word frequency effect accompanied by a significant pseudohomophone advantage, causing researchers to modify their models of basic reading processes in order to account for these apparently discrepant effects. The present experiment demonstrated that the traditional mixed block presentation of pseudohomophones and nonwords may be responsible for this pattern of results.

The results of Experiment 6, which have been replicated in two other experiments (see Borowsky, Owen & Masson, in press), supported the hypothesis that base-word frequency effects for pseudohomophones are sensitive to list context, and revealed a *pseudohomophone naming disadvantage* that has never been reported in the *naming* literature. A standard pseudohomophone advantage (in the by-subjects analyses) was obtained in the mixed list condition for both Herdman et al.'s items and our new items. However, when pseudohomophones and nonwords were presented in pure blocks, and particularly when pseudohomophones were presented first, a pseudohomophone *disadvantage* was obtained for both sets of stimuli. There were no significant pseudohomophone base-word frequency effects for Herdman et al.'s (1996) items, in any of the conditions of Experiment 6, despite the fact that the base-words for these stimuli have been shown to elicit a reliable frequency effect in word naming (Borowsky & Masson, 1999, and thus these base-words were not reexamined here). However, with our new items, even if one only considers the effects that are significant both by-subjects and by-items, there is a significant base-word frequency effect for the base-words themselves, as well as for the pseudohomophones derived from these base-words, *especially when pseudohomophones are presented first.* This base-word frequency effect also survives the constraint of analyzing only the items that participants concurred with as sounding like real words.

The finding that the significant pseudohomophone base-word frequency effect becomes a trend when the by-subjects analysis is constrained by PLDT accuracy suggests that the pseudohomophone base-word frequency effect can sometimes be inflated by the inclusion of items that participants do not consider to sound like words. Thus, having demonstrated that this experiment has sufficient power to detect a pseudohomophone base-word frequency effect with our items, and given that all participants named both our items and Herdman et al.'s items, it would appear that Herdman et al.'s items are not sensitive to base-word frequency. It should be noted that Herdman et al.'s stimuli were drawn from a restricted frequency range (0-1000), whereas stimulus sets that have produced the pseudohomophone base-word frequency effect have been drawn from a larger frequency range (0-3000). Furthermore, half of Herdman et al.'s pseudohomophones contained illegal bodies that do not occur in real English words (e.g., _awx).

An analysis of potential practice effects did not compromise the base-word frequency effect or the lexicality effect (i.e., the pseudohomophone advantage/disadvantage). Similarly, an analysis with the new items matched in terms of plosivity did not compromise the pattern of results obtained with the full set of items (Herdman et al.'s items could not be analyzed in this manner due to the number of high and low frequency pseudohomophone and nonword triplets that did not match in terms of plosivity). Thus, it appears that practice and plosivity did not affect the results of the current experiment.

The overall data supports the notion that: (1) the pseudohomophone base-word frequency effect on naming latency is seen when pseudohomophones are presented in a pure block before nonwords, and it is accompanied by relatively slow pseudohomophone naming latency and a pseudohomophone naming disadvantage, whereas (2) mixed list presentations tends to result in no base-word frequency effect accompanied by relatively faster pseudohomophone naming latency and a pseudohomophone naming advantage. There is neither a base-word frequency effect nor a lexicality effect when pseudohomophones are presented in a pure block after nonwords, accompanied by the fastest naming responses of all the conditions. Grainger et al.'s (2000) and Marmurek and Kwantes' (1996) research also supports the finding that base-word pseudohomophone frequency effects can be observed in pure list conditions; however, their research did not address carryover effects from prior nonword naming nor did their research address the context specificity of the pseudohomophone (dis)advantage. Can dual- or single-route models account for the present pattern of data?

Dual-route interpretation of the results. According to dual-route accounts of visual word recognition, mixed list composition may invoke different processing strategies for pseudohomophone and nonword naming than pure list presentation. This strategic reliance account has previously been used to account for the modulation of word frequency effects in cases where words are presented in pure blocks or when they are mixed with nonwords (e.g., Experiment 5; Baluch & Besner, 1991; Monsell et al., 1992). When pseudohomophones are presented in a pure block prior to nonwords, it is plausible that participants would often attempt phonological lexical access in the pseudohomophone block of trials (indeed, being told that these items are designed to sound like real words must serve as an invitation to verify their phonological lexical status), thus increasing response latency relative to mixed list presentation and allowing more opportunity for frequency-sensitive representations (or frequency sensitive connections between lexical and semantic representations; see Borowsky & Besner, 1993, and McCann & Besner, 1987) to affect the response. This is consistent with the idea that speech can be produced after spelling-sound correspondences have been assembled and checked against stored phonological lexical representations. In contrast, participants would rarely bother to check representations in their phonological-lexical or semantic representations when presented with a pure block of nonword trials, thus decreasing nonword response latency relative to mixed list presentation. The lack of lexicality and base-word frequency effects when nonwords are presented prior to pseudohomophones may simply reflect a carryover effect of continuing to *not* verify phonological-lexical or semantic status when presented with pseudohomophones in the second block. These results are consistent with the idea that speech can be produced once spelling-sound correspondences have been assembled without necessitating phonological lexical access.

In mixed-list experiments, the probability of using each of these opposing strategies must regress towards a more moderate level for both pseudohomophones and nonwords. In other words, participants must be less inclined to verify the pseudohomophones' phonological-lexical or semantic representations when naming given that a large proportion of the trials are nonwords that would have no such representations. The decrease in intentional lexical or semantic access would serve to wash out any underlying frequency effect, and also decrease pseudohomophone naming latency relative to the condition where pseudohomophones were presented first. In contrast, nonwords in mixed lists would be subjected to futile lexical or semantic verification more often than when presented in pure lists, serving to increase nonword naming latency relative to pure list presentation. The regression of the opposing pure-list strategies towards a more moderate level does not limit the response latencies of the mixed-list stimuli from completely crossing over and producing a pseudohomophone advantage. The item analyses in Experiment 6, taken together with the robust pseudohomophone advantage in the literature on mixed block presentation of pseudohomophones and nonwords, support this account.

A sufficient account must also be capable of dealing with the null pseudohomophone base-word frequency effect that often accompanies the pseudohomophone advantage (see Borowsky & Masson, 1999, for a review). One way to do this is to disengage the mechanisms responsible for frequency effects from those responsible for the pseudohomophone advantage. For example, McCann and Besner (1987) suggested that the pseudohomophone advantage reflects the benefits of accessing phonological lexical representations, whereas the lack of frequency effect is due to not utilizing connections from the phonological lexical system to the semantic system. If one further assumes that intentionally utilizing these frequency sensitive links during lexical-semantic verification adds additional time to pseudohomophone naming latency in pure blocks relative to mixed blocks (a reasonable assumption given that these links occur only after one has reached the lexical level of representations), and that intentionally *not* using these links when nonwords are presented in pure blocks subtracts time from nonword naming latency relative to mixed blocks, then the present strategy account could be easily merged with McCann and Besner's account.

Single-route interpretation of the results. Seidenberg et al. (1996) have also provided a single-route account for the pseudohomphone naming advantage that is separate from the mechanism that accounts for frequency effects in their parallel distributed processing model. This account is implemented through the addition of articulatory units that are sensitive to the familiarity of the pronunciation of the pseudohomophones (and presumably their base-word frequency if the pseudohomophone advantage were sufficiently large). The lack of base-word frequency effects in pseudohomophone naming is considered to be due to a lack of semantic activation (similar to the links account offered by McCann & Besner, 1987). However, it is difficult to conceive of how a connectionist single-route model could be made to produce a pseudohomophone disadvantage *and* a significant pseudohomophone base-word frequency effect under pure block presentation conditions without recourse to either: (1) the implementation of a *second* semantically mediated route or (2) strategic shifts in "grain size" (i.e., sub-lexical versus lexical level representational units), both of which are more concordant with dual-route accounts of visual word recognition. Thus, it remains to be seen whether these models can invoke strategic mechanisms that can produce a pseudohomophone disadvantage *and* a significant pseudohomophone base-word frequency effect under pure block presentation conditions. Indeed, the present results provide a challenge for all classes of computational models to implement a strategy mechanism as described above to account for the double dissociation of lexicality effects (i.e., pseudohomophone advantage versus disadvantage) and single dissociation of the base-word frequency effect (i.e., null versus negative) on naming latency as a function of list context (i.e., mixed versus pure lists).

Pseudohomophone disadvantages. Although this pseudohomophone *naming* disadvantage has not been previously reported, it is interesting to note that a pseudohomophone disadvantage in orthographic lexical decision has been reported in the literature, and that the effect was also interpreted as being due to lexical influence. Coltheart, Davelaar, Jonasson and Besner (1977; Davelaar et al., 1978) examined the effect of homophony (i.e., homophonic words are responded to faster than matched non-homophones) when pseudohomophones and nonwords were used as distracters in an orthographic lexical decision task (i.e., a standard lexical decision task where participants make their judgment based on spelling, not on sound). They showed that participants were slower to respond that a pseudohomophone was not a word compared to responding that a nonword was not a word. The authors interpreted this pseudohomophone disadvantage as evidence that lexical phonology contributed to orthographic lexical decision performance.

Conclusions (Experiment 6)

The traditional approach to studying phonological lexical access, whereby pseudohomophones and nonwords are named within a single block of mixed trials (e.g., Herdman et al., 1996; McCann & Besner, 1987; Seidenberg et al., 1996) has typically yielded a pseudohomophone advantage and a null pseudohomophone base-word frequency effect. However, base-word frequency effects can be obtained in pseudohomophone naming if the following criteria are met: (1) Pseudohomophones should be presented in pure blocks of trials, preferably before any nonword stimuli, (2) The subjects should be told about the nature of the stimuli in the block of trials that they are about to see, (3) Pseudohomophone stimuli that participants do not consider to "sound like" real English words should be removed on a participant-by-participant basis, and (4) The base-word stimuli themselves should be capable of eliciting a frequency effect on base-word naming to begin with (Borowsky & Masson, 1999). Given that the pseudohomophone advantage tends to reverse to a *disadvantage* under such conditions, this particular finding provides an interesting test for current models of word recognition. A lexical verification strategy, whereby the presentation of a pure block of pseudohomophones maximizes the probability that phonological lexical-semantic access will occur (and most often when pseudohomophones are presented first), a pure block of nonwords minimizes this probability, and a mixed block involving both types of stimuli results in a regression towards a more moderate probability, accounts for the present results. The co-occurrence of a base-word frequency effect with a pseudohomophone naming disadvantage suggests that the pseudohomophone naming disadvantage would better serve as a course-grained measure of phonological lexical/semantic access under pure-block presentation conditions, in contrast to the pseudohomophone naming advantage that has been observed in the mixed-block conditions here, and by previous researchers.

In general, the present results illustrate that skilled readers can strategically adjust their reliance upon lexical/semantic access due to the context of the word list.

Although this experiment could not determine whether the verification process was lexical or semantic in nature, future experiments may be able to disentangle this issue. It would be quite interesting to determine the degree to which whole-word orthographic lexical or semantic representations are required to develop phonological lexical representations. Specifically, this issue could be addressed by examining whether readers who have poor SV processes (e.g., surface dyslexics) or poor semantic access (e.g., deep dyslexics) produce the double dissociation of lexicality effects (i.e., pseudohomophone advantage versus disadvantage) and single dissociation of the base-word frequency effect (i.e., null versus negative) on naming latency as a function of list context (i.e., mixed versus pure lists). Alternatively, a priming paradigm similar to a study by Borowsky and Besner (2000) could be used to separate the contributions of orthographic lexical and semantic processing during the verification procedure. In particular, a pseudohomophone naming trial could provide a context for a critical real word naming trial, whereby the critical word to be named would be either: (1) semantically, but not orthographically, related to the pseudohomophone base-word, (2) orthographically, but not semantically, related to the pseudohomophone base-word, or (3) neither semantically or orthographically related to the pseudohomophone base-word (i.e., a neutral context). Such experiments would provide further details regarding how SV and/or semantic processes can influence PD processing.

Chapter 3

NEUROANATOMICAL CORRELATES OF SIGHT VOCABULARY AND PHONETIC DECODING

Neuroimaging provides an important converging method of investigation for those scientists interested in the study of human cognitive processes (Ashcraft, 2002). Functional magnetic resonance imaging (fMRI) has been used to examine the neural basis of many cognitive functions. For example, researchers have conducted studies on the neural basis of memory (e.g., Buckner, Koutstaal, Schacter, Wagner & Rosen, 1998), mathematical processing (e.g., Dehaene, Spelke, Pinel, Stanescu & Tsinkin, 1999), and, the focus of the current experiment, basic visual word recognition (e.g., Price, Moore, Humphreys & Wise, 1997). However, before discussing the contributions of neuroimaging research to the area of basic word recognition, the fundamentals of fMRI will be introduced.

Fundamentals of fMRI

Signal generation. Magnetic resonance imaging is a practical neuroimaging tool because it is non-invasive (i.e., no exogenous tracers have to be used as in PET, and no skull material has to be removed as in electro-cortical stimulation). Magnetic resonance imaging works because the hydrogen nuclei can be used to generate measurable electromagnetic signals. In particular, local differences in measurable signals emanating from hydrogen nuclei in the body/brain allow for images to be reconstructed that capture structural differences in the human brain. Images can also be reconstructed to obtain local changes in the measurable electromagnetic signal due to specific neural activity. Functional MRI utilizes changes in blood-oxygenated level dependence (BOLD; see Kwong et al., 1992), which researchers have shown to be correlated with neuronal activity.

Seminal work by Fox and Raichle (1986) illustrated the dynamic relationship between neuronal activity and cerebral blood flow (CBF) in a positron emission tomography (PET) study. The authors demonstrated that CBF and cerebral metabolic rate of oxygen consumption ($CMRo_2$), an index of neuronal metabolic activity, were highly correlated during resting-state measurements across 48 brain regions. During an activation-state, whereby focal vibratory stimulation was induced on the finger pads of nine participants, the same high degree of correlation between CBF and $CMRo_2$ was found for *non-activated* brain regions, that is, brain regions excluding the somatosensory cortex. However, CBF and $CMRo_2$ were not correlated in *activated* brain regions (i.e., CBF and $CMRo_2$ were decoupled). In particular, CBF to active regions of neurons increased by about 29%, whereas $CMRo_2$ only increased by 5%. The local increase in CBF occurred .5 to 2 seconds following the onset of vibratory stimulation. As will be discussed later, the relatively large CBF response to neuronal activity is advantageous for fMRI purposes (Frith & Friston, 1997).

As stated above, fMRI utilizes changes in BOLD. Deoxyhemoglobin, which is paramagnetic (i.e., enhances magnetism), decreases the amount of magnetic signal because it creates a local heterogeneous magnetic environment (i.e., intravoxel dephasing of the signal; Kwong et al., 1992). As the ratio of oxyhemoglobin to deoxyhemoglobin increases, there is an increase in the MRI signal due to an increase in the transverse relaxation time (T_2^*). The oxyhemoglobin/deoxyhemoglobin ratio is dependent upon CBF, cerebral blood volume, and $CMRo_2$ (Kwong et al., 1992) and, as demonstrated by Fox and Raichle (1986), is a very sensitive index of neural activity. Raichle (2001) has recently stated that the local changes in oxygen levels, which give rise to the magnetic signal, are a result of activation inputs to groups of neurons and not due to neuronal output (Logothetis, Pauls, Augath, Trinath & Oeltermann, 2001).

The BOLD function is composed of three components: (1) the rising edge time, (2) peak, and (3) falling edge. Compared to the stimulus onset, the hemodynamic response is delayed by about 2 seconds (Menon & Kim, 1999). Furthermore, and depending upon the task, the *rising edge* may take about 15 seconds, while the *falling edge* may add another 10 to 20 seconds to the hemodynamic response function. Menon and Kim state that the rising edge is more stable than the falling edge, both within and across participants. Despite the differences in variability between the rising and falling edges, Menon and Kim argue that the entire hemodynamic function should be used for analysis simply because this increases the power of the analysis.

Spatial and Temporal Resolution. Kwong et al. (1992) state that the use of fMRI principles based upon blood-tissue contrasts provides unambiguous three-dimensional spatial-temporal localization of human behavioural processes. Currently, the spatial resolution of fMRI images is very good (i.e., approximately 2mm) compared to other neuroimaging techniques; however, the temporal resolution is limited (i.e., on the order of seconds; Demb et al., 1999; Frith & Friston, 1997; Horwitz, Tagamets & McIntosh, 1999). Menon and Kim's (1999) review of fMRI suggests that the lower limit of spatial-temporal resolution will be limited by the fact that the blood supply is not regulated by individual neurons but rather by clusters of neurons 0.5 to 1.5 mm in size.

In cognitive-neuropsychological research, block design studies are often used to increase the signal-to-noise ratio. Images during several blocks of cognitive trials are often accumulated, normalized using a stereotactic brain atlas (e.g., Talairach & Tournoux, 1988), and averaged across participants to form a composite cognitive brain map (Demb et al., 1999). However, the increase in signal-to-noise from averaging across participants is offset by a reduction in spatial resolution (e.g., from 2mm to 8mm) necessary for stereotaxic normalization.

Verification of our fMRI protocol. It has been well established that the left hemisphere controls the right side of the body, and vice versa. Borowsky, Owen, and Sarty (in press) investigated the contribution of contralateral hemispheric control in a simple motor task. Sixteen participants engaged in a thumb and finger touching task, which was hypothesized to engage the contralateral motor cortex specific to the hand region. The specific protocol was a repeated block design with an initial acquisition period to allow for the BOLD response to establish a steady state, followed by a sequence containing the active state for eight seconds and then rest the rest state for 32 seconds, which was repeated for a total of five blocks. Borowsky, Owen, and Sarty (in press) obtained ten-slice, full-cortex volumes of images. The data were analyzed using BOLDfold with an eta cutoff of .73 (Sarty & Borowsky, 2002; see methods section for more details). Borowsky, Owen, and Sarty (in press) found a contralateral advantage in the motor cortex of both the right and left hemispheres for 14 out of 16 participants. Interestingly, the two participants who did not show a contralateral advantage for the left hemisphere were the only two participants who showed activation in Broca's area. In a post-experiment interview, both of these participants stated that they found themselves using a verbal mediation strategy (e.g., counting). This study provided verification that our fMRI protocol was appropriate to extend into the language domain, which has a less well-established neurological model (cf. Binder & Price, 2001, Demb et al., 1999; Pugh et al., 2000).

Dual-Route Models of Visual Word Recognition

Basic behavioural and neuropsychological research have illustrated that skilled readers can rely on two processing routes (e.g., Baluch & Besner, 1991; Borowsky, McDougall et al., 2002; Castles & Coltheart, 1993; Marshall & Newcombe, 1973). Dual-route models of visual word recognition make a distinction between lexical and sublexical sources of phonology (e.g., Baron & Strawson, 1976; Coltheart, 1978; Coltheart et al., 2001). As stated previously, the PD route processes novel words by parsing letter-string into graphemes that are then mapped onto phonemes, whereas the SV route processes exception and familiar words by directly mapping lexical orthographic representations onto lexical phonology representations. Results from fMRI studies have also indicated that skilled normal readers have access to both sublexical and lexical level processes (Posner & Raichle, 1994; Pugh et al., 2000).

Ventral-dorsal model. As discussed in the introduction, Pugh et al. (2000) have developed a model of basic visual word recognition that captures the cognitive dual-route architecture. In particular, Pugh et al. suggest that skilled readers can rely on both the *ventral pathway* (i.e., SV processing) and *dorsal pathway* (PD processing). Figure 7 illustrates these pathways. The ventral pathway is involved in mapping

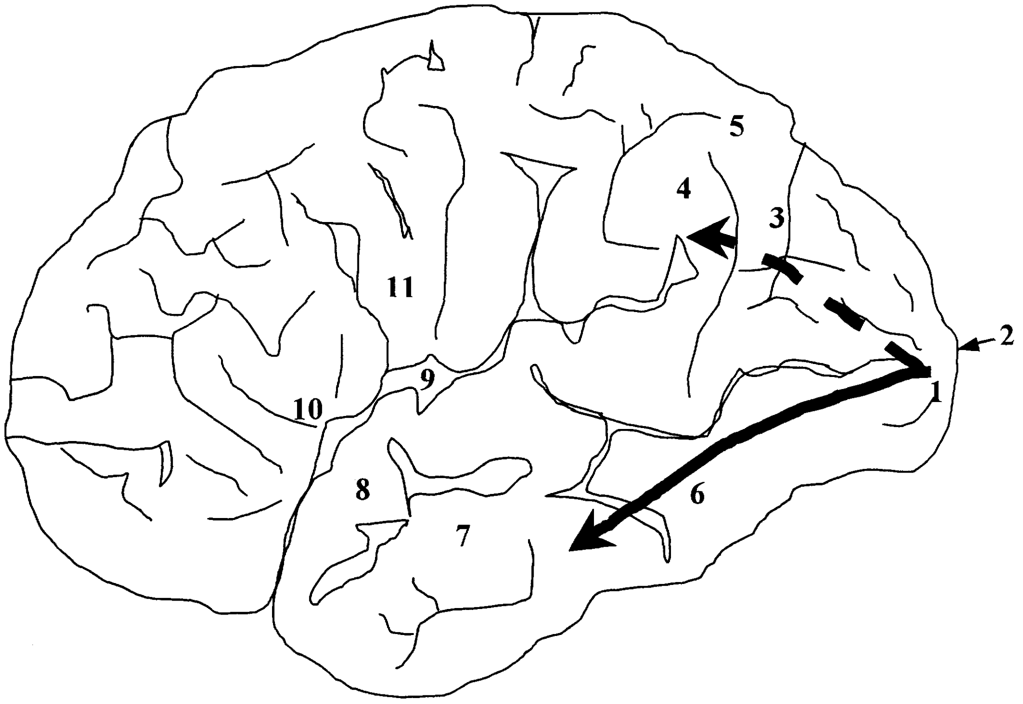


Figure 7. A general overview of the pathways involved in *sight vocabulary* (the solid line) and *phonetic decoding* (the broken line) reading processes. 1. lateral occipital region, 2. medial occipital region, 3. angular gyrus, 4. supramarginal gyrus, 5. inferior parietal lobule, 6. inferior temporal gyrus, 7. middle temporal gyrus, 8. anterior portion of the superior temporal gyrus, 9. insular cortex (buried behind the temporal cortex), 10. Broca's area, 11. motor cortex. Regions numbered 1, 2, 6, 7 and 8 correspond to the *ventral pathway* (or SV) in Pugh et al.'s (2000) model, whereas regions numbered 1, 2, 3, 4, and 5 correspond to the *dorsal pathway* (or PD). In contrast, regions numbered 2 and 9 correspond to Posner and Raichle's (1994) *automatic pathway*, whereas regions numbered 3, 4, 5, and 10 correspond to the *nonautomatic, or controlled, pathway*.

orthographic lexical stimuli onto lexical phonological stimuli, whereas the dorsal pathway is involved in the sublexical analysis of word stimuli, and the establishment of lexical-semantic representations. Explicitly, the ventral pathway includes Brodmann's areas 17, 18, and 19 in the occipital lobe, and areas 20, 21, and 30 of the temporal lobe, whereas the dorsal pathway includes Brodmann's areas 18, and 19 in the occipital lobe, and areas 22, 39, and 40 of the temporal-parietal region.

Automatic and non-automatic processing. As described earlier, Hasher and Zacks' (1979) notion of controlled and automatic processing has been adopted by some dual-route models of basic reading processes (e.g., Paap & Noel, 1991). It is often assumed that SV processing is more automatic than PD processing. Similarly, a second neurological dual-route model of basic reading processes has also described reading processes in these terms. In particular, Posner and Raichle (1994) have also proposed a dual-route type model of visual word recognition and semantic generation based upon their many PET studies (see Figure 7). The authors stated that words, nonwords, and consonant strings activate lateral occipital regions of both the right and left hemisphere, and corresponds to *visual feature* processing. Passively viewing visually presented words and nonwords activates the left medial occipital cortex, whereas consonant strings did so to a lesser degree. This selective activity corresponds to a *word form* system. Passively listening to aurally presented words activated the temporal regions of both hemispheres, and in particular, Wernicke's area. The involvement of Wernicke's area corresponds to a *phonological lexical* processing. There was relatively no indication that passive viewing or listening to words produces activity in cross-modal brain regions. That is, passively listening to words does not activate areas associated with passively viewing words. At the level of producing speech in response to either reading or listening to words, the brain activity also included primary and secondary motor areas, as well as the *insular cortices*. The insular cortices are located on the medial surface of the lateral fissure, which separates the temporal and frontal lobes.

Reading and listening to words involves more than simply encoding stimuli and producing speech. We often engage in reading in order to derive meaning. To capture the semantic aspect of reading, Posner and Raichle (1994) utilized a (overt) semantic verb generation task, whereby participants were asked to generate verbs for visually presented nouns. The generation task activated Broca's area, Wernicke's area, anterior cingulate, and the right cerebellum. However, the insular cortices, which were active during speech production, were less active. Further study revealed that if participants practiced specific noun-verb associations, their patterns of brain activity were indistinguishable from participants who named the nouns aloud (i.e., there was insular cortical activity).

Based upon these patterns of findings, Posner and Raichle suggested that the brain may have two pathways for visual word recognition and semantic generation. The visual word form area in the medial extrastriate region of the occipital lobe is common to both pathways. If a word is well learned, it is automatically processed by the *enhanced word form system* in the insular cortices. However, Broca's area, Wernicke's area, anterior cingulate, and the right cerebellum region contribute to the processing of previously unlearned words (i.e., nonautomatic processing). Explicitly, the automatic processing pathway includes Brodmann's areas 17, 18, and 19 in the occipital lobe, and the insular cortices of the frontal lobe, whereas the nonautomatic processing pathway includes Brodmann's areas 18, and 19 in the occipital lobe, areas 22, 39, and 40 of the temporal-parietal region, and areas 44 and 45 of the frontal lobe.

Taking the Ubiquitous Word Frequency Effect into Account

The word frequency effect is a pervasive phenomenon in the word recognition literature. Recall that the presence of a word frequency effect has often been interpreted as evidence for SV processing (e.g., Baluch & Besner, 1991; Forster, 1985; Monsell et al., 1992; Paap et al., 1987; Zevin & Balota, 2000). Furthermore, several researchers have also interpreted the absence of a word frequency effect as evidence for PD processing (e.g., Monsell et al., 1992; Zevin & Balota, 2000). It appears that the ventral-dorsal and automaticity models are well developed to test whether there are neuro-anatomical correlates of SV and PD processing. Following from the previous experiments, a stimulus dissociation was used to promote reliance on either SV or PD processing. Exception words were considered SV-reliant stimuli because they do not follow typical spelling-sound correspondences, whereas pseudohomophones were considered PD-reliant stimuli because they lack orthographic lexical representations. As such, the ventral-dorsal model (Pugh et al., 2000) would predict that high frequency exception words would be processed via the ventral pathway. To the degree that low frequency exception words require semantic mediation (see also Strain et al., 1995), low frequency exception words may also be processed via the dorsal pathway. As pseudohomophones do not have familiar word forms, pseudohomophones should be processed along the dorsal pathway. According to the automaticity model of Posner and Raichle (1994), high frequency exception words would have very familiar lexical representations and, thus, would be processed in the insular cortices. Exception words have more familiar orthographic-phonological representations compared to novel pseudohomophones, which would only have a familiar phonology. Therefore, exception words should have a processing advantage in terms of more insular cortical activation. On the other hand, pseudohomophones should produce more activation in Broca's area, Wernicke's area, anterior cingulate, and the right cerebellum regions. The purpose of Experiment 7 was to examine the neural underpinnings of SV and PD processing as they relate to the word frequency effect, and to compare and contrast these two neurological dual-route models of visual word recognition.

Experiment 7

Methods

Participants. Nine right-handed native English participants (six male, three female) were studied. Each participant gave informed consent as approved by the University of Saskatchewan Behavioral Sciences Ethics Committee. Saskatoon District Health provided operational approval for this study (see Appendix A).

Materials. The words and pseudohomophones were selected from stimuli that were used in previous experiments.[6] A subset of 80 exceptions words was selected from Experiment 5. These items did not follow the typical spelling-sound correspondences observed in English. The frequency of the items was determined by examining the Kučera and Francis (1967) word frequency norms. High frequency exception words (n = 40) had a mean word frequency of 799 (range: 84-4393),

---

[6] While the present study was being conducted the majority of the pseudohomophones from Experiment 6 were being used in another fMRI task that compared a phonological lexical decision task to a rhyming decision task. Thus, a new list of pseudohomophones was generated from previous studies so that the participants did not see or name the same set of items twice.

whereas the low frequency exception words (n = 40) had a mean frequency of five (range: 0-13). The pseudohomophones were collected from several published stimulus sets (e.g., Marmurek & Kwantes, 1996; McCann & Besner, 1986; Taft & Russell, 1992). High frequency pseudohomophones (n = 40) had a mean base-word frequency of 212 (range: 43-1961), whereas the low frequency pseudohomophones (n = 40) had a mean base-word frequency of six (range: 0-19).

Experimental design and procedure. The experimental design was a hybrid of event-related and block designs. The critical trials consisted of five blocks of eight stimuli, to which participants were to name aloud. Following each naming block, there was a rest period during which participants were told to relax and focus on their breathing. This experiment was carried out on a 1.5T Siemens Symphony Magnetom imager. A PC running Micro Experimental Laboratories software triggered each image acquisition, and the timing of the stimulus presentations. Stimuli were presented using a Sharp Notevision 3 data projector. Ten slice volumes of axial echo-planar images (TR = 1600 ms, TE = 55 ms, FOV = 250mm, echo-planar matrix size = 64^2 for acquisition and were Fourier transformed to 128^2 by zero-filling during reconstruction) were acquired continuously and synchronized to the stimulus presentations. An additional five volumes were acquired prior to the first block of critical trials in order to achieve a steady state of image contrast. The fourth most inferior slice of each volume was centered on the posterior commissure. The slice thickness was 8 mm with a slice spacing of 2 mm. High-resolution spin echo, spin warp T1-weighted anatomical images (TR = 525 ms, TE = 15 ms, matrix size = 64^2 for both acquisition and reconstruction) were acquired in axial, sagittal, and coronal planes for the purpose of overlaying the activation maps. The spin echo, spin warp axials matched the echo planar imaging sequence.

The sequence of events was as follows: (1) blank screen for five volumes, (2) a fixation (+) mark appeared for two volumes to indicate that a block of eight stimuli were about to be presented, (3) eight stimuli were presented for two volumes (i.e., 3200 ms) each during which time participants named the presented stimulus, (4) following the eighth stimulus, a blank screen appeared for 17 volumes (i.e., 27,200 ms), (5) the sequence, beginning with the fixation mark, was repeated for four more blocks. Following this sequence of events, the participant rested for 3-4 minutes before the next naming task began. Based upon the results of Experiment 6, which showed order effects for pure blocks of pseudohomophones and nonwords, it was decided that, in order to maximize the opportunity to observe frequency effects for pseudohomophones, a fixed order of stimulus presentation be used. Participants were presented low frequency exception words, high frequency exception words, high frequency pseudohomophones, and then low frequency pseudohomophones. Because exception words are considered to be SV-reliant stimuli, which would prime lexical/semantic access, this fixed order sequence maximizes lexical/semantic verification for the pseudohomophones.

Image analysis. The BOLDfold method of analysis (Sarty & Borowsky, 2002) was used to analyze the data. After correcting for baseline drift, the mean BOLD function for each voxel, collapsing across the 5 repetitions of the naming and rest periods, was empirically determined and then repeated five times. The empirically determined BOLD function was then correlated to the actual data as a measure of consistency across repetitions. The squared correlation (r^2) represents the goodness of fit between the *mean BOLD function* and the *observed BOLD data*, capturing the variance accounted for in the data by the mean BOLD response. Buckner (1998) has stated that analysis methods that make no a priori assumptions about the shape and timing of the BOLD function, such as the BOLDfold method described here, are beneficial in terms of fMRI analysis protocols. This method also serves to reduce the number of false activations associated with the traditional *t*-test method, and it is less sensitive to motion artefacts (Borowsky, Owen & Sarty, in press; Sarty & Borowsky, 2002).

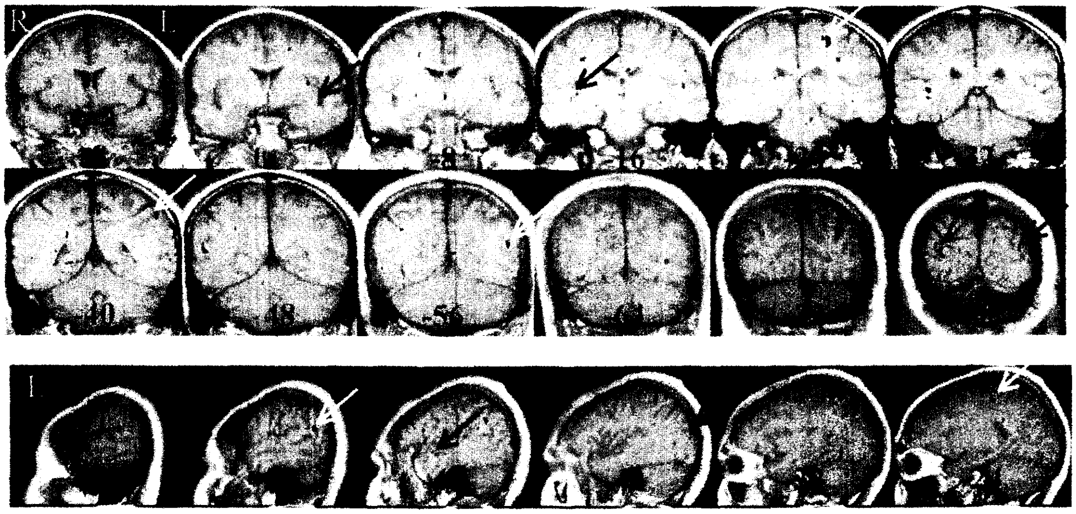
The analyses proceeded in two stages. First, the more traditional analysis method of normalizing the images (i.e., transforming the images to Talairach coordinates) and then averaging across participants (i.e., merging the functional datasets) was performed using AFNI (Cox, 1996). The images were spatially smoothed with a 3 mm full-width at half maximum Gaussian kernel (FWHM = 3 mm). T-tests were conducted to determine whether there were frequency effects for each stimulus type. As it was also of theoretical interest to determine whether there was a stimulus-type effect, comparisons were made between high frequency exception words and high frequency pseudohomophones, and between low frequency exception words and low frequency pseudohomophones. The t-test maps were also used to define specific regions of interest (ROIs). Second, an analysis of individual activation maps was performed to ensure that the data averaging procedure represented the majority of individual activation maps (see Borowsky, Owen & Sarty, 2002). The major analyses focused on three main ROIs: (1) the dorsal pathway region (including the angular gyrus, supramarginal gyrus, and the posterior aspect of the superior temporal gyrus), (2) the ventral pathway region (including the lateral extrastriate and the left inferior occipito-temporal regions), and (3) the insular cortices, bilaterally. The number of participants that showed activation in each of these ROIs were calculated for each naming task.

Results

Averaged data analysis. The comparison of high frequency exception word versus low frequency exception word naming showed more activation in the left middle occipital gyrus (Talairach x-y-z coordinates -41, -80, -15, based upon a normalized stereotaxic atlas of the human brain; Brodmann's area 18 and 19; see Figure 8A), and inferior parietal lobule (Talairach coordinates -59, -40, -41; Brodmann's area 39 and 40). The right middle occipital region (Talairach coordinates 30, -80, -13; Brodmann's area 18 and 19) also showed significantly greater activation for high frequency exception words. Bilateral activation of the insular cortices was prominent for high frequency exception words (left hemisphere Talairach coordinates -43, 0, 2; right hemisphere Talairach coordinates 42, -16, -10). There was significantly greater activity associated with low frequency exception word naming in the left precentral gyrus (Talairach coordinates -25, -24, -50; Brodmann's area 6) and superior temporal gyrus (Talairach coordinates -56, -57, -18; Brodmann's area 22). In general, there was more activity associated with high frequency exception word

High Frequency Minus Low Frequency Exception Word Naming

8A



High Frequency Minus Low Frequency Pseudohomophone Word Naming

8B

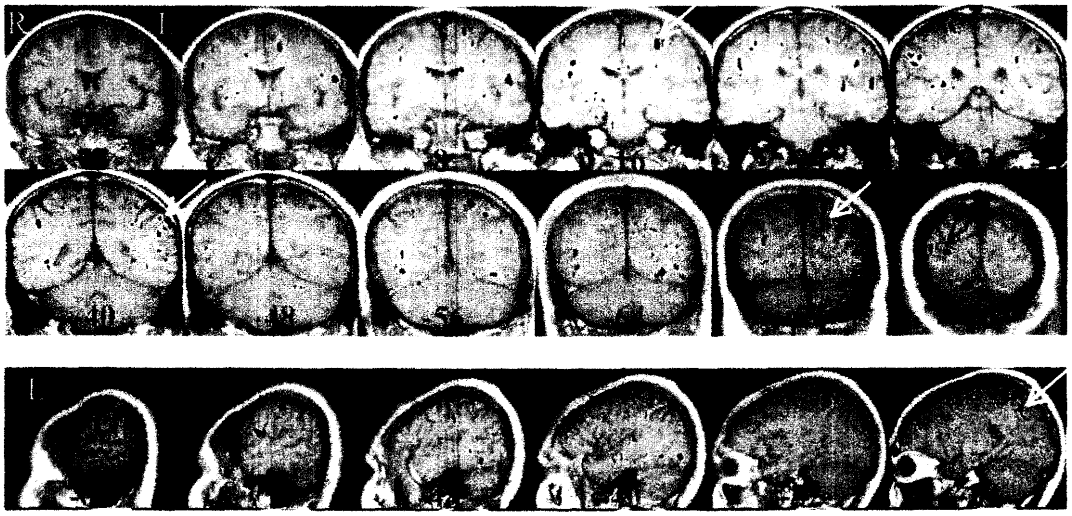


Figure 8. T-test maps comparing high and low frequency exception word naming activations (8A) and high and low frequency pseudohomophone naming activations (8B). A critical *t* of 2.751 was used for all t-test maps. Z values at the bottom of the images represent millimeters (in Talairach coordinates) anterior to the vertical anterior commissure line in the Y-direction for the coronal sections and millimeters lateral to the midline plane in the X-direction for the sagittal sections. The green arrows represent areas of activation consistent with ventral and insular pathways, whereas the white arrows represent areas of activation along the dorsal pathway and motor output. The gold arrows are the right-hemisphere homologue of middle occipital gyrus. Red to yellow activation represents increasing BOLD intensities that are greater for high frequency items, whereas blue to pale-blue represents increasing BOLD intensities that are greater for low frequency items.

naming in ventral and insular regions, whereas low frequency exception words appeared to be processed along a more dorsal route. In contrast, the comparison of high frequency pseudohomophone versus low frequency pseudohomophone exhibits no frequency differences in areas associated with the ventral pathway (e.g., left middle occipital gyrus) or the insular cortex (see Figure 8B). Low frequency pseudohomophone naming did show more activation in the right middle occipital gyrus and left precentral gyrus. Low frequency pseudohomophone naming also produced greater activation in the left superior occipital area (Talairach coordinates -48, -76, -16; Brodmann's area 19), left superior parietal area (Talairach coordinates -23, -72, -44; Brodmann's area 7), and left superior temporal gyrus (Talairach coordinates -64, -27, -10; Brodmann's area 22).

Lexicality effects were examined by comparing the activation during high frequency exception word naming versus high frequency pseudohomophone naming. Figure 9 illustrates that exception word naming produced greater activation in the left middle occipital gyrus and corresponding right hemisphere homologue. Exception word naming also produced greater bi-lateral superior parietal (left Talairach coordinates -21, -72, -43; right Talairach coordinates 24, -72, -43; Brodmann's area 7), left lateralized inferior parietal lobule (Talairach coordinates -43, -40, -36; Brodmann's area 39 and 40) and insular cortex activation. Although the t-test maps show that exception word naming is highly distributed, there is clear ventral occipito-temporal activation.

Individual data analysis. Borowsky, Owen, and Sarty (2002) have argued that after examining averaged activation maps, it is prudent to examine the number of

High Frequency Exception Word Minus Pseudohomophone Naming

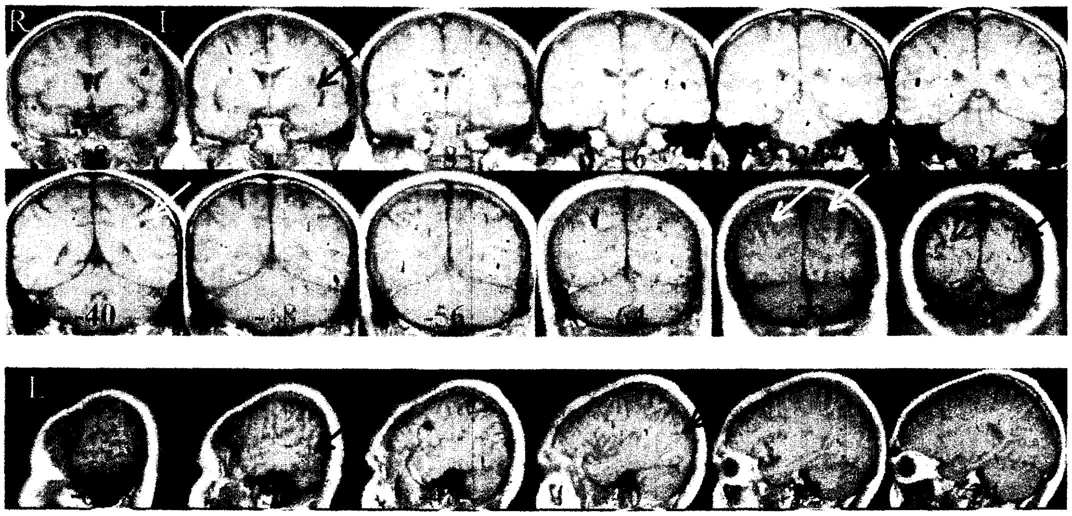


Figure 9. T-test maps comparing high frequency exception word naming activations to high frequency pseudohomophone naming activations. A critical *t* of 2.751 was used for all *t*-test maps. Z values at the bottom of the images represent millimeters (in Talairach coordinates) anterior to the vertical anterior commissure line in the Y-direction for the coronal sections and millimeters lateral to the midline plane in the X-direction for the sagittal sections. The green arrows represent areas of activation consistent with ventral and insular pathways, whereas the white arrows represent areas of activation along the dorsal pathway and motor output. The gold arrows are the right-hemisphere homologue of middle occipital gyrus. Red to yellow activation represents increasing BOLD intensities that are greater for exception words, whereas blue to pale-blue represents increasing BOLD intensities that are greater for pseudohomophones.

participants that contribute to a particular effect (see also Polk & Farah, 2002). It may be the case that a few participants heavily contribute to an effect or that a few participants mask specific effects. More participants (5/9) showed greater activation during the high frequency exception word task in ROIs associated with the ventral pathway, whereas fewer participants (4/9) showed greater activation during the low frequency exception word naming task in ROIs associated with the dorsal pathway (see Appendix F to review the individual intensity maps). In addition, more participants (5/9) showed greater activation in the left insular cortex for the high frequency exception word naming task than for the low frequency exception word naming task. More participants (7/9) showed ventral pathway activation for high frequency pseudohomophone naming, whereas fewer participants (4/9) showed greater activation in the dorsal pathway regions during low frequency pseudohomophone naming (see Appendix G to review the individual intensity maps). In addition, more participants (5/8) showed greater activation in the left insular cortex for the high frequency pseudohomophone naming task than for the low frequency pseudohomophone naming task. Although none of these effects are significant by a sign test, they do illustrate the need to assess the stability of the averaged effects (see Borowsky, Owen & Sarty, 2002; Polk & Farah, 2002).

Discussion

The current study provides some additional support for both the ventral-dorsal and automaticity models. Familiar lexical stimuli were processed in both the occipito-temporal regions (i.e., ventral pathway) and insular cortices, whereas less familiar words and pseudohomophones were processed in the superior occipital and inferior pariatel lobule (i.e., dorsal pathway). Interestingly, there was no frequency difference for the pseudohomophones, which were unfamiliar orthographic stimuli, in either the left middle occipital gyrus or insular cortex. Contrary to what would be predicted by the ventral-dorsal model (Pugh et al., 2000), there was greater activation in the left inferior parietal lobule for high frequency exception words as compared to high frequency pseudohomophones, whereas high frequency pseudohomophone naming produced greater activity in the posterior aspect of the left insular cortex.

Following the suggestions of Borowsky, Owen, and Sarty (2002), the individual activation maps were also examined. Here the evidence supporting the ventral-dorsal and automaticity models was much more equivocal. It was expected that more people would show greater activation in the ventral pathway and insular cortex for high frequency items, and greater activation in the dorsal pathway for low frequency items. Although numerically more participants showed activation that was consistent with these models, these trends did not approach significance on a sign test.

Nevertheless, there was a word frequency effect in the middle occipital gyrus and insular cortices, which interacted with lexicality. In particular, high frequency exception words showed greater activation in these areas compared to low frequency exception words; however, no differences were found in these areas between high and low frequency pseudohomophones. The presence and absence of frequency effects across lexicality is consistent with the neurological and cognitive dual-route models of visual word recognition. Indeed, the presence of a word frequency effect has often been interpreted as evidence of SV processing, whereas the absence of a word frequency effect has been suggestive of PD processing (e.g., Monsell et al., 1992; Zevin & Balota, 2000).

Conclusions (Experiment 7)

Whether the functional neuro-anatomy of basic reading processes is consistent with cognitive theories of reading is an interesting question. This experiment extended previous fMRI research by examining if the neuro-correlates of the word frequency effect reflected a ventral-dorsal distinction that has been previously discussed in the literature. Most importantly, a ventral-dorsal distinction was observed for high and low frequency exception words, respectively. However, the insular cortices were also associated with high frequency exception word processing. These results are consistent with both Pugh et al.'s (2000) and Posner and Raichle's (1994) models and, therefore suggest that the ventral-dorsal and automatic/controlled models should be integrated. Taken together, these findings support a cognitive-neurological dual-route model of reading processing.

General Discussion

The experiments outlined in this dissertation examined the putative types of reading processes and their relationship to one another. The crux of this investigation involved the debate concerning the number of reading processes available to skilled readers. In order to explore this debate in further detail, three programmes of research were presented. In particular, these experiments addressed: (1) whether the nature of the connections at the lexical level of representation differs from the type of connections at the sublexical level, as suggested by numerous dual-route models (e.g., Coltheart et al., 2001), (2) the degree to which context influences reliance upon SV and PD processes, and (3) if there are neuroanatomical correlates of SV and PD processing. A brief review of the pertinent findings from the present body of research and their relevance to the single- versus dual-route debate will be discussed. Questions concerning a dual-route interpretation of these results are raised. Parallels are then drawn between the types of subcomponents identified in dual-route models of visual word recognition and pedagogical practices.

Lexical Interactivity

The purpose of Experiments 1-4 was to examine the nature of lexical-level (i.e., SV) connections between orthography and phonology, and to provide a framework for discussing single- and dual-route models of visual word recognition. In a previous study, Borowsky et al. (1999) had determined that the connections from sublexical-level orthography to phonology (i.e., graphemes to phonemes along the PD route) were facilitation-dominant. In particular, orthographic processing was found to benefit phonological processing and, therefore, it was argued that this effect indicates the needs for facilitative connections from orthography to phonology. Borowsky et al. also determined that direct connections from sublexical-level phonology to orthography were either non-existent or equally facilitative and inhibitory, as phonological processing only served to bias sublexical orthographic discriminations. Since single-route models only have one type of connection between all levels of orthography and phonology, it was argued that such models must predict the same pattern of effects at the lexical SV level. As dual-route models have separate lexical- and sublexical-level connections, it was argued that such models do not have to predict the same pattern of facilitation and bias effects at the lexical level of representation that was observed at the sublexical level.

The results of Experiments 1-4 indicated that there was a facilitation-dominant connection from lexical orthography to phonology and either equally facilitative and inhibitory connections or no direct connections at all from lexical phonology to orthography. These particular findings have not been previously reported in the literature; however, the findings do mirror those of Borowsky et al. (1999). Taken together, this evidence does not distinguish between whether there is a single set of connections from orthography to phonology or if there are two identical sets of connections. However, these experiments were important for constraining the types of connections necessary for models of visual word recognition and speech perception. In particular, those models that are designed to have modular orthographic and phonological representations (e.g., Massaro et al., 1988) need to incorporate facilitation-dominant connections from orthography to phonology, whereas models that are designed to have interactive orthography to phonology representations (e.g., Harm & Seidenberg, 1999; Zorzi et al., 1998) would require that the orthography to phonology connections reflect greater facilitation. The general framework for examining single- and dual-route models of visual word recognition outlined in Chapter 1 provided the foundations to examine how these models can account for context effects.

Context Effects

The purpose of Experiments 5 and 6 was to examine how context influences reliance upon SV and PD. Single-route models are designed around the assumption that SV and PD are redundant, whereas dual-route models are designed around the assumption that SV and PD are independent processes (see Owen & Borowsky, 2002b). Given that single-route models incorporate redundancy between SV and PD, it should be the case that indices of these two processes *should not* be amenable to selective manipulations. In contrast, dual-route models would predict that indices of SV and PD processing can be selectively manipulated. To examine these predictions, the extant literature has often used the word frequency and orthographic length effects as indices of SV and PD processing, respectively (e.g., Monsell et al., 1992; Weekes, 1997).

Experiment 5 illustrated that subtle list context manipulations were enough to influence skilled readers reliance on SV and PD processes. For example, when nonwords were added to a list of regular words, the orthographic length effect increased, however, the word frequency effect did not change. Furthermore, the word frequency effect appeared more resilient to context effects, which is suggestive that SV-lexical processing is more automatic than PD processing. Such selective modification effects are not consistent with the single-route assumption that SV and PD processes redundant. As most previous experiments have only assessed word frequency or orthographic length effects, previous research has not assessed whether the word frequency effect can be manipulated independently of the orthographic length effect. Even so, some concern was raised about the adequacy of word frequency and orthographic length effects as veridical indices of SV and PD processing. For example, exception words had a larger orthographic length effect than the matched regular words. This novel finding does not follow from a dual-route account of visual word recognition, which would have to predict that regular words would have a greater orthographic length effect than exception words. However, dual-route models that assume parallel or cascaded SV and PD processing and a buffer system that waits for both PD and SV output are better equipped to account for the orthographic length effects for exception words (e.g., Coltheart et al., 2001; Zorzi et al. 1998). However, such explanations compromise the idea of using orthographic length effects as a *process-pure* index of PD processing.

Experiment 6 was designed to address previously controversial findings regarding phonological lexical access. The pseudohomophone naming literature had previously shown that there was a pseudohomophone naming advantage over nonwords, which was assumed to be due to the fact that pseudohomophones can benefit from stored phonological lexical knowledge. However, the pseudohomophone naming advantage did not co-occur with a pseudohomophone base-word frequency effect, an index of lexical access. To account for a pseudohomophone naming advantage despite a lack of a base-word frequency relationship, many researchers have had to modify their models of visual word recognition. For example, both Herdman, LeFevre & Greenham (1994) and Seidenberg et al. (1996) suggested that the pseudohomophone naming advantage was due to an articulation advantage for previously pronounced phonological outputs. Nevertheless, recent studies have revealed that pseudohomophone naming can be influenced by base-word frequency (e.g., Borowsky, Owen & Masson, in press; Grainger et al., 2000; Marmurek & Kwantes, 1996; Taft & Russell, 1992). As word frequency effects have been argued to be independent of the articulation stage of processing (e.g., Monsell, 1991: cf. Balota & Chumbley, 1985), it was of some interest to determine whether the traditional models of visual word recognition could account for both the former and latter findings.

The basic patterns of Experiment 6, and Borowsky, Owen, and Masson (in press; Experiments 2 and 3), replicated previous research. In particular, the pseudohomophone naming advantage did not co-occur with a pseudohomophone base-word frequency effect when pseudohomophones were presented in a mixed block of naming trials with nonwords. Yet when pseudohomophones were presented in a pure block prior to nonwords a pseudohomophone naming disadvantage was observed, which co-occurred with a pseudohomophone base-word frequency effect. The specificity of the pseudohomophone base-word frequency effect co-occurring with a pseudohomophone naming disadvantage has not been previously reported in the literature. Taken together, these results suggest that the pseudohomophone naming advantage occurs due to the benefit of previously established phonological lexical representations for pseudohomophones. However, if readers are encouraged to engage in lexical/semantic verification of pseudohomophones as sounding-like real words, a pseudohomophone naming disadvantage would be observed due to extra processing time required to consult lexical/semantic representations. If one assumes that the connections between the phonological lexicon and the orthographic/semantic lexicon are frequency sensitive, then it makes sense that the pseudohomophone naming disadvantage should co-occur with a base-word frequency effect.

The pseudohomophone naming effects discussed here can easily be accounted for in terms of a dual-route model. That is, as pseudohomophones must be initially processed via PD because they do not have lexically-based SV representations, pseudohomophone naming could be independent of base-word frequency effects, especially in situations where the context is biased towards PD processing. However, when lexical/semantic verification strategies are encouraged, the PD output would be checked against lexical/semantic representations using frequency sensitive connections. It remains to be determined if the verification strategy is lexical or semantic in nature.

Single-route models would be hard pressed to account for such strategy effects. Although Plaut et al, (1996) have argued that strategy effects might be modeled by allowing their single-route connectionist architecture to switch between different "grain sizes" (i.e., sublexical to lexical level units) of orthography to phonology mapping, such descriptions are more concordant with the dual-route perspective.

The context effects reported here appear to be in accord with dual-route models that assume parallel SV and PD processing (e.g., Coltheart et al., 2001; Zorzi et al., 1998). In contrast, single-route models, which assume that SV and PD processes are redundant, cannot account for selective manipulations of SV or PD processes observed in Experiment 5 or the strategy effects observed in Experiment 6.

Dual-Route Cognitive-Neurological Models of Reading

Experiment 7 addressed whether there were neuro-correlates of the ubiquitous word frequency effect. Two neurological models of basic reading processes predict that word frequency effects should be observed in neurological activation maps of visual word recognition (Posner & Raichle, 1994; Pugh et al., 2000). The averaged data analysis did provide some support for both of these models. That is, there was a word frequency effect for exception words. In particular, high frequency exception words engaged the left occipito-temporal regions and the insular cortices (i.e., the ventral-insular pathway) more than low frequency words, whereas low frequency exception words engaged the inferior parietal lobule (i.e., the dorsal pathway) more than high frequency words. Unique to this experiment was the finding that the insular cortex augmented the ventral processing. Although the individual data analysis was much more equivocal in terms of support for the ventral-dorsal and automaticity models proposed by Pugh et al. and Posner and Raichle, respectively, the results did *indicate* the importance of assessing individual differences (see also Borowsky, Owen & Sarty, 2002).

The neuroimaging evidence showing a difference in the word frequency effects across stimulus types indicated that skilled readers have access to two reading processes. This effect is concordant with many cognitive models of basic visual word recognition. However, caution must be taken before researchers can conclude that readers have access to two reading processes simply because different regions of the brain respond to different stimulus types. It is quite plausible that multiple brain regions operate in concert when processing a visual letter-string. Although one stimulus type may have a ventral pathway processing advantage, and another stimulus type may have a dorsal pathway processing advantage, the degree to which these different brain regions operate in-concert or interact may effectively reduce what appears to be a neurologically-based dual-route model of reading to a single processing route. That is, if two anatomically distinct regions are highly interactive and operate in-concert regardless of the stimulus type, a single-route model of processing may be more descriptive.

Future studies may want to include analyses of not only the isolable brain regions that contribute to basic reading processes, but also the rise and peak functions of the hemodynamic response in each region of interest. The degree to which rise and peak functions of the hemodynamic response are locked to one another across different brain regions may provide further insight as to the degree of modularity/interactivity amongst basic visual word processes by providing information about the independence of isolable sub-systems (Buckner, 1998; Frith & Friston, 1997).

Evaluating Models of Visual Word Recognition

Overall, the present series of experiments has provided support for dual-route models of visual word recognition. Skilled readers can rely on dissociable SV and PD reading processes. In addition, evidence was provided that supported a cascaded or parallel processing architecture. Together, the present series of experiments are most consistent with the dual-route cascade model of Coltheart et al. (2001) and the dual-route connectionist model of Zorzi et al. (1998). That is, lexical representations can be accessed independently of sublexical representations, and readers can vary the degree to which they rely on both sources of knowledge. However, both of these particular models would need to modify the types of connections between orthographic and phonological representations in order to account for the results from Experiments 1-4.

The difference between Coltheart et al.'s and Zorzi et al.'s dual-route models is whether skilled visual word recognition utilizes one or two types of processes. In Coltheart et al.'s (2001) model, the SV route maps *localist*, whole-word orthographic representations onto whole-word phonological representations, whereas the PD route applies spelling-sound *rules* to map graphemes onto phonemes. Thus, this model associates the dual reading routes with two types of reading processes. In contrast, Zorzi et al.'s (1998) model utilizes one type of process, parallel distributed processing, but they separate direct and mediated mappings of orthography to phonology. The distinction between parallel distributed versus rule-based localist dual-route will be an important area for future research.[7]

However, before tackling the localist/distributed representation question, it may be more prudent to further investigate the type of processing that is involved in SV processing. Seidenberg and colleagues (Harm & Seidenberg, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) have maintained that semantics can mediate orthographic to phonological processing. As such, a semantically mediated processing

---

[7] There has been a debate regarding rule-based localist versus parallel distributed knowledge representations in the extant literature (e.g., Besner et al., 1990; Seidenberg et al., 1994); however, these arguments often pit dual- and single-route models against one another. Borowsky et al. (1999) noted that such arguments often confound the type of processing (e.g., rule-based localist and parallel distributed) with the type of model (e.g., dual-route and single-route models, respectively). However, these issues are orthogonal. For example, Zorzi et al. (1998) have proposed a dual-route model that contains *distributed* representations, whereas Kwantes and Mewhort (1999) have proposed a single-route model that contains *localist* representations.

route augments the single-route orthography-phonology model (i.e., they also propose a "dual-route" model). Plaut et al. (1996) have argued that there is a division of labour between the orthography-phonology and orthography-semantics-phonology routes. Regular words and nonwords can be read via the orthography-phonology route as these items have consistent orthography-phonology mappings. High frequency exception words, which have inconsistent orthography-phonology mappings, can also be named via the orthography-phonology because such items have strong orthography-phonology connections. On the other hand, low frequency exception words require extra processing time to resolve phonological discrepancies between regularized and non-regularized (or correct) pronunciations. This extra processing time allows for semantics to contribute to the phonological processing.

Strain et al. (1995) have provided evidence for the "division of labour" model. They showed that a semantic variable, imagery, correlated with low frequency exception word naming but not with high frequency exception word or high and low frequency regular word naming response latencies. Strain and Herdman (1999) replicated and extended the earlier study by demonstrating that semantic facilitation of naming varied as a function of reader skill. In particular, readers with low phonological coding skills, as assessed by the Word Attack and Sound Blending subscales of the Woodcock-Johnson reading test, demonstrated a positive correlation between imagery and low frequency exception word naming response latencies. Readers with high phonological coding skills did not show the semantic facilitation effect. Thus, the results are consistent with the single-route perspective that familiar words or highly skilled readers will rely on the orthography-to-phonology pathway, whereas unfamiliar words and poor readers will utilize the (slower) semantic route.

This emerging body of evidence suggests that readers do rely on two reading processes, one semantic and the other non-semantic, which is consistent with Seidenberg and colleagues' (Harm & Seidenberg, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) single, "non-semantic" route architecture. However, the division of labour as outlined by Plaut et al. (1996) and Strain et al. (1995) is not consistent with all semantic mediation investigations. Baluch and Besner (2001) showed that semantics may also influence the naming of high frequency words. Utilizing the Persian language, which has opaque words (i.e., words for which the vowels are not specified) and transparent words (i.e., words for which the vowels are specified), they found that high and low frequency opaque words with higher imageability ratings were named faster than matched words with lower imageability ratings. In general, semantics appears to facilitate low frequency exception word naming, and can, under controlled circumstances, facilitate high frequency exception (opaque) word naming.

If exception words are SV-reliant stimuli, the Baluch and Besner (2001) results suggest that SV processing is semantically mediated. However, there is evidence that is contrary to this supposition. First, acquired reading disorders can affect semantic processing while leaving SV and PD processing relatively, though not completely, intact (e.g., deep dyslexia; Marshall & Newcombe, 1973; Buchanan, Hildebrandt & MacKinnon, 1999). Similarly, acquired phonological dyslexia selectively affects PD processing, yet acquired surface dyslexia selectively affects SV processing (see Funnell, 1983; McCarthy & Warrington, 1986, respectively). Secondly, Owen and

Borowsky (2002b) have shown that participants tend to make errors indicative of SV processing when naming briefly presented and visually degraded stimuli. A recent review of some of the SV-type errors indicated that very few errors were semantically related to the target. Taken together, this evidence supports the notion that SV processing is independent of semantic processing and, thus, provides support for two non-semantic and one semantic processing routes as captured by dual-route models of visual word recognition. Indeed, a brief review of pedagogical reading practices tends to support a framework consisting of separate PD, SV, and semantic processing.

Word Recognition Skills of Deaf Readers

As mentioned in the introduction, readers who are deaf often read at a grade four level (Conrad, 1979). As the English writing system captures phonographic relationships, it is important to address is whether readers who are deaf can access phonological information from orthographic patterns despite their lack of skill with spoken English. Interestingly enough, Hanson and Fowler (1987) have shown that readers who are deaf are sensitive to phonology. In particular, both hearing and deaf participants were more accurate in identifying that orthographically similar pairs of words (e.g., WAVE and SAVE) rhymed compared to orthographically similar, but phonological dissimilar pairs of words (e.g., HAVE and SAVE). Furthermore, Chamberlain and Mayberry (2001) have shown that readers who are deaf are slower to reject pseudohomophones as words in a lexical decision task compared to nonwords. Hanson (1989) reports several other findings that are consistent with the idea that readers who are deaf have some access to (spoken) phonology.[8]

Perfetti and Sandak (2000) postulate that the acquisition of spoken phonology could occur due to auditory feedback, lip-reading, cued speech, and learning to write. However, several questions remain as to whether readers who are deaf have access to just lexical-level spoken phonology, sublexical-level spoken phonology, or both. Further empirical studies are needed to address this question. Nevertheless, to address the concern of "cognitive poverty" raise by Conrad (1979), Perfetti and Sandak (2000) conclude that print exposure is probably more important for readers who are deaf than for those who are hearing, simply because reading would serve to improve underspecified spoken phonological representations. This conclusion raises the issue of how one teaches all children to read so that they can increase their exposure to print.

Pedagogical Reading Practices

A survey of the recent history (i.e., from the 1800's) regarding the pedagogy of reading indicates a tension between instructional methods aimed at engaging and refining PD processes and those aimed at SV processes and semantic processes. Huey (1908; see also Sadoski & Paivio, 2001) outlined five different instructional techniques. The oldest technique is called the *alphabetic method.* This method involves starting with studying individual letter sounds, and then moving to two-letter combinations, three-letter combinations and short words, monosyllabic words,

---

[8] People who are deaf and who know a signed language (e.g., American Sign Language) do have access to a phonological system that is based upon the visual codes of their language. Despite the fact that the words "phoneme" and "phonology" are often associated with *spoken* representations, it is also the case that signed languages have a phonological system based upon phonemes (i.e., meaningless primitives; e.g., location, hand shape, movement, and orientation). Thus, with respect to readers who are deaf, it is important to distinguish access to *spoken phonological* representations from access to a visually based phonology.

disyllabic words, and, finally, to sentence-level comprehension. The *phonic method* involves sound analysis. That is, children are taught individual grapheme-phoneme correspondences. However, in English a single grapheme may correspond to several different phonemes (e.g., the vowel *a* in *a*go, *a*t, *a*te, c*a*r). The *phonetic method* uses diacritics to differentiate the specific sounds associated with the same printed letter (e.g., a, ä, ā). The *word method* requires that the whole sound of the word be associated with the complete printed word. This method often involves associating whole word sounds with pictures that have the written words printed underneath, and dates back to Comenius' 1657 book *Orbis Pictus* (Huey 1908; Sadoski & Paivio, 2001). The *sentence method* assumes that thoughts (or complete sentences) represent natural units of language and, therefore, sentence-level meanings should be taught before the sentence is broken down into words and specific sounds. In the classroom, instructors often use a combination of these methods.

It is interesting to note that the first three methods emphasize PD reading processes by focusing on a sublexical analysis of written words. The word method emphasizes SV processes by establishing orthographic and phonological lexical associations. The sentence method really focuses on semantics and context. Notice that all of these pedagogical practices emphasize at least one of the basic visual word recognition components. Although the research presented in this document cannot comment on the best approach to the pedagogy of reading, it appears that both basic and applied areas of reading converge on the same component processes of PD, SV, and semantics. As in the dual- versus single-route debate that has engaged the basic visual word recognition literature, differences in pedagogical approaches, especially those that emphasize a combination of some of the five basic approaches, often reveal differences in the assumed relationship between PD and SV. Balanced approaches (e.g., using phonic and word approaches) often endorse a dual-route perspective, whereas Huey's (1908) approach to teach meaning and words before phonetic analysis (which should not be taught before age 9 according to Huey) endorses a single-route perspective in which PD processing is considered redundant within SV processing.

Coda

Huey (1908) remarked that the development of a complete account of basic reading processes would mark the pinnacle of a psychologist's career. Nearly 100 years later, researchers are still in the process of refining, weighing, and integrating various accounts of basic visual word recognition. The present series of experiments has further illuminated the relationship between SV and PD processes, and has provided unique details about: (1) the nature of lexical-level connections, (2) the degree to which readers can adjust their reliance on SV and PD, and (3) the neurological model underlying basic visual word recognition. In combination, these details provide further constraints upon the development and implementation of visual word recognition models. The fruitfulness of this series of experiments is evident by the number of future research ideas already outlined earlier. Despite the fact that researchers are still attempting to understand basic visual word recognition processes, Huey's statement that, "the world is making solid progress with specific problems, and bears promise of a day when education shall rest on foundations better grounded than were the individual and unverified opinions about 'Reading,' for instance, even twenty-five years ago" (p. 184) is still germane.

References

Ashcraft, M. H. (2002). *Cognition* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Balota, D.A., & Chumbley, J.I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 340-357.

Balota, D.A., & Chumbley, J.I. (1985). The locus of word-frequency effects in the production task: Lexical access and/or production?. *Journal of Memory & Language, 24,* 89-106.

Balota, D.A., & Spieler, D.H. (1999). Word frequency, repetition, and lexicality effects in word recognition tasks: Beyond measures of central tendency. *Journal of Experimental Psychology: General, 128,* 32-55.

Baluch, B., & Besner, D. (2001). Basic processes in reading: Semantics affects speeded naming of high-frequency words in an alphabetic script. *Canadian Journal of Experimental Psychology, 55,* 63-69.

Baluch, B., & Besner, D. (1991). Visual word recognition: Evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 644-652.

Baron, J., & Strawson, C. (1976). Use of orthographic and word-specific knowledge in reading words aloud. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 386-393.

Bernstein, S.E., & Carr, T.H. (1996). Dual-route theories of pronouncing printed words: What can be learned from concurrent task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 86-116.

Besner, D. (1999). Basic processes in reading: Multiple routines in localist and connectionist models. In R.M. Klein & P. McMullen (Eds.). *Converging methods for understanding reading and dyslexia.* Cambridge, MA: MIT Press.

Besner, D., Twilley, L., McCann, R.S., & Seergobin, K. (1990). On the association between connectionism and data: Are a few words necessary? *Psychological Review, 97,* 432-446.

Binder, J., & Price, C.J. (2001). Functional neuroimaging of language. In R. Cabeza & A.Kingstone (Eds.) *Handbook of Functional Neuroimaging of Cognition.* Cambridge, MA: MIT Press.

Borowsky, R., & Besner, D. (2000). Lexical access codes in visual word recognition: Are joint effects of context and stimulus quality diagnostic? *Canadian Journal of Experimental Psychology, 54,* 196-207.

Borowsky, R., & Besner, D. (1993). Visual word recognition: A multistage activation model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 813-840.

Borowsky, R., & Besner, D. (1991). Visual word recognition across orthographies: On the interaction between context and degradation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 272-276.

Borowsky, R., & Masson, M. E. J. (1999). Frequency effects and lexical access: On the interpretation of null pseudohomophone base-word frequency effects. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 270-275.

Borowsky, R., & Masson, M.E.J. (1996a). Semantic ambiguity effects in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 63-85.

Borowsky, R., & Masson, M.E.J. (1996b, November). *Frequency effects in word and pseudohomophone naming.* Poster session presented at the annual meeting of the Psychonomic Society, Chicago, Il.

Borowsky, R., Owen, W.J., & Fonos, N. (1999). Reading speech and hearing print: Constraining models of visual word recognition by exploring connections with speech perception. *Canadian Journal of Experimental Psychology, 53,* 294-305.

Borowsky, R., Owen, W.J., & Masson, M.E.J. (in press). Reevaluating the diagnostics for phonological lexical access: When the pseudohomophone naming advantage becomes a disadvantage. *Memory & Cognition.*

Borowsky, R., Owen, W.J., & Sarty, G.E. (in press). The role of the left hemisphere in motor control of touch: A functional magnetic resonance imaging analysis. *Brain and Cognition.*

Borowsky, R., Owen, W.J., & Sarty, G.E. (2002). Individual differences contradict analyses of averaged data: fMRI of silent and aloud word generation. Manuscript submitted for publication.

Borowsky, R., McDougall, P., MacKinnon, G.E., & Hymel, S. (2002). On the diagnosis of surface and phonological dyslexias: Measuring reliance on sight vocabulary and phonetic decoding during real word recognition. Manuscript submitted for publication.

Buchanan, L., Hildebrandt, N., & MacKinnon, G.E. (1999). Phonological processing reexamined in acquired deep dyslexia. In R.M. Klein & P. McMullen (Eds.). *Converging methods for understanding reading and dyslexia*. Cambridge, MA: MIT Press.

Buckner, R.L. (1998). Event-related fMRI and the hemodynamic response. *Human Brain Mapping, 6,* 373-377.

Buckner, R.L., Koutstaal, W., Schacter, D.L., Wagner, A.D., & Rosen, B.R. (1998). Functional-anatomic study of episodic retrieval: I. Retrieval effort versus retrieval success. *NeuroImage, 7,* 151-162.

Carello, C., Lukatela, G., & Turvey, M.T. (1994). Lexical involvement in naming does not contravene prelexical phonology: Comment on Sebastián-Gallés (1991). *Journal of Experimental Psychology: Human Perception and Performance, 20,* 192-198.

Carroll, D.W. (1999). *Psychology of language* (3rd ed.). Pacific Grove, CA: Brooks/Cole Publishing Company.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 24,* 149-180.

Chamberlain, C., & Mayberry, R., (2001). Pseudohomophone effects in good and poor readers who are deaf and use ASL. Poster presented at the 8th Annual Meeting of the Society for the Scientific Study of Reading, Boulder, CO.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151-216). San Diego, CA: Academic Press.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed processing approaches. *Psychological Review, 100*, 589-608.

Coltheart, M., Davelaar, E., Jonasson, J.T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535-555). Hillsdale, N.J.: Lawrence Erlbaum.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1197-1121.

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

Conrad, R. (1979). *The deaf schoolchild: Language and cognitive function*. New York: Harper Row.

Cox, R.W. (1996). AFNI: Software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research, 29,* 162-173.

Davelaar, E., Coltheart, M., Besner, D., & Jonasson, J.T. (1978). Phonological recoding and lexical access. *Memory & Cognition, 6,* 391-402.

Dehaene, S., Spelke, E., Pinel, P., Stanescu, R., & Tsinkin, S. (1999). Sources of mathematical thinking: Behavioral and brain-imaging evidence. *Science, 284,* 970-974.

Dell, G.S., Schwartz, M.F., Martin, N., Saffran, E.M., & Gagnon, D.A. (1997).

Lexical access in aphasic and nonaphasic speakers. *Psychological Review, 104,* 801-838.

Demb, J., Poldrack, R.A., & Gabrieli, J.D.E. (1999). Functional neuroimaging of word processing in normal and dyslexic readers. In R.M. Klein and P.A. McMullen (Eds.) *Converging Methods for Understanding Reading and Dyslexia.* Cambridge, MA: The MIT Press.

Dennis, I., & Newstead, S.E. (1981). Is phonological recoding under strategic control? *Memory & Cognition, 9,* 472-477.

Forster, K.I. (1985). Lexical acquisition and the modular lexicon. *Language and Cognitive Processes, 1,* 87-108.

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

Fowler, C.A., & Deckle, D.J. (1991). Listening with eye and hand: Cross-modal contributions to speech perception. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 816-826.

Fox, P.T., & Raichle, M.E. (1986). Focal physiological uncoupling of cerebral blood flow and oxidative metabolism during somatosensory stimulation in human subjects. *Proceedings of the National Academy of Science USA, 83,* 1140-1144.

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

Frith, C.D., & Friston, K.J. (1997). Studying brain function with neuroimaging. In M.D. Rugg (Ed.) *Cognitive Neuroscience.* London: MIT Press.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123,* 71-99.

Frost, R., & Katz, L. (1989). Orthographic depth and the interaction of visual and auditory processing in word recognition. *Memory & Cognition, 17,* 302-310.

Funnell, E. (1983). Phonological processes in reading: New evidence from acquired dyslexia. *British Journal of Psychology, 74,* 159-180.

Gelb, I.J. (1963). *A study of writing* (Rev. ed.). Chicago: The University of Chicago Press.

Glushko, R.J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 674-691.

Goldin-Meadow, S., & Mylander, C. (1990). Beyond the input given: The child's role in the acquisition of language. *Language, 66,* 323-355.

Grainger, J., Spinelli, E., & Ferrard, L. (2000). Effects of baseword frequency and orthographic neighborhood size in pseudohomophone naming. *Journal of Memory and Language, 42,* 88-102.

Hanson, V. (1989). Phonology and reading: Evidence from profoundly deaf readers. In D. Shankweiler & I.Y. Liberman (Eds.). *Phonology and reading disability: Solving the reading puzzle.* Ann Arbor, MI: The University of Michigan Press.

Hanson, V., & Fowler, C.A. (1987). Phonological coding in word reading: Evidence from hearing and deaf readers. *Memory & Cognition, 15,* 199-207.

Harm M.W., & Seidenberg, M.S. (2001). *Computing the Meanings of Words in Reading: Division of Labor Between Visual and Phonological Processes* Manuscript under review.

Harm M.W., & Seidenberg, M.S. (1999). Phonology, reading acquisition, and dyslexia: Insight from connectionist models. *Psychological Review, 106,* 491-528.

Hasher, L., & Zacks, R.T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356-388.

Hawkins, H.L., Reicher, G.M., Rogers, M., & Peterson, L. (1976). Flexible coding in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 380-385.

Henderson, L. (1982). *Orthography and word recognition in reading.* San Diego, CA: Academic Press.

Hendriks, A.W., & Kolk, H.H.J. (1997). Strategic control in developmental dyslexia. *Cognitive Neuropsychology, 14,* 321-366.

Herdman, C.M., LeFevre, J., & Greenham, S.L. (1996). Baseword frequency and pseudohomophone naming. *The Quarterly Journal of Experimental Psychology, 49A,* 1044-1061.

Herdman, C.M., LeFevre, J., & Greenham, S.L. (1994). Implicating the lexicon: Base-word frequency effects in pseudohomophone naming. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 575-590.

Hino, Y., & Lupker, S.J. (2000). Effects of word frequency and spelling-to-sound regularity in naming with and without preceding lexical decision. *Journal of*

Experimental Psychology: Human Perception and Performance, 26, 166-183.

Horwitz, B., Tagamets, M-A., & McIntosh, A.R. (1999). Neural modeling, functional brain imaging, and cognition. *Trends in Cognitive Sciences, 3,* 91-98.

Howard, D., Patterson, K., Wise, R., Brown, D., Friston, K., Weiller, C., & Frackowiak, R. (1992). The cortical localization of the lexicons. *Brain, 115,* 1769-1782.

Huey, E.B. (1908). *The psychology and pedagogy of reading.* New York: The MacMillian Company.

Jacobs, A.M., Rey, A., Zeigler, J.C., & Grainger, J. (1998). MROM-P: An interactive activation, multiple read-out model of orthographic and phonological processes in visual word recognition. In J. Grainger & A.M. Jacobs (Eds.), *Localist connectionist approaches to human cognition* (pp. 147-188). Mahwah, NJ: Erlbaum.

Jared, D. (1997). Spelling-sound consistency affects the naming of high frequency words. *Journal of Memory and Language, 36,* 505-529.

Jared, D., McRae, K., & Seidenberg, M.S. (1990). The basis of consistency effects in word naming. *Journal of Memory and Language, 29,* 687-715.

Kay, J., Lesser, R., & Coltheart, M. (1996). Psycholinguistic assessments of language processing in aphasia (PALPA): An introduction. *Aphasiology, 10,* 159-180.

Kawamoto, A.H., Kello, C.T., Jones, R., & Bame, K. (1998). Initial phoneme versus whole word criterion to initiate pronunciation: Evidence based on response latency and initial phoneme duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 862-885.

Kolb, B., & Whishaw, I.Q. (1990). *Fundamentals of human neuropsychology* (3rd ed.). New York: W.H. Freeman and Company.

Kučera, H., & Francis, W. (1967). Computational analysis of present-day American English. Providence, RI: Brown University Press.

Kwantes, P.J., & Mewhort, D.J.K. (1999). Modeling lexical decision and word naming as a retrieval process. *Canadian Journal of Experimental Psychology, 53,* 306-315.

Kwong, K.W., Belliveau, J.W., Chesler, D.A., Goldberg, I.E., Weisskoff, R.M., Poncelet, B.P., Kennedy, D.N., Hoppel, B.E., Cohen, M.S., Turner, R., Cheng, H.-M., Brady, T.J., & Rosen, B.R. (1992). Dynamic magnetic resonance imaging of human brain activity. *Proceedings of the National Academy of Science USA, 89,* 5675-5679.

Laxon, V., Smith, B., & Masterson, J. (1995). Children's nonword reading: Pseudohomophones, neighbourhood size, and priming effects. *Reading Research Quarterly, 30,* 126-144.

LeFevre, J., Sadesky, G.S., & Bisanz, J. (1996). Selection procedures in mental addition: Reassessing the problem size effect in adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 216-230.

Leong, C.K. (1999). Phonological and morphological processing in adult students with learning/reading disabilities. *Journal of Learning Disabilities, 32,* 224-238.

Liberman, A., & Mattingly, I. (1985). The motor theory of speech perception revised. *Cognition, 21,* 1-36.

Loftus, G.R., & Masson, M.E. (1994). Using confidence intervals in within-subject designs. *Psychological Bulletin and Review, 1,* 476-490.

Logan, G.D. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492-527.

Logothetis, N.K., Pauls, J., Augath, M., Trinath, T., & Oeltermann, A. (2001). Neurophysiological investigation of the basis of the fMRI signal. *Nature, 412,* 150-157.

Lorch, R.F., & Myers, J.L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 149-157.

Lukatela, G., & Turvey, M.T. (1993). Similar attentional, frequency, and associative effects for pseudohomophones and words. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 166-178.

Lupker, S.J., Brown, P., & Colombo, L. (1997). Strategic control in a naming task: Changing routes or changing deadlines? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 570-590.

MacDonald, J., & McGurk, H. (1978). Visual influences on speech perception processes. *Perception & Psychophysics, 24,* 253-257.

Marmurek, H.H.C., & Kwantes, P.J. (1996). Reading words and wirds: Phonology and lexical access. *The Quarterly Journal of Experimental Psychology, 49A,* 396-714.

Marshall, J.C., & Newcombe, F. (1973). Patterns of paralexia: A psycholinguistic approach. *Journal of Psycholinguistic Research, 2,* 175-199.

Massaro, D.W. (1989). Testing between the TRACE model and the fuzzy logical model of speech perception. *Cognitive Psychology, 21,* 398-421.

Massaro, D.W., & Cohen, M.M. (1993). The paradigm and the fuzzy logical model of perception are alive and well. *Journal of Experimental Psychology: General, 122,* 115-124.

Massaro, D.W., Cohen, M.M., & Thompson, L. (1988). Visual language in speech perception: Lipreading and reading. *Visual Language, 22,* 8-31.

Masson, M.E.J., & Borowsky, R. (1998). More than meets the eye: Context effects in word recogntion. *Memory & Cognition, 26,* 1245-1269.

McCann, R.S., & Besner, D. (1987). Reading pseudohomophones: Implications for models of production assembly and the locus of word-frequency effects in naming. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 14-24.

McCarthy, R., & Warrington, E.K. (1986). Phonological reading: Phenomena and paradoxes. *Cortex, 22,* 359-380.

McClelland, J.L., & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88,* 375-407.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264,* 746-748.

McLeod, P., Plunkett, K. & Rolls, E.T. (1998). *Introduction to connectionist modelling of cognitive processes.* New York: Oxford University Press.

Menon, R.S., & Kim, S.-G. (1999). Spatial and temporal limits in cognitive neuroimaging with fMRI. *Trends in Cognitive Sciences, 3,* 207-216.

Monsell, S. (1991). The nature and locus of word frequency effects in reading. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 148-197). Hillsdale, NJ: Erlbaum.

Monsell, S., Patterson, K.E., Graham, A., Hughes, C.H., & Milroy, R. (1992). Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 452-467.

Owen, W.J., Blake, L., & Borowsky, R. (2002). Evidence for two reading routes: On the veridicality of word frequency and length effects as indices of sight vocabulary and phonetic decoding. Manuscript under review.

Owen, W.J., & Borowsky, R. (2002a). Examining the interactivity of lexical orthographic and phonological processing. *Canadian Journal of Experimental Psychology.*

Owen, W.J., & Borowsky, R. (2002b). Evaluating the relationship between phonetic decoding and sight vocabulary: Evidence for single- or dual-routes? Manuscript under review.

Paap, K.R., Johansen, L.S., Chun, E., & Vonnahme, P. (2000). Neighborhood frequency does affect performance in the Reicher task: Encoding or decision? *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1691-1720.

Paap, K.R., McDonald, J.E., Schvaneveldt, R.W., & Noel, R.W. (1987). Frequency and pronounceability in visually presented naming and lexical decision tasks. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 221-244). Hillsdale, NJ: Erlbaum.

Paap, K.R., & Noel, R.W. (1991). Dual-route models from print to sound: Still a good horse race. *Psychological Research, 53,* 13-24.

Paul, P.V., & Quigley, S.P. (1994). American Sign Language-English bilingual education. In P. L. McAnally. *Language learning practices with deaf children.* Austin, TX: PRO-ED.

Perfetti, C.A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Education, 5,* 32-50.

Petersen, S.E., Fox, P.T., Snyder, A.Z., & Raichle, M.E. (1990). Activation of extrastriate and frontal cortical areas by visual words and word-like stimuli. *Science, 249,* 1041-1044.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56-115.

Polk, T.A., & Farah, M. J. (2002). Functional MRI evidence for an abstract, not perceptual, word-form area. *Journal of Experimental Psychology: General, 131,* 65-72.

Posner, M.I., & Raichle, M.E. (1994). *Images of mind.* New York: Scientific American Library.

Price, C.J., Moore, C.J., Humphreys, G.W., & Wise, R.J.S. (1997). Segregating semantic from phonological processes during reading. *Journal of Cognitive Neuroscience, 9,* 727-733.

Price, C.J., Wise, R.J.S., Watson, J.D.G., Patterson, K., Howard, D., & Frackowiak, R.S.J. (1994). Brain activity during reading: The effects of exposure duration and task. *Brain, 117,* 1255-1269.

Pugh, K.R., Mencl, W.E., Jenner, A.R., Katz, L., Frost, S.J., Lee, J.R., Shaywitz, S.A., & Shaywitz, B.A. (2000). Functional neuroimaging studies of reading and reading disability (developmental dyslexia). *Mental Retardation and Developmental Dysabilities Reasearch Reviews, 6,* 207-213.

Pugh, K.R., Shaywitz, B.A., Constable, R.T., Shaywitz, S.A., Skudlarski, P., Fulbright, R.K., Brone, R.A., Shankweiler, D.P., Katz, L., Fletcher, J.M., & Gore, J.C. (1996). Cerebral organization of component processes in reading. *Brain, 119,* 1221-1238.

Raichle, M.E. (2001). Bold insights. *Nature, 412,* 128-130.

Ratcliff, R., & McKoon, G. (1997). A counter model for implicit priming in perceptual word identification. *Psychological Review, 104,* 319-343.

Sadoski, M., & Paivio, (2001). *Imagery and text: A dual coding theory of reading and writing*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., Publishers.

Sarty, G.E., & Borowsky, R. (2002). Functional MRI activation maps from empirically defined curve fitting. Manuscript submitted for publication.

Scarborough, D.L., Cortese, C., & Scarborough, H.S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 1-19.

Seidenberg, M.S. (1985). The time course of phonological code activation in two writing systems. *Cognition, 19,* 1-30.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523-568.

Seidenberg, M.S., Petersen, A., MacDonald, M.C., & Plaut, D.C. (1996). Pseudohomophone effects and models of word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 48-62.

Seidenberg, M.S., Plaut, D.C., Petersen, A.S., McClelland, J.L., & McRae, K. (1994). Nonword pronunciation and models of word recogntion. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1177-1196.

Seidenberg, M.S., Waters, G.S., Barnes, M.A., & Tanenhaus, M.K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning & Verbal Behavior, 23,* 383-404.

Simpson, P.K. (1990). *Artificial neural systems: Foundations, paradigms, applications, and implementations.* Toronto: Pergamon Press.

Singer, M., & Remillard, G. (2001). Automatic or controlled text inference processes. Manuscript under review.

Small, S.L., Noll, D.C., Perfetti, C.A., Hlustic, P., Wellington, R., & Schneider, W. (1996). Localizing the lexicon for reading aloud: Replication of a PET study using fMRI. *Neuroreport, 7,* 961-965.

Strain, E., Patterson, K., & Seidenberg, M.S. (1995). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1140-1154.

Strain, E., & Herdman, C.M. (1999). Imageability effects in word naming: An individual differences analysis. *Canadian Journal of Experimental Psychology, 53,* 347-359.

Swinney, D.A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18,* 645-659.

Taft, M., & Russell, B. (1992). Pseudohomophone naming and the word frequency effect. *The Quarterly Journal of Experimental Psychology, 45A*, 51-71.

Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain.* New York: Thieme Medical Publishers, Inc.

Taraban, R., & McClelland, J.L. (1987). Conspiracy effects in word pronunciation. *Journal of Memory and Language, 26,* 608-631.

Weekes, B.S. (1997). Differential effects of number of letters on word and nonword naming latency. *The Quarterly Journal of Experimental Psychology, 50A,* 439-456.

Zevin, J.D., & Balota, D.A. (2000). Priming and attentional control of lexical and sublexical pathways during naming. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 26,* 121-135.

Zipf, G.K. (1935). *The psycho-biology of language: An introduction to dynamic philology.* Boston: Houghton Mifflin.

Zorzi, M. (2000). Serial processing in reading aloud: No challenge for a parallel model. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 847-856.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1131-1161.

Appendix A: Ethic and Operational Approval

UNIVERSITY ADVISORY COMMITTEE
ON ETHICS IN BEHAVIOURAL SCIENCE RESEARCH

NAME: R. Borowsky and G. Sarty (W.J. Owen) **BSC#:** 2000-09
Department of Psychology/Medical Imaging

DATE: February 14, 2000

The University Advisory Committee on Ethics in Behavioural Science Research has reviewed the Application for Ethics Approval for your study "Basic Reading Processes: Reliance on Sight Vocabulary (SV) and Phonetic Decoding (PD) During Normal Reading and Reading Acquisition" (2009).

1. Your study has been APPROVED.
2. Any significant changes to your proposed study should be reported to the Chair for Committee consideration in advance of its implementation.
3. The term of this approval is for 3 years.

I wish you a successful and informative study.

V Thompson

Valerie Thompson, Chair
University Advisory Committee
on Ethics in Behavioural Science Research

VT/bjk

Office of Research Services, University of Saskatchewan
Kirk Hall Room 210, 117 Science Place, Saskatoon SK S7N 5C8 CANADA
Telephone: (306) 966-8576 Facsimile: (306) 966-8597 http://www.usask.ca/research/

SASKATOON
DISTRICT
HEALTH

SDH
Research Services Unit
Box 16
Royal University Hospital
103 Hospital Drive
Saskatoon, SK
S7N OW8
Phone: 306.655.6796 Fax: 306.655.1519

DATE: March 16, 2000

TO: √ Dr. R. Borowsky and Dr. G. Sarty, Dept. of Psychology/Medical Imaging

FROM: Joanne Franko, Manager
Research Services Unit

RE: **Research Project #:** BSC2000-09
Project: Basic Reading Processes: Reliance on Sight Vocabulary and Phoenetic Decoding During Normal Reading and Acquisition

---

Saskatoon District Health is pleased to provide you with operational approval of the above-mentioned research project.

Please advise me when the data collection phase of the research project is completed. Also, I would appreciate receiving a copy of the final report of this research project.

I would like to wish you every success with your project and encourage you to contact me if I can assist you with it.

If you have any questions, please feel free to call at 655-6796.

Yours truly,

Joanne Franko

Joanne Franko, MSc
Manager, Research Services Unit

c.c. Dr. B. Burbridge, Medical Imaging

Note: SDH operational approval is one of several steps for overall approval to conduct research in the District. If you have a faculty appointment with the U of S, approvals must also be obtained from your Department Head, your College Administration, and the Office of Research Services, University of Saskatchewan before a research project can commence.

Appendix B: Experiments 1-4 Stimuli

bar – far – tar

bop – hop – top

cob – mob – rob

cat – mat – vat

cap – map – rap

Appendix C: Experiment 5 Stimuli

Regular words	Exception words	Base-words	Pseudohomophones	Nonwords
air	are	aid	ade	ikt
black	blood	blue	bloo	blyve
board	both	born	boarn	proarn
brown	broad	broke	broak	goak
cost	come	came	caim	kelled
did	do	day	daie	vaie
days	does	deal	deel	leel
down	done	dead	deap	feap
dark	door	date	dait	vait
free	four	five	fyve	foo
food	front	force	forse	lorse
feel	full	fall	fawl	fyse
girl	give	gave	gaiv	laiv
goes	gone	game	gaim	guz
green	great	group	groope	greel
had	have	has	hazz	pazz
hand	head	half	haff	saff
hear	heard	held	helled	haim
heat	heart	hold	hoald	woald
leave	learn	line	lyne	gyne
land	love	late	layt	chayt
mouth	month	move	moove	coove
much	most	mean	meen	reen
must	move	mind	mynd	pung
nine	none	nice	nyse	nawl
well	once	worth	werth	terth
with	one	was	wuz	waim
off	own	out	owt	ewt
per	put	pay	paie	taie
same	said	sort	soart	doart
saw	says	say	saie	chaie
south	some	sound	sownd	sait
sense	source	serve	sirve	dirve
stock	stood	state	stait	prait
trial	truth	trade	traid	gaid
to	two	take	taik	haik
while	where	word	wehn	mird
home	whom	why	whye	grye
whole	whose	what	whut	lut
which	world	white	whyte	pyte
will	would	wife	wyfe	byfe

year	your	young	yung	plung
apt	aunt	ace	aice	waice
bare	bear	boat	bote	bome
bound	bought	beard	beered	keered
boss	bowl	bone	boan	berse
brain	bread	bride	bryde	brype
brief	break	brave	braiv	jaiv
bridge	breath	bright	bryte	bryke
bulk	bull	burn	bern	baij
bunch	bush	bunk	bunc	kunc
ease	earn	ear	eer	bleer
flame	flood	fleet	fleat	leat
fool	foot	foam	fome	fote
guess	gross	guard	gard	vard
grew	grow	grade	graid	naid
hence	height	host	hoest	haiv
loss	lose	lake	laik	lum
match	meant	mine	myne	byne
mist	monk	mate	mait	chait
nerve	ninth	nurse	nerse	woan
pine	pint	pipe	pype	sype
pope	post	pike	pyke	ryke
proud	prove	pride	pryd	fyde
proof	pull	page	paij	pern
prime	push	prize	pryze	myze
ranch	realm	roast	roste	doste
role	roll	roof	rufe	dufe
shed	shoe	shy	shye	jye
song	soul	seed	sead	vead
sole	soup	seal	seel	geel
speech	spread	spite	spyte	dyte
sweet	suite	soap	sope	bope
sweep	sweat	swore	swoar	voar
thrust	thread	thumb	thum	thaik
throat	threat	throat	throte	drote
toast	tomb	tore	toar	brore
tin	ton	tie	tye	brye
twice	touch	taste	taist	tait
tooth	tough	teach	teech	feech
torn	tour	tool	tule	lule
wage	wear	wave	waiv	woest
win	won	wage	waije	faije
wore	wood	wake	waik	haik
breach	breast	braids	brades	prawt
broach	brooch	bruise	bruze	brares
carve	caste	cake	caik	coze

cliff	climb	cloak	cloke	noke
coil	comb	cork	kork	rork
couch	cough	curse	kerse	jerse
dole	dost	doll	dawl	rawl
dodge	dough	debts	detts	stetts
ditch	dread	drawer	drore	blore
gaze	gauge	ghost	goste	noste
glide	ghoul	geese	gease	bease
gland	glove	gleam	gleem	glerm
hoarse	hearth	haste	haiste	daiste
hoot	hood	haze	haiz	hyne
hoop	hook	hark	harc	hoke
ledge	leapt	leash	leesh	beesh
mince	mauve	moan	mone	vone
munch	mould	messed	mest	mype
mulch	mourn	mirth	merth	kerth
mug	mow	mop	mawp	momp
pare	pear	pave	paiv	baiv
pleat	plaid	plead	pleed	plaip
pray	poll	pose	poze	paik
pork	pour	perk	pirk	sirk
scribe	scarce	scrape	scraip	preed
saint	seize	scare	scair	gair
sag	sew	shave	shaiv	traiv
shout	shove	shine	shyne	styne
snatch	sieve	sneak	sneek	yeek
sour	soot	soak	soke	sarc
sparse	sponge	spike	spyke	ryke
starch	stead	stroll	stroal	woal
stack	steak	stole	stoal	groal
swerve	suave	swear	sware	swuze
swoop	suede	swipe	swype	swest
swell	swear	swamp	swomp	swerth
truce	tread	toque	tuke	huke
trance	trough	traits	trates	treel
vale	vase	veal	veel	vaits
wisp	womb	weave	weeve	wuke
wipe	wool	worm	werm	weam
yeast	yearn	yacht	yawt	yaids

Appendix D: Experiment 6 Stimuli

Base-words, Pseudohomophones, and Nonwords Used in Experiment 6

Base-word	*Pseudohomophone*	*Nonword*
host	hoest	hoert
when	wehn	sehn
state	stait	shait
turn	terhn	gerhn
down	doun	loun
miles	mylz	mydz
mind	mynd	nynd
out	owt	ost
white	whyt	ghyt
held	helled	helked
drive	dryv	dryn
least	leest	leext
game	gaim	gair
wife	wyfe	vyfe
fine	fyne	fyce
hot	hawt	hant
walk	wawk	wawf
boat	bote	boke
golf	gawlf	gawlt
late	layt	payt
guide	gyde	gyfe
field	feeld	teeld
floor	flore	flove
wise	wyz	vyz
woke	woak	woaf
hope	hoap	hoaj
born	boarn	boarm
pride	pryd	pryf
spot	spawt	spawl
tune	toon	toov
nice	nyse	nyre
clean	cleen	cleem
fort	foart	loart
hold	hoald	hoalt
more	mohr	nohr
breeze	breaz	brean
brave	braiv	brair
bone	boan	boam
burn	bern	berv
theme	theem	theen
flash	phlash	phlast

tool	tule	tufe
swiss	swhis	swhin
edge	ehj	ehp
swore	swoar	swoam
colt	coalt	coaft
drawer	drore	drose
stroll	stroal	stroat
dot	dawt	davt
hedge	hedj	bedj
soak	soke	sofe
seeks	seaks	seafs
moths	mawths	mamths
class	klass	plass
trump	truhmp	kruhmp

Appendix E: Experiment 7 Stimuli

High Frequency Exception Words

have, one, says, two, door, heart, broad, prove

move, most, own, once, head, spread, touch, none

does, learn, give, world, front, threat, foot, whom

heard, where, both, grow, love, month, breath, bread

gone, full, four, won, wood, bought, bush, thread

Low Frequency Exception Words

yearn, sponge, vase, tread, suave, poll, cough, hearth

plaid, dost, hood, breast, gauge, seize, pour, leapt

steak, wool, sieve, caste, mow, brooch, soot, suede

climb, ghoul, mould, hook, dread, sew, womb, stead

shove, pear, mourn, trough, swear, dough, comb, mauve

High Frequency Pseudohomophones

sorse, proov, stawc, kynd, streem, shayp, looz, brawd

blynde, leegue, ment, helth, haff, sownd, phrunt, kee

thoe, soote, toor, dore, phawl, wunce, werss, tutch

brayk, wurth, gawn, darc, staij, wurck, sed, surch

yung, chyuld, speetch, squair, choyse, dowt, kort, ferm

Low Frequency Pseudohomophones

sood, klenz, skreim, pynte, stayk, woulph, aks, seez

kerb, chood, kof, ayk, werm, shef, kaij, def

playge, spunj, fayn, rewd, relm, sware, brooz, shrood

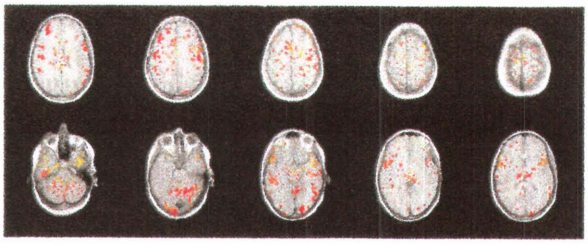
sord, wod, stoal, worp, kord, loab, trawt, yot

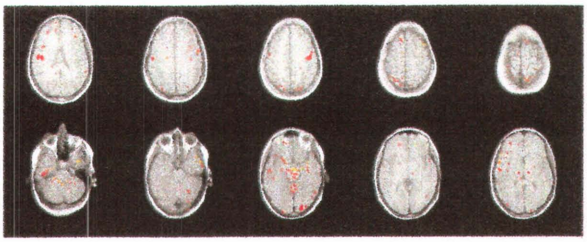
chok, crood, hurse, wosp, gool, yurn, toom, weerd

Appendix F: Individual Intensity Maps for High and Low Frequency Exception Word Naming

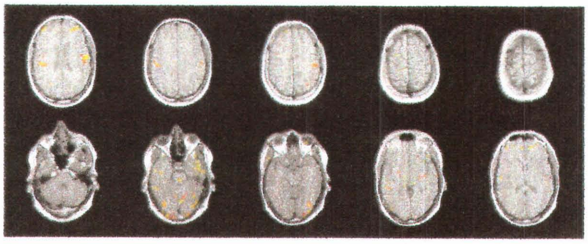
Participant HF Exception Word Naming LF Exception Word Naming

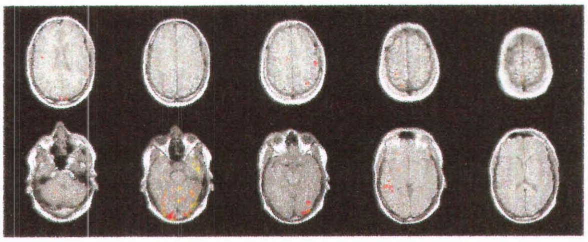
1



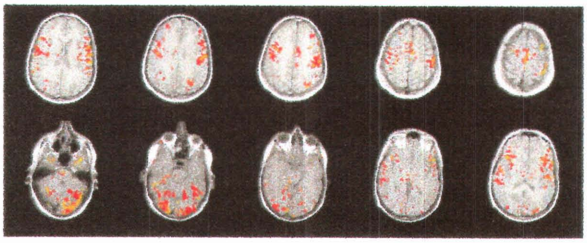


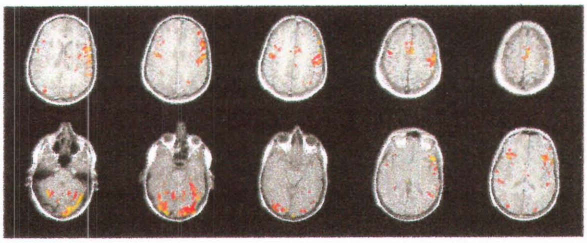
2

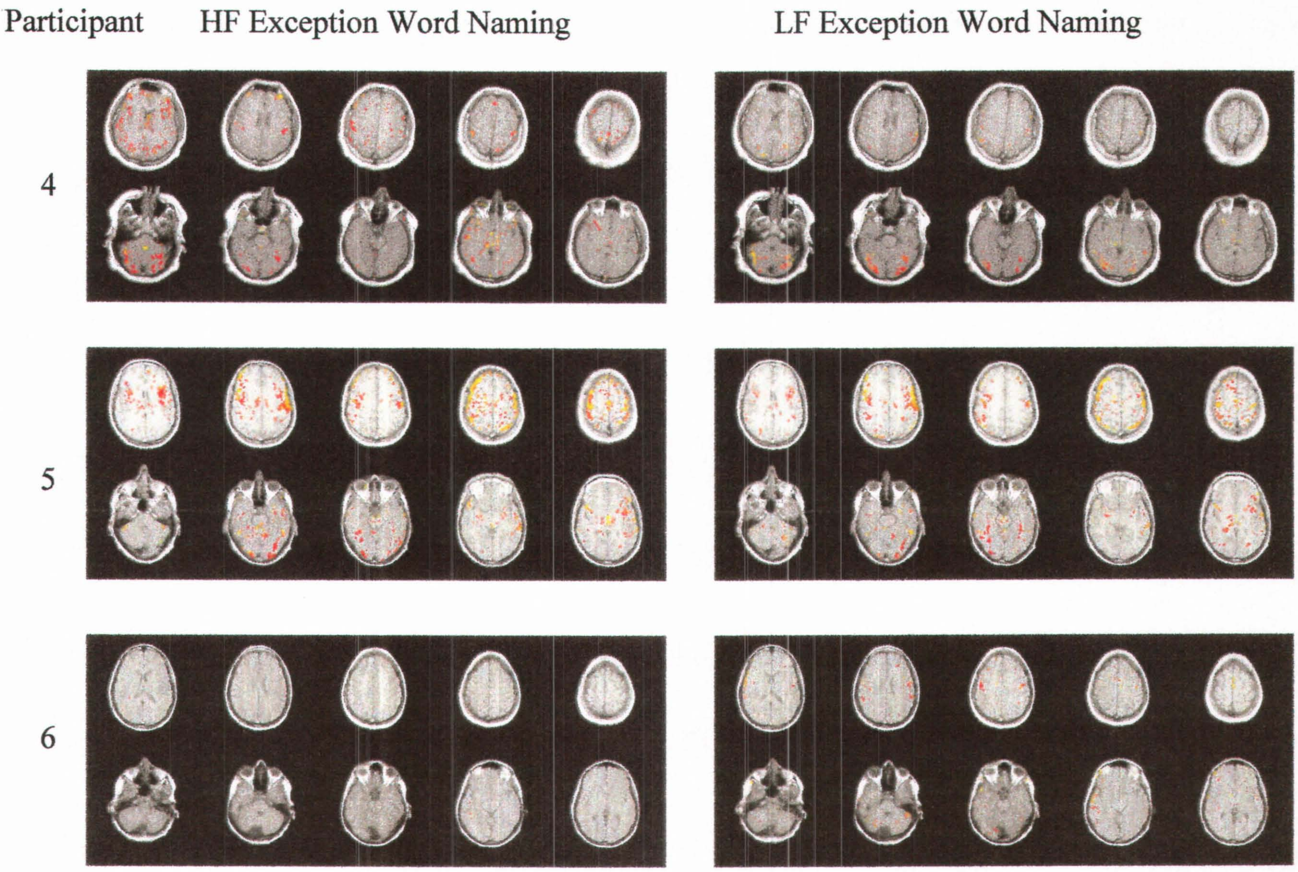


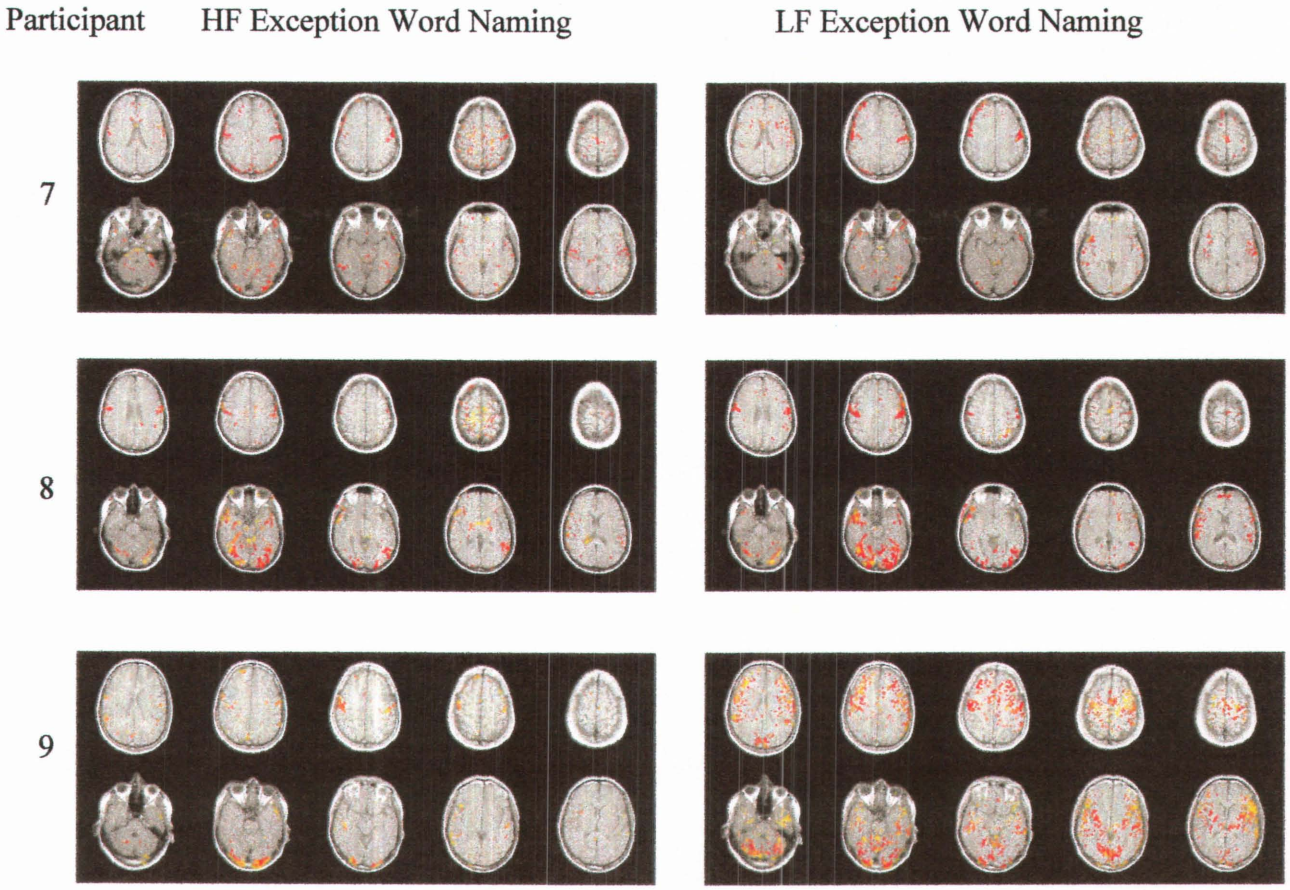


3



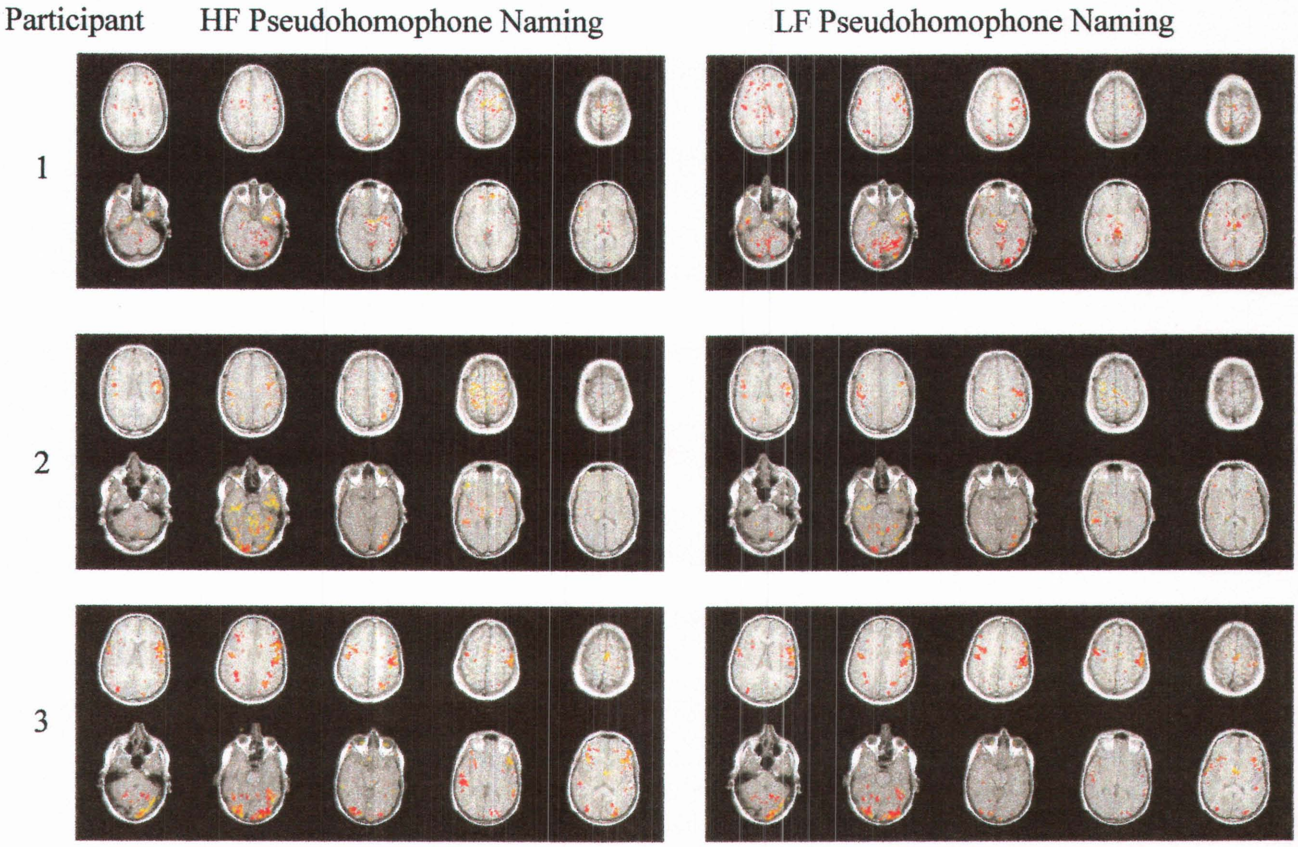


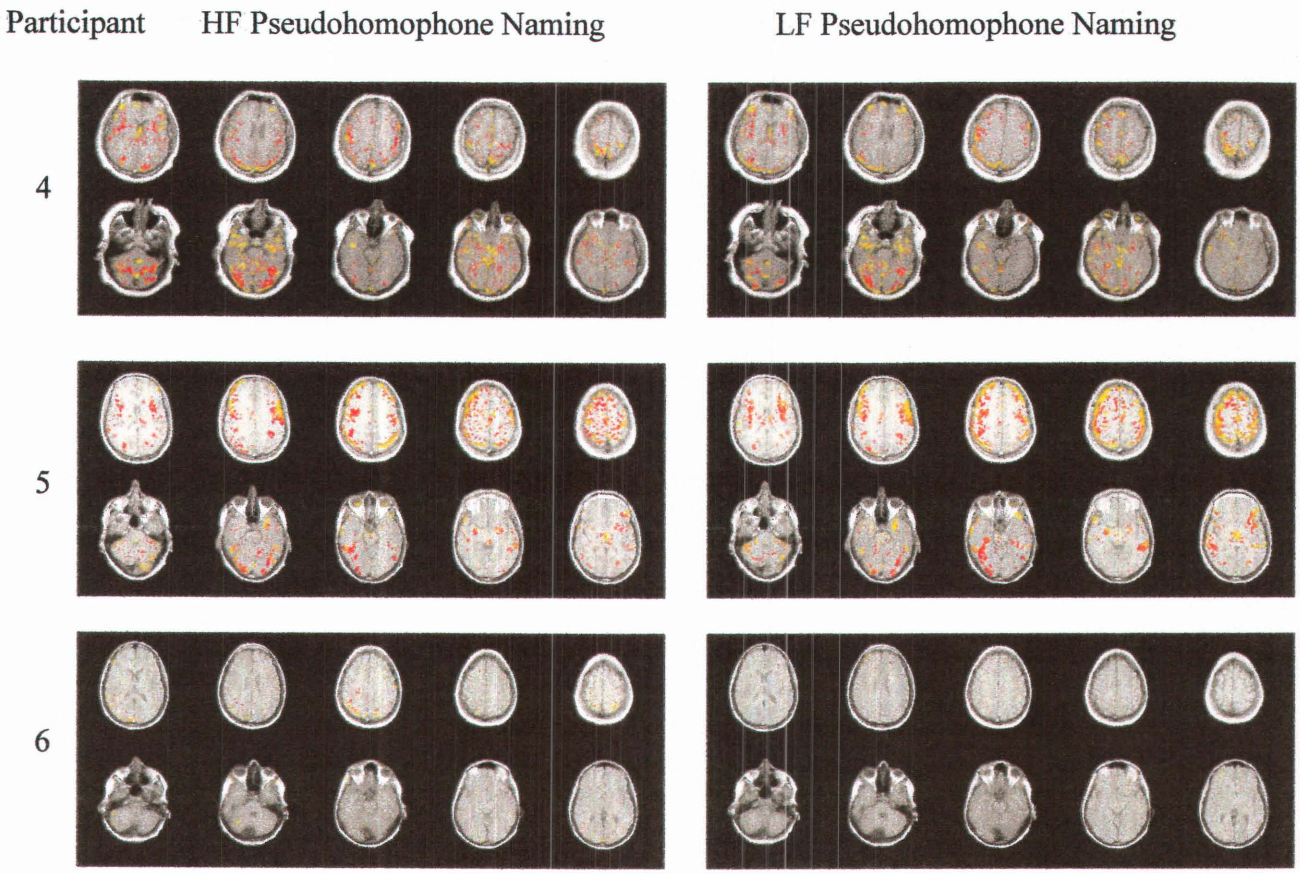

Participant
HF Exception Word Naming
LF Exception Word Naming
4
5
6

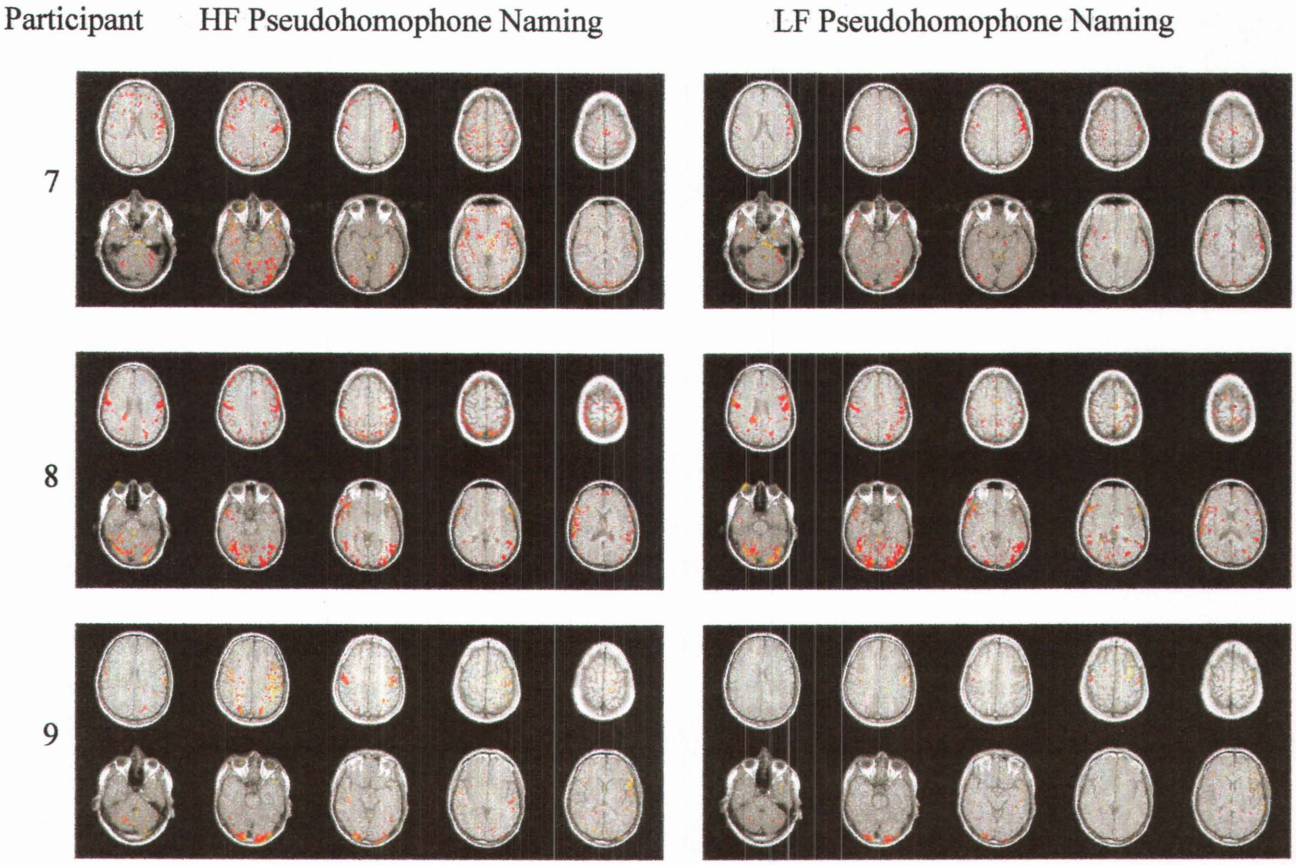


Individual intensity maps comparing high frequency exception word naming activations to low frequency exception word naming with an eta threshold cutoff of .65, and a BOLDfold magnitude > 5 (i.e., maximum minus minimum BOLD response > 5). Red to yellow activation represents increasing BOLD intensities. Specifically, red represents BOLD intensities between 5 and 10, orange represents BOLD intensities between 10 and 15, and yellow represents BOLD intensities between 15 and 100. HF = high frequency and LF = low frequency.

Appendix G: Individual Intensity Maps for High and Low Frequency Pseudohomophone Naming




Participant
HF Pseudohomophone Naming
LF Pseudohomophone Naming
4
5
6



Individual intensity maps comparing high frequency pseudohomophone naming activations to low frequency pseudohomophone naming with an eta threshold cutoff of .65, and a BOLDfold magnitude > 5 (i.e., maximum minus minimum BOLD response > 5). Red to yellow activation represents increasing BOLD intensities. Specifically, red represents BOLD intensities between 5 and 10, orange represents BOLD intensities between 10 and 15, and yellow represents BOLD intensities between 15 and 100. HF = high frequency and LF = low frequency.