Effects of Orthographic, Phonologic, and Semantic Information Sources on Visual and Auditory

Lexical Decision

by

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Submitted to the Graduate Faculty of

School of Health and Rehabilitation Sciences in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2006

UNIVERSITY OF PITTSBURGH

HEALTH AND REHABILITATION SCIENCES

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EFFECTS OF ORTHOGRAPHIC, PHONOLOGIC, AND SEMANTIC INFORMATION
SOURCES ON VISUAL AND AUDITORY LEXICAL DECISION

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University of Pittsburgh, 2006

The present study was designed to compare lexical decision latencies in visual and auditory

modalities to three word types: (a) words that are inconsistent with two information sources,

orthography and semantics (i.e., heterographic homophones such as *bite/byte*), (b) words that are

inconsistent with one information source, semantics (i.e., homographic homophones such as *bat*),

and (c) control words that are not inconsistent with any information source. Participants ($N =$

76) were randomly assigned to either the visual or auditory condition in which they judged the

lexical status (word or nonword) of 180 words (60 heterographic homophones, 60 homographic

homophones, and 60 control words) and 180 pronounceable nonsense word foils. Results

differed significantly in the visual and auditory modalities. In visual lexical decision,

homographic homophones were responded to faster than heterographic homophones or control

words, which did not differ significantly. In auditory lexical decision, both homographic

homophones and heterographic homophones were responded to faster than control words.

Results are used to propose potential modifications to the Cooperative Division of Labor Model

of Word Recognition (Harm & Seidenberg, 2004) to enable it to encompass both the visual and

auditory modalities and account for the present results.

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PREFACE

This dissertation is dedicated to Raymond G. Daniloff, PhD and to James Case, PhD. Daniloff, without your inspiration and support, I never would have considered doctoral studies. You inspired me and stuck by me. I know that you have been with me in spirit, pushing me forward, and providing emotional support, just as you did in life. Jim, you are the epitome of *The Giving Tree*. Your emails about life and my degree provided inspiration and peace. Thank you both for always believing in me. I miss you both and hope you can read this from the heavens.

I have been fortunate to be surrounded by incredible people who provided me with tools to overcome obstacles. Without their support, I would not have gone beyond my high school degree. I must thank my mother, Deborah Sarah Satterfield Nixon, my father, John Daniel Nixon, my sister Christen Leigh Nixon, and my step-mother, Arlene F. Nixon for their love and support throughout this educational process. Thank you for being there. My maternal grandparents were always there to encourage me: Ruth Lasater Satterfield (deceased, Thanksgiving Day 1996) and Robert Beeler Satterfield, PhD (deceased, December 2005) as well as my paternal grandparents, Eunice Rosella Nixon (deceased, September 5, 2005) and John Daniel Nixon (deceased, 1/1995). Aunt Rachael (Chapman; Knoxville, TN) as soon as I finish, I really am coming to visit – and not for a drive through! Thanks for the ear and room during my drives to and from Texas.

My friends have been essential throughout my educational career: They have been understanding when I could not go out secondary to writing and even taken the time to listen to my incessant babblings about the papers and projects I have written. There were also those at Pittsburgh who were with me throughout the dissertation, Heather's voice, Stacey's ear, Jill's "google", my co-workers at the Institute of Education Sciences (IES), and the many students who participated in my studies.

Leonard L. LaPointe, PhD (aka, L3 and Chick), thank you for your mentorship during my master's at Arizona State University and for continuing to advise me after I went to Pitt for the doctorate. I hope to impact others the way you have me. Other faculty members from Arizona State University have continued encouraging me: M. Jeanne Wilcox, PhD and Jean Brown, PhD.

At the University of Pittsburgh many faculty members and post-doctoral fellows provided me with the resources to complete this study and degree: Thomas F. Campbell, PhD, Malcolm R. McNeil, PhD, David Plaut, PhD, Sheila Pratt, PhD, Connie A. Tompkins, PhD, Michael Harm, PhD, Charles Perfetti, PhD, David Klahr, PhD, Erik Reichle, PhD and more. I appreciated the opportunities to study with each of you and with the faculty from Carnegie Mellon.

Thank you Barbara (Barbara R. Foorman, PhD; University of Texas Health Sciences Center – Houston) and employees of the Executive Branch on the Education and Workforce Development Subcommittee. Thank you also to all the employees (particularly Peggy McCardle and Dan Berch) of the Child Development and Behavior Branch of NICHD (NIH) for the new position!

Last but definitely not least, I thank Christine A. Dollaghan, PhD for advising me through the many projects I have undertaken including this dissertation. Thank you for affording me the means to pursue my dreams and shaping me into a more objective researcher. With your guidance, I have developed a program of research that provides a framework for my career.

1.   Introduction

The orthographic, phonologic, and semantic characteristics of words are among the information sources that can influence word recognition. For many words in English, the relationship among these information sources is consistent. That is, a word's orthographic pattern maps to a single phonologic pattern which in turn maps to a single semantic pattern. However, for some words the relationships among orthography, phonology, and semantics are inconsistent. Inconsistency exists when a single pattern in one information source (e.g., the orthographic body *–ow*) maps to more than one pattern in another information source (e.g., the phonologic rimes /$\overline{\text{oʊ}}$/ and /$\overline{\text{aʊ}}$/).

The influence of inconsistency among orthographic, phonologic, and semantic information sources on word recognition has been investigated by manipulating inconsistency in various modalities (i.e., auditory or visual) and conditions (e.g., semantic decision, lexical decision, etc.). However, past research has focused on inconsistencies arising from a single information source, even if multiple inconsistencies may have existed with other information sources. For example, Holden (2002) and Pexman and Lupker (1999) studied the influence of phonology-to-orthography inconsistency on visual lexical decision latencies. Although both studies manipulated stimuli that were also phonology-to-semantics inconsistent (i.e., homophones), this characteristic of the stimuli was not considered a contributing influence. The present study was designed to contrast the effects of single and multiple sources of orthographic, phonologic, and semantic inconsistency on word recognition latencies in visual and auditory lexical decision tasks. We begin with an overview of certain key assumptions of word recognition models, focusing on models of word recognition described in an interactive framework, hereafter referred to generally as interactive models (e.g., Harm & Seidenberg, 2004;

McClelland & Elman, 1986a, 1986b; Plaut, McClelland, Seidenberg, & Patterson, 1996; Stone & Van Orden, 1994; Van Orden, Bosman, Goldinger, & Farrar, 1997; Van Orden & Goldinger, 1994; Van Orden, Pennington, & Stone, 1990). We then review the evidence concerning the influence of single sources of inconsistency on word recognition latencies as well as the similarities and differences between visual and spoken word recognition, prior to presenting the plan of the current study.

1.1.   Characteristics of Models of Word Recognition

Models of word recognition (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Gaskell & Marslen-Wilson, 1997, 2002; Grossberg, 2000; Harm & Seidenberg, 2004; Luce, Goldinger, Auer, & Vitevitch, 2000; Luce & Pisoni, 1998; Norris, McQueen, & Cutler, 2000a, 2000b; Plaut et al., 1996; Ratcliff, Gomez, & McKoon, 2004; Rodd, Gaskell, & Marslen-Wilson, 2004; Stone & Van Orden, 1994; Zorzi, 2000) vary in their stated and unstated assumptions about processing directionality (i.e., feedforward and feedback) among orthographic, phonologic, and semantic information sources, the relevance of each information source to processing, and the extent to which processing influences are specific to the visual and auditory modalities.[1] For example, some models of word recognition assume a feedforward processing architecture in which information is processed from stimulus to response in a unidirectional fashion (Rueckl, 2002); indeed, some models overtly reject the possibility of feedback processing (Norris et al., 2000a, 2000b). Conversely, interactive models, allow both feedforward and feedback processing connections (e.g., Harm & Seidenberg, 2004; Van Orden, Bosman et al., 1997). In such models, information is processed interactively between stimulus and response such that information from subsequent processing operations can feed activation back to the original stimulus information

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[1] See Appendix A for examples of several models of word recognition. Hyperlinks lead to the section describing each model in this Appendix.

and to the intermediate processing stages to influence word recognition (Rueckl, 2002; Stone, Vanhoy, & Van Orden, 1997). Although the existence of feedback processing influences on visual or spoken word recognition continues to be debated (for a review, see Montant, 2000; Norris et al., 2000a, 2000b; Rueckl, 2002; Samuel, 2001; Stone et al., 1997; Tanenhaus, Magnuson, McMurray, & Aslin, 2000), a number of recent word recognition models assume a feedback processing architecture (e.g., Grossberg, 2000; Harm & Seidenberg, 2004; Plaut et al., 1996; Rueckl, 2002; Stone & Van Orden, 1994; Van Orden, Bosman et al., 1997; Van Orden et al., 1990).

Assumptions about the influence of orthographic, phonologic, and semantic information sources on word recognition are usually constrained by a model's focus on either the auditory modality or the visual modality. Understandably, most spoken word recognition models emphasize the importance of phonologic and semantic information but rarely address the potential impact of orthographic information on processing (e.g., Gaskell & Marslen-Wilson, 1997; Grossberg, 2000; Luce et al., 2000). Although activated orthographic information associated with a spoken word could also feed activation back to phonologic and semantic information to influence word recognition, few spoken word recognition models have addressed this possibility and one model, Merge (Norris et al., 2000a, 2000b), explicitly disavows any influence of orthographic information on spoken word recognition. On the other hand, visual word recognition models emphasize the importance of orthographic and phonologic information and although some acknowledge the potential impact of semantic information on processing of written words (e.g., Coltheart et al., 2001; Kawamoto, Farrar, & Kello, 1994; Plaut et al., 1996;

Rodd et al., 2004),[2] few studies have examined the concurrent effects of all three information sources during visual word recognition.

1.2. Interactive Models of Word Recognition

Interactive models of word recognition can easily encompass both visual and spoken word recognition, particularly those that are fully interactive. Although not overtly addressed in all interactive models, most interactive models assume that orthographic, phonologic, and semantic information interact to influence visual and/or spoken word recognition (e.g., Gibbs & Van Orden, 1998; Gottlob, Goldinger, Stone, & Van Orden, 1999; Harm & Seidenberg, 2004; Plaut et al., 1996; Stone & Van Orden, 1994; Van Orden, Bosman, et al., 1997; Van Orden et al., 1990; Van Orden & Goldinger, 1994; Van Orden, Jansen op de Haar, & Bosman, 1997).[3] Interactions occur via feedforward and feedback processing among the information sources, which are represented by nodes or sets of units in the model's architecture (Appendix A). An input pattern (written or spoken, word or nonword) initiates parallel feedforward and feedback activation of the input's associated orthographic, phonologic, and semantic nodes. The information source containing nodes with representations most similar to the perceptual information in the input pattern receives the strongest initial activation and this strong activation helps focus activation across information sources by providing some boundaries. Activation oscillates among nodes within information sources and among information sources and is typically strongest for nodes that activate representations similar to the input pattern. Thus, in visual word recognition, presenting a letter pattern most strongly activates the orthographic nodes, and the activated orthographic nodes focus activation of the stimulus's associated

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[2] Rodd and colleagues (2004) used only interactivity between orthography and semantics in their model, but this does not preclude interactivity among orthography, phonology, and semantics.
[3] Interactive models of word recognition do not always state overtly that they may account for visual and spoken word recognition. However, it is inherent in the assumption of complete interactivity that such models should be able to account for processing in both modalities.

phonologic and semantic nodes ([Figure 1](#)). Likewise, in spoken word recognition, presenting a

phonologic (i.e., spoken) pattern most strongly activates the phonologic nodes, and the activated

phonologic nodes focus activation of the stimulus's associated orthographic and semantic nodes

([Figure 2](#)).
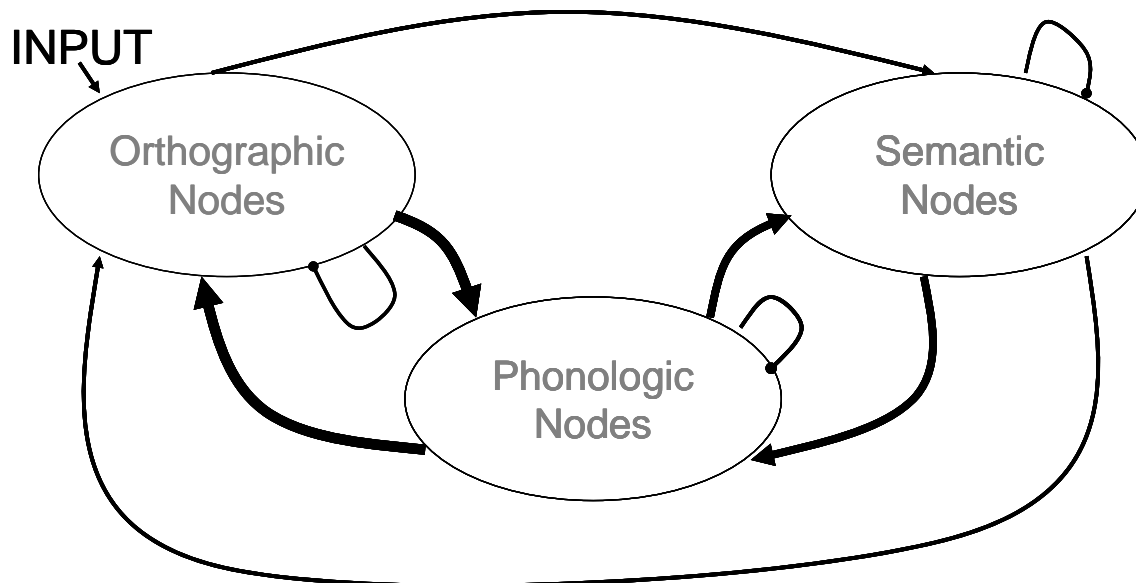
Figure 1. Interactive framework applied to visual word recognition.

Line thickness indicates the strength of connections between nodes. Loops back to each information source indicate interactivity among nodes within an information source. Figure adapted from Van Orden, Bosman, and colleagues (1997) and from Van Orden, Jansen op de Haar, and Bosman (1997).

Some interactive models assume that the local relationships or connections between two

information sources (i.e., orthography and phonology, phonology and semantics, and

orthography and semantics) vary in strength. For example, the local relationship between

orthographic and phonologic information is generally assumed to be the strong because it entails

statistical mappings between graphemes and phonemes in which one typically predicts the other

with a high degree of accuracy (e.g., the grapheme *b* overwhelmingly maps to the phoneme /b/;

Gottlob et al., 1999; Van Orden, Bosman et al., 1997). However, factors other than statistical

relationships affect the strengths assumed for local relationships in interactive models. In

general, semantic information is assumed to be activated more strongly by phonologic

information than by orthographic information because spoken language is learned earlier and

used more often than written language (Frost, 1998). Accordingly, the relationship between

orthography and semantics is often assumed to be the weakest of the three local relationships

(e.g., Frost, 1998; Gottlob et al., 1999; Harm & Seidenberg, 2004; Stone & Van Orden, 1994;

Van Orden, Bosman et al., 1997; Van Orden et al., 1990; Van Orden, Jansen op de Haar, &

Bosman, 1997).
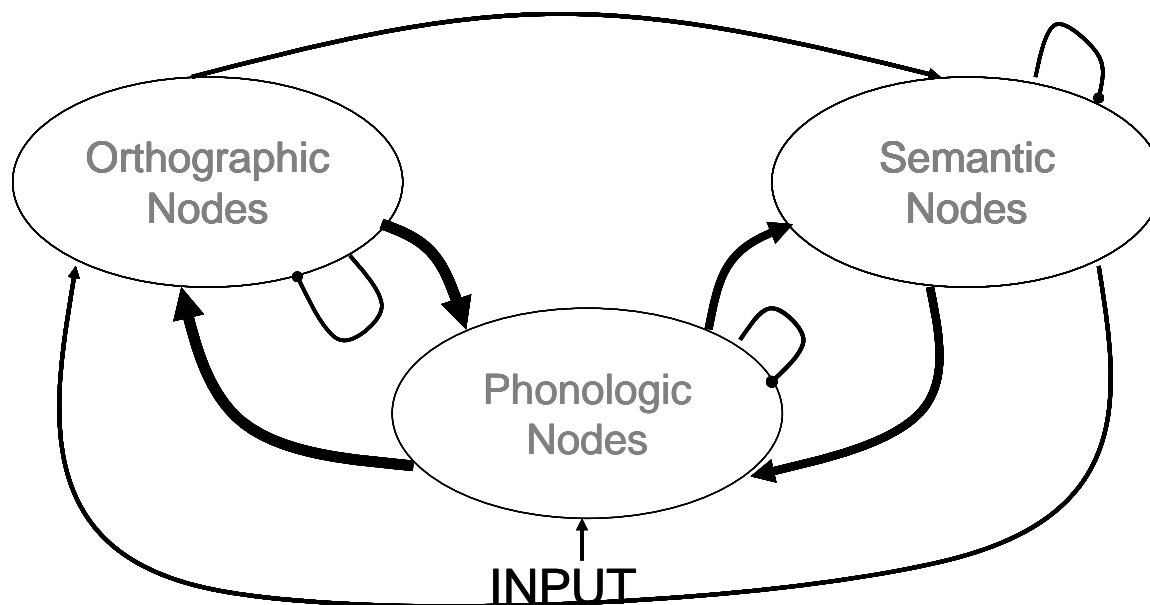
Figure 2. Interactive framework applied to spoken word recognition.

Same general descriptive information applies to this figure as to Figure 1. Note the different inputs for Figure 1 compared with Figure 2. Figure adopted from Van Orden, Bosman, and colleagues (1997) and from Van Orden, Jansen op de Haar, and Bosman (1997).

In a fully interactive model, the strengths of each local relationship may be interpreted as

modality of input independent (i.e., the same across modalities). For example, in some

descriptions of the [Resonance Model](#), the strengths of the local relationships are overtly proposed to be modality of input independent (e.g., Van Orden, Bosman et al., 1997; Van Orden, Jansen op de Haar, & Bosman, 1997). That is, the local relationship between orthography and phonology is proposed to be stronger than the local relationship between phonology and semantics and the local relationship between orthography and semantics is proposed to be the weakest of all local relationships for both visual word recognition and spoken word recognition. This might seem strange for spoken word recognition because accessing orthographic knowledge is unnecessary when recognizing spoken words; however, the importance of written language and the extent with which it is used may elevate the importance of the local relationship between orthography and phonology (e.g., Van Orden et al., 1990; Van Orden, Bosman et al., 1997; Van Orden, Jansen op de Haar, & Bosman, 1997). An alternate hypothesis is for an interactive model to allow variable strengths for the local relationships, which are determined by task demands and modality of input demands. The latter approach would account for processing differences between modalities without necessitating separate models for each modality. For example, the local relationship between orthography and phonology may have a stronger role in visual word recognition than in spoken word recognition because written input should most strongly activate orthographic information. Likewise, the local relationship between phonology and semantics may have a stronger role in spoken word recognition than in visual word recognition because spoken input most strongly activates phonologic information.

Throughout visual and auditory processing, orthographic, phonologic, and semantic nodes are hypothesized to continuously feed activation forward and backward to each other, gradually converging on local information matches between activated patterns of nodes (e.g., Harm & Seidenberg, 2004; Stone & Van Orden, 1994; Van Orden, Bosman et al., 1997; Van

Orden & Goldinger, 1994; Van Orden, Jansen op de Haar, & Bosman, 1997). Local information

matches are mutually reinforced by cycles of feedforward and feedback activation as they

gradually cohere into local resonances between orthographic and phonologic information,

phonologic and semantic information, and orthographic and semantic information. For example,

resonance occurs when only small mismatches, if any, remain between the orthographic nodes

activated by a written stimulus input and the orthographic nodes activated by feedback from

phonologic information. This activation feeds back and forth, oscillating, until achieving

minimal cross-talk (i.e., mismatch), at which point resonance occurs for the local relationship

between orthography and phonology. While local resonances are cohering, the activated patterns

of nodes across all three information sources feed activation forward and backward to each other

until they converge on strong and stable global information matches. In turn, global information

matches are mutually reinforced by cycles of feedforward and feedback activation as they

gradually cohere into global resonance among orthographic, phonologic, and semantic

information that can support responding (Harm & Seidenberg, 2004; Stone & Van Orden, 1994;

Van Orden, Bosman et al., 1997; Van Orden & Goldinger, 1994; Van Orden, Jansen op de Haar,

& Bosman, 1997).

1.2.1.   Influences on the Speed of Coherence

Although activation of orthographic, phonologic, and semantic information associated

with an input pattern is assumed to begin in parallel and occur continuously, information

matches can cohere into local resonances at different times. General stimulus characteristics

such as word frequency and neighborhood density, might modulate the speed with which local

and global resonances cohere during word recognition. For example, low frequency words

generally are responded to more slowly than are high frequency words (Balota, Cortese, Sergent-

Marshall, Spieler, & Yap, 2004; Brown & Watson, 1987; Dobbs, Friedman, & Lloyd, 1985; Fiez, Balota, Raichle, & Petersen, 1999; Luce & Pisoni, 1998). A number of other characteristics of stimulus words have been reported to modulate response latencies in language processing tasks including age of acquisition (e.g., Brown & Watson, 1987), familiarity (e.g., Balota et al., 2004; Lewellen, Goldinger, Pisoni, & Greene, 1993), neighborhood size (e.g., Luce & Pisoni, 1998; Peereman & Content, 1997; Sears, Hino, & Lupker, 1995; Vitevitch, 2002), uniqueness point (e.g., Radeau, Morais, Mousty, Saerens, & Bertelson, 1992; Radeau, Mousty, & Bertelson, 1989), imageability (e.g., Balota et al., 2004; Pecher, 2001), concreteness (e.g., Balota et al., 2004), acoustic duration (e.g., Luce & Pisoni, 1998), and orthographic length (e.g., Balota et al., 2004; Whaley, 1978). Some of these phenomena are described in context of the models of word recognition in Appendix B.

In addition to these general influences, coherence is hypothesized to take longer when there is inconsistent feedforward and/or inconsistent feedback activation (Gottlob et al., 1999; Stone & Van Orden, 1994; Van Orden & Goldinger, 1994). Inconsistent activation is created when one activated pattern in an information source activates more than one pattern in another information source (Stone et al., 1997). For example, in spoken word recognition, hearing a word with the phonologic rime pattern /-$\overline{ou}$l/ feeds activation to six orthographic body patterns, -

oal, -*ol*, -*ole*, -*oll*, -*oul*, and –*owl*. The availability of six orthographic body patterns matching a single phonologic rime pattern is predicted to delay the match between the phonologic pattern and a single orthographic pattern, which in turn should slow coherence of the local resonance between phonology and orthography (Ziegler & Ferrand, 1998). In a fully interactive model, such local inconsistencies could result in additional inconsistencies as feedforward and feedback cycles progress (e.g., Van Orden, Bosman et al., 1997; Ventura, Morais, Pattamadilok, &

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Kolinsky, 2004; Ziegler & Ferrand, 1998; Ziegler, Ferrand, & Montant, 2004). Thus, for example, in visual word recognition, when a word is presented with the orthographic body pattern *–oal*, activation of the matching phonologic rime pattern /-$\overline{ou}$l/ should feed activation back not only to the target but also to the other five possible orthographic bodies, further slowing coherence of the local resonance between phonology and orthography (Stone et al., 1997).

The effects of inconsistency on visual and spoken word recognition have been primarily considered with respect to individual information sources (e.g., a single phonologic representation mapping to more than one orthographic representation). However, an input pattern could also receive inconsistency from more than one information source, which could conceivably result in even slower coherence of the global resonance. For example, a homographic homophone, such as *bat*, has a single phonologic representation that maps to a single orthographic representation, but its phonologic and orthographic representations each map to more than one unrelated semantic representation (e.g., "a flying mammal", "to wink", or "to hit a baseball"; Kellas, Ferraro, & Simpson, 1988; Klein & Murphy, 2001; Klepousniotou, 2002; Rodd, Gaskell, & Marslen-Wilson, 2002). Therefore, semantics is the only source with inconsistency for a homographic homophone. By contrast, for heterographic homophones a single phonologic representation (e.g., /b$\overline{ai}$t/) maps to more than one orthographic representation (e.g., *bite/byte*) as well as to more than one unrelated semantic representation (Pexman, Lupker, & Reggin, 2002).

Although homographic homophones and heterographic homophones provide an opportunity to determine whether word recognition latencies are affected by the cumulative number of inconsistent information sources, no previous word recognition study has contrasted such stimuli in visual or auditory lexical decision. Instead, previous research, primarily in visual

word recognition, has focused on the impact of single-source inconsistencies, such as phonology-to-semantics inconsistency and phonology-to-orthography inconsistency. We turn now to an overview of the literature concerning the effects of single-source inconsistencies on word recognition latencies, focusing on results from lexical decision studies involving homographic homophones or heterographic homophones.

1.3. Single-Source Inconsistencies

1.3.1. Phonology and Orthography

A number of studies have manipulated phonology-to-orthography inconsistency in visual and auditory lexical decision. In this literature, the presence of phonology-to-orthography inconsistency at most grain-sizes[4] in lexical stimuli has been shown to slow lexical decision latencies (e.g., Holden, 2002; Ziegler & Ferrand, 1998). As of yet, heterographic homophones, which are phonology-to-orthography inconsistent at the whole-word grain-size, have only been manipulated in visual word recognition tasks including visual lexical decision. Investigators have reported longer visual lexical decision latencies to heterographic homophones than to nonheterographic homophonic control words, a finding that is known as the heterographic homophone disadvantage (Table 1; e.g., Holden, 2002; Pexman, Lupker, & Jared, 2001). Likewise, there were longer visual lexical decision latencies to words with phonology-to-orthography inconsistent rime-body correspondences than to their consistent control words (Table 1; e.g., Holden, 2002; Stone et al., 1997). The similar patterns of visual lexical decision results for lexical (i.e., heterographic homophones) and sublexical grain-sizes (e.g., rime-body correspondences) of phonology-to-orthography inconsistent words have been hypothesized to

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[4] Grain-sizes are measures of word units including sublexical units as small as letters and phonemes and lexical units as large as whole words.

reflect the same disruptive influence arising from inconsistency between phonology and orthography (Holden, 2002; Stone et al., 1997).

In the auditory modality, the influence of phonology-to-orthography inconsistency at whole-word grain-sizes (i.e., heterographic homophones) has yet to be investigated, but a few studies have addressed phonology-to-orthography inconsistency at sublexical grain-sizes (Table 1; Frost et al., 2003; Ventura et al., 2004; Ziegler & Ferrand, 1998; Ziegler et al., 2004). Parallel to the visual lexical decision latency results, auditory lexical decision latencies were longer to words with phonology-to-orthography inconsistent rime-body correspondences than to consistent control words in French (Ziegler et al., 2004; Ziegler & Ferrand, 1998), in Portuguese (Ventura et al., 2004), and in American English (Frost et al.,2003). This phonology-to-orthography inconsistency disadvantage for auditory lexical decision latencies has been hypothesized to arise from the same source as the phonology-to-orthography inconsistency disadvantage for visual lexical decision latencies (Frost et al., 2003; Stone et al., 1997; Ventura et al., 2004; Ziegler et al., 1997, 2004; Ziegler & Ferrand, 1998). Therefore, phonology-to-orthography inconsistency at sublexical grain-sizes slowed both visual and auditory lexical decision latencies in the above studies.

1.3.2.   Phonology and Semantics

By contrast with the rather consistent findings concerning the impact of phonology-to-orthography inconsistency on word recognition, the evidence on phonology-to-semantics inconsistency is more variable. A particular concern in this literature is the lack of attention to the features of the words selected to be semantically ambiguous. For example, a number of studies have shown shorter visual lexical decision latencies to semantically ambiguous words (i.e., words having more than one semantic representation) than to non-ambiguous control words

Table 1. Summary of Lexical Decision Studies Manipulating Phonology-to-orthography Inconsistency by Modality

Manipulation	Example	Modality	Finding	Citation(s)
Phonology-to-orthography inconsistency vs. consistency of whole-word correspondences (Heterographic homophones)	*bite/byte* → /ba͞ɪt/	VWR	Longer decision latencies than nonhomophonic control words	Holden, 2002, exp. 4 Pexman et al., 2001 Pexman & Lupker, 1999 Pexman, Lupker, & Reggin, 2002 however see, Davelaar, Coltheart, Besner, & Jonasson, 1978
			More errors than nonhomophoninc control words	Pexman et al., 2001 Pexman & Lupker, 1999 Pexman, Lupker, & Reggin, 2002 However see, Davelaar et al., 1978
Phonology-to-orthography inconsistency vs. consistency of rime-body correspondences	/-o͞ʊl/ → *-oal, -ol, -ole, -oll, -oul, -owl*	VWR	Longer decision latencies and more errors than for consistent monosyllabic English and French words	Holden, 2002 Stone et al., 1997 Ziegler, Montant, & Jacobs, 1997 however see, Peereman, Content, & Bonin, 1998; Balota et al., 2004
		SWR	Longer decision latencies and more errors than for consistent monosyllabic English, French, & Portuguese words	Frost, Fowler, & Rueckl, 2003, exp. 2a Ventura et al., 2004, exps. 1 & 2 Ziegler & Ferrand, 1998 Ziegler et al., 2004, Exp. 1

Note. VWR = Visual word recognition; SWR = Spoken word recognition; RT = Reaction time

(Table 2; e.g., Azuma & Van Orden, 1997; Hino et al., 2002, exp. 1a; Pexman, Lupker, & Hino, 2002), a finding that has been hypothesized to reflect an increased speed of coherence of local and global resonances resulting from the cumulative activation of multiple semantic representations (e.g., Pexman, Hino, & Lupker, 2004; Pexman & Lupker, 1999; Rodd et al., 2002; Smith & Besner, 2001). Findings from one study (Rodd et al., 2002) of British-English speakers suggest, however, that it may be important to differentiate between related and unrelated meanings of semantically ambiguous words. Rodd and colleagues (2002) found that visual and auditory lexical decision latencies were slower to homographic homophones than to control words as would be expected if inconsistency slows coherence of resonances, which in turn slows response latencies, but that visual and auditory lexical decision latencies were faster to polysemous words (with more than one related meaning) than to control words. These findings suggest that the existence of more than one unrelated semantic representation for a homographic homophone may decrease the strength of semantic activation yielding slower lexical decision latencies, whereas more than one related semantic representation for a polysemous word may increase the strength of semantic activation yielding faster lexical decision latencies. Although a subsequent study employing Japanese Katakana (Pexman et al., 2004) failed to replicate the effects reported by Rodd and colleagues (2002), differences between the shallow orthography of such stimuli as compared to English stimuli make it difficult to compare the findings of these two studies. At a minimum, the findings of Rodd and colleagues (2002) suggest that it may be important to distinguish semantically ambiguous stimuli according to whether their multiple meanings are related or unrelated, a conclusion that is supported by the analysis of stimuli described in the next section.

Table 2. Summary of Lexical Decision Studies Manipulating Phonology-to-semantics Inconsistency by Modality

Manipulation	Example	Modality	Finding	Citation(s)
Semantically ambiguous words (homographic homophones & polysemous words) vs. non-semantically ambiguous words	See below	VWR	Shorter RTs and fewer errors than control words (Japanese Katakana)	Hino et al., 2002, exp. 1a Pexman et al., 2004 (exp. 4)
			Shorter RTs than control words (English)	Azuma & Van Orden, 1997 Kellas et al., 1988 Pexman et al., 2004 (exp. 1) Pexman & Lupker, 1999 Pexman, Hino, & Lupker, 2002 exps., 1a & 1b
			Fewer errors than control words (English)	Pexman et al., 2004 (exp. 1) Pexman, Hino, & Lupker , 2002, exps. 1a & 1b
Homographic homophones vs. words with no unrelated and with few related semantic representations	bat → /bæt/ → "flying mammal", "used to hit a baseball", "flutter eyelids"	VWR	Longer RTs than control words (English)	Rodd et al., 2002, exps. 1 & 2
			Shorter RTs than control words (Japanese Katakana)	Pexman et al., 2004 (exp. 4)
			Fewer errors than control words (Japanese Katakana)	Pexman et al., 2004 (exp. 4)
		SWR	Longer RTs than control words (English)	Rodd et al., 2002, exp. 3
Polysemous words vs. words with few related and no unrelated semantic representations	lease → /lis/ → "rental", "term of contract", "to rent", etc.	VWR	Shorter RTs than control words (English)	Rodd et al., 2002, exps. 1 & 2
		SWR	Shorter RTs than control words (English)	Rodd et al., 2002, exp. 3

Note. VWR = visual word recognition; SWR = spoken word recognition; RT = reaction time

1.3.3. Analyses of Stimuli in Previous Lexical Decision Studies

A careful look at the stimulus words employed in several of the influential studies described above shows that the words used as heterographic homophones, homographic homophones, and polysemous may not have been defined and/or controlled adequately. For example, semantically ambiguous words have included homographic homophones/homonyms and polysemous words and have more than one unrelated or related semantic representation for one orthographic and one phonologic representation (Azuma & Van Orden, 1997; Hino, Lupker, & Pexman, 2002; Klein & Murphy, 2001; Klepousniotou, 2002; Rodd et al., 2002).

To examine this possibility, stimulus words from five studies, Edwards, Pexman, and Hudson (2004), Pexman and colleagues (2001), Pexman & Lupker (1999), Pexman, Lupker, and Reggin (2002), and Rodd and colleagues (2002), were analyzed to determine how often words selected to represent one type could also represent another word type.

Control words intended not to be heterographic homophones or homographic homophones, but having multiple unrelated semantic representations are of primary concern because the heterographic homophone disadvantage might be stronger in comparison to a control word that is actually a homographic homophone. As shown in Table 3, a substantial percentage (34-50%) of control words intended not to be heterographic homophones could be classified as semantically ambiguous; between 26 and 34% of these were also homographic homophones.

Table 3. Percentage of Control Words with Alternate Classifications from Several Heterographic Homophone Visual Lexical Decision Studies

Study	Experiment(s)	Heterographic homophone	Homographic homophone	Homographic Heterophone	Acronym
Edwards et al. (2004)	1 & 2	10.11%	25.84%	0.00%	1.12%
Pexman et al. (2001)	1 – 5	15.15%	33.33%	0.00%	0.00%
Pexman et al. (2001)	6	7.55%	33.96%	0.00%	0.00%
Pexman, Lupker, & Reggin (2002)	1 & 2	16.67%	33.33%	0.00%	0.00%
Pexman & Lupker (1999)	1 & 2	9.68%	32.26%	0.00%	0.00%

Similar findings are seen in the heterographic homophones employed in these studies, more than one-fourth of which (27-32%) could also be classified as homographic homophones (Table 4).

Table 4. Percentage of Heterographic Homophones with Alternate Classifications from Several Heterographic HomophoneVisual Lexical Decision Studies

Study	Experiment(s)	Spelling Variant	Homographic homophone	Homographic Heterophone
Edwards et al. (2004)	1 & 2	1.12%	30.34%	4.49%
Pexman et al. (2001)	1-5	2.86%	22.86%	2.86%
Pexman et al. (2001)	6	0.00%	32.08%	1.89%
Pexman, Lupker, & Reggin (2002)	1 & 2	0.00%	29.41%	5.88%
Pexman & Lupker (1999)	1 & 2	0.00%	26.67%	3.33%

Nonhomographic homophone control words were less affected by such cross-classification; the percentage of such words representing more than one word class ranged from 10 to 20 (Table 5). However, up to 32% of nonhomographic homophone control words were actually homographic homophones and between 10 and 20% of nonhomographic homophone control words were heterographic homophones. In short, these analyses further cloud the interpretation of the contradictory findings concerning the impact of homophones on lexical decision latencies.

Table 5. Percentage of Control Words with Alternate Classification from Several Homographic Homophone/Polysemous Word Lexical Decision Studies

Study	Experiment(s)	Heterographic homophones	Homographic homophones
Rodd, Gaskell, & Marslen-Wilson (2002)	2 (Vis)	19.64%	0.00%
Rodd, Gaskell, & Marslen-Wilson (2002)	3 (Aud)	18.63%	0.00%
Pexman & Lupker (1999)	1 & 2 (Vis)	9.68%	32.26%

Note. Vis = Visual lexical decision; Aud = Auditory lexical decision

Studies of semantic ambiguity (i.e., homographic homophony/polysemy) also included cross-classified stimuli (e.g., Pexman & Lupker, 1999; Rodd et al., 2002). Pexman and Lupker (1999) manipulated both polysemy and homophony in a visual lexical decision task to determine whether the polysemous word advantage and heterographic homophone disadvantage would co-

occur. Although Pexman and Lupker (1999) did not set out to manipulate homographic

homophones distinct from polysemous words, 68% of their polysemous stimulus words were

homographic homophones (Table 6) and of the control words 32% were homographic

homophones and 10% were heterographic homophones (Table 5). Even in the study by Rodd

and colleagues (2002) who attempted to contrast related and unrelated semantic representations

of semantically ambiguous words, more than 15% of the words used as homographic

homophones were also heterographic homophones (Table 6).

Table 6. Percentage of Homographic Homophones/Polysemous Words with Alternate Classifications from Several Homographic Homophone/Polysemous word Lexical Decision Studies

Study	Experiment	Heterographic homophones	Polysemous Words
Rodd, Gaskell, & Marslen-Wilson (2002)	2 (Vis)	18.18%	0.00%
Rodd, Gaskell, & Marslen-Wilson (2002)	3 (Aud)	17.82%	0.00%
Pexman & Lupker (1999)[5]	1 & 2 (Vis)	25.00%	32.14%

Note. Vis = Visual lexical decision; Aud = Auditory lexical decision

In addition to the possible cross-classification revealed by these analyses, recent evidence

suggests that a number of additional characteristics of word stimuli may have been controlled

insufficiently. Balota and colleagues (2004) analyzed visual lexical decision latencies for 2,428

monosyllabic words; by contrast with most previous work, these investigators reported that

phonology-to-orthography inconsistency did not have negative effects. However, Balota and

colleagues (2004) noted that words with greater "semantic connectivity (i.e., words that are

imageable and words with more semantic representations) yielded faster lexical decision

latencies.

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[5] Pexman and Lupker (1999) used "polysemous words" which included mostly homographic homophones. Accordingly, that classification is used for this table. The debate about the difference between homographic homophones (homonyms) and polysemous words is summarized by Klein and Murphy (2001). This debate has led to inconsistent use of terminology, which makes this literature difficult to navigate.

Another concern with respect to the stimuli used in the existing literature is the frequent use of identical word and nonword stimuli across experiments, sometimes without comment. For example, Pexman, Lupker, and Reggin (2002) created their stimulus lists by forming subsets of lists used in past studies. Such an approach might be justifiable on theoretical grounds, but the generalizability of findings to the broader set of potential stimulus words is unknown.

Finally, in addition to problems with stimulus definition and selection, previous work on visual and spoken word recognition has generally focused on the effects of individual sources of inconsistency even when stimuli enable other sources of inconsistency to operate simultaneously. Results from studies contrasting heterographic homophones and control words have been interpreted as arising from single-source inconsistency (phonology-to-orthography; e.g., Holden, 2002; Pexman & Lupker, 1999; Rodd et al., 2002), despite the fact that heterographic homophones actually have two sources of inconsistency (orthography and semantics). Previous research indicates that inconsistency from more than one unrelated semantic representation for homographic homophones as well as from more than one unrelated semantic representation and more than one orthographic representation for heterographic homophones may slow visual lexical decision latencies (e.g., Holden, 2002; Pexman et al., 2001; Pexman & Lupker, 1999; Rodd et al., 2002). Moreover, inconsistency from two information sources may slow lexical decision latencies to a greater degree than inconsistency from just one information source. However, until lexical decision latencies to carefully controlled heterographic homophones, homographic homophones, and control words are contrasted in a single study, strong conclusions about the effects of inconsistency on lexical decision latencies cannot be drawn. One purpose of the present study was to provide such evidence.

1.4. Comparing Visual and Auditory Processing

Empirical evidence is also scant concerning the extent to which word recognition processes are similar or different in the visual and auditory modalities. A comparison of the visual (Exp. 2) and the auditory (Exp. 3) lexical decision latencies reported by Rodd and colleagues (2002) for similar stimuli revealed an overall mean visual lexical decision latency (595.40 ms) that was almost 400 ms shorter than the mean auditory lexical decision latency (963.00 ms). This is consistent with the contrast between spoken input which arrives over time, and visual input in which the entire stimulus is available immediately. However, apart from the additional time required for stimulus presentation, it appears that most models would predict similar processing stages in the two modalities and several investigators have suggested that ambiguity may have comparable effects in the two modalities. For example, Rodd and colleagues (2002) reported that polysemous words and homographic homophones resulted in similar ambiguity effects in both modalities, although they did not conduct statistical comparisons of the visual and auditory modalities. Likewise, longer lexical decision latencies have been reported for words with phonology-to-orthography inconsistent rime-body correspondences than to words with phonology-to-orthography consistent rime-body correspondences in both the visual and auditory modality (e.g., Frost et al., 2003; Holden, 2002; Ziegler et al., 2004). However, such results provide only indirect evidence concerning the effects of inconsistency in the visual and auditory modality. Thus, a second purpose of the present study was to directly compare visual and auditory lexical decision latencies to heterographic homophones, homographic homophones, and control words.

2.   Purpose

The present study was designed to compare lexical decision latencies in the visual and auditory modalities to three word types: (a) word stimuli that are inconsistent with two information sources, orthography and semantics (i.e., heterographic homophones), (b) word stimuli that are inconsistent with one information source, semantics (i.e., homographic homophones), and (c) and word stimuli that are not inconsistent with any information source (i.e., control words). There were two hypotheses:

(1)   Lexical decision latencies will differ significantly by word type within each modality.

(2)   There will not be an interaction between modality and word type. (i.e., The effects of inconsistency will be similar in the visual and auditory modalities.)

3. Methods

The same general participant selection criteria, stimuli, and experimental procedures were used for both visual lexical decision and auditory lexical decision. In what follows, the procedures common to both conditions are presented first, followed by the procedures specific to each condition.

3.1. Participants

Of the 84 students recruited initially, 83 native English-speaking undergraduate students from the University of Pittsburgh's Psychology Subject Pool met the criteria below and were enrolled in the study. Based on a questionnaire (Appendix C), individuals were excluded if they reported any of the following: (a) a native language other than English; (b) physical limitations that could affect responding (e.g., paralyzed or weak response hand); (c) history of learning disabilities (e.g., language learning disabilities, dyslexia, reading difficulties, etc.) or neurological impairments (e.g., Attention Deficit Hyperactivity Disorder, stroke, traumatic brain injury, seizures, etc.); (d) participation in a college course dedicated to phonetic transcription. One individual failed the hearing screening and was excluded from participation. Two participants mentioned academic placement in "special reading classes" while enrolled in primary school but did not report persistent reading difficulties and were included in the protocol. Participants passed an audiological screening at 25 dB HL for 1,000, 2,000, and 4,000 Hz and reported normal or corrected-to-normal vision.

The participants ranged in age from 18 to 27 ($M = 18.61$, $SD = 1.29$), 52% were females and 17% were members of racial/ethnic minorities. Eligible participants were assigned to the

visual or auditory condition using a random numbers table. As shown in Table 7 there were no

significant differences between the participant groups for age or level of completed education.[6]

Table 7. Group Differences for Age and Level of Completed Education

Measure	Visual ($n = 40$)		Auditory ($n = 43$)		
	M	*SD*	*M*	*SD*	*t* (74)
Age	18.52	1.01	18.70	1.51	0.61
Completed education	1.25	0.78	1.35	0.61	0.65

3.2.   Stimuli

To select the stimulus words for this study, a database of monosyllabic words was

compiled from three sources: (a) previous studies (Azuma, 1996; Azuma & Van Orden, 1997;

Borowsky & Masson, 1996; Folk, 1999; Folk & Morris, 1995; Holden, 2002; Jared, Levy, &

Rayner, 1999; Klein & Murphy, 2001; Klepousniotou, 2002; Pexman & Lupker, 1999; Pexman,

Lupker, & Reggin, 2002); (b) a dictionary of heterographic homophones and homographs

(Hobbs, 1999); and, (c) a large set of orthography-to-phonology and phonology-to-orthography

consistent and inconsistent monosyllabic words identified in Nixon (2002). Each of the resulting

6,355 monosyllabic words was first analyzed to determine whether it qualified as a homographic

homophone, a heterographic homophone, or a control word according to the following criteria.

Homographic homophones were defined as words with a single orthographic representation and

a single phonologic representation, but more than one unrelated semantic representation as

evidenced by having more than one dictionary entry in the Wordsmyth Internet dictionary.[7]

Heterographic homophones were defined as words with a single phonologic representation but at

least two orthographic representations, each denoting an unrelated semantic representation.

Control words were defined as words that were not heterographic homophones, homographic

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[6] Level of completed education was recorded as follows: high school (1), freshman year of college (2), sophomore year of college (3), junior year of college (4), senior year of college (5).
[7] The Wordsmyth Dictionary-Thesaurus (www.wordsmyth.net) contains a word list with definitions for nearly 50,000 headwords and linkages among these to exact synonyms and near synonyms.

homophones, or homographic heterophones. These criteria were used to identify 650 sets of

heterographic homophones with 1,546 orthographic representations, 1,130 homographic

homophones with 2,544 unrelated semantic representations, and 3,679 control words were

identified.

The resulting pool of potential stimuli was then examined to exclude words that met any

of the following criteria: (a) words without entries in Wordsmyth; (b) function words (e.g.,

prepositions, articles, copulas, etc.); (c) contractions (e.g., *we've*); (d) proper nouns; (e)

acronyms (e.g., *AIDS*); (f) homographs, i.e., words with a single orthographic representation but

more than one phonologic representation (e.g., *bow* → /b$\overline{au}$/ and /b$\overline{ou}$/); (g) words meeting the

criteria for both heterographic homophones and homographic homophones (e.g., *ball* and *bawl*

are heterographic homophones, but *ball* also has two unrelated semantic representations, "a

spherical or nearly spherical body" and "a large social function at which there is formal

dancing"; and, (h) spelling variants of the same word (e.g., *blond* and *blonde*). After these

exclusions, the resulting pool contained 233 heterographic homophone sets (35.85% of the sets

identified initially) with 524 orthographic representations (33.89% of those identified initially),

790 homographic homophones (69.91%) with 1,759 semantic representations (69.14%), and

3,389 control words (92.12%).

To estimate frequency of occurrence for stimuli and to control for differences in semantic

representation dominance for heterographic homophones and homographic homophones, an

Internet frequency estimate was obtained for each word in the pool by entering it into an Internet

search engine and recording the number of hits returned (Blair, Urland, & Ma, 2002).

Significant and large correlations have been found (Blair et al., 2002) between such Internet

frequency estimates and the Kučera and Francis (1967) written word frequencies ($r = .89$) and

CELEX word frequencies ($r = .78$). Because such Internet frequency estimates are compiled

from formal, informal, and conversational texts they are likely to include new, informal, and

slang words not represented in other word frequency databases. In addition, Internet frequency

estimates can be refined to estimate the frequency and semantic dominance of each semantic

representation for a word by searching for co-occurrences of words in web pages (Blair et al.,

2002), which was an important consideration for the present study as described below.

3.2.1.   Internet Frequency Estimates of Semantic Representations

To estimate the frequency of related and unrelated semantic representations, which was

particularly important for selecting homographic homophones in the present study, Internet

frequency estimates were obtained for semantic representations of each potential stimulus word

by modifying the search method used by Blair and colleagues (2002) to search for co-

occurrences of words in web pages. These co-occurrences were defined by an orthographic

representation's semantic use, which included its related semantic representation(s) in

Wordsmyth (i.e., the definitions included in a single dictionary entry). The orthographic

representation of a potential stimulus word was entered into Google® and limited by its defining

characteristics, synonyms, near synonyms, and related words (see Appendix D). For example,

the control word *beep* has three related semantic representations in Wordsmyth: "a short, usually

high-pitched warning signal"; "to emit a short warning signal"; "to cause to emit a short warning

signal". Therefore, the overall Internet frequency estimate for the related semantic

representations of *beep* would be obtained by entering *beep (warning OR signal OR horn OR*

short OR warn). This method was also used to obtain Internet frequency estimates for unrelated

semantic representations of homographic homophones, by limiting the search for each

orthographic representation to the defining characteristics of each unrelated semantic

representation. Henceforth, this estimate is referred to as the semantic representation frequency estimate. For example, *tag* has two unrelated semantic representations according to Wordsmyth: [1]*a piece of cardboard, thin metal, plastic or other material that identifies, labels, or shows the price of that to which it is attached;*[8] and, [2]*a children's game in which one player chases the others until he or she touches one of them, who then becomes the pursuer.* Therefore, the semantic representation frequency estimate for each unrelated semantic representation of *tag* could be obtained for [1]*tag* by entering *tag (label OR price OR cardboard OR name OR sale OR sell)* and [2]*tag* by entering *tag (game OR player OR chase OR touch).*

3.2.2. Internet Estimates of Semantic Dominance for Heterographic Homophones and Homographic Homophones

A semantic dominance score was calculated for the unrelated semantic representations of heterographic homophones and homographic homophones by obtaining the percentage of total Internet frequency estimates accounted for by each unrelated semantic representation. This was done by dividing the semantic representation frequency estimate by the sum of all semantic representation frequency estimates sharing one phonologic representation and multiplying this number by one hundred (for scores see Appendix E). The semantic representation with the largest semantic dominance score was considered dominant. If semantic dominance estimates differed by $\leq 5\%$ the heterographic homophone or homographic homophone was considered to have balanced semantic dominance. Heterographic homophones and homographic homophones with one highly dominant semantic representation (i.e., a semantic dominance score that was $\geq$ 50% from that of the second most frequent semantic representation) were excluded. Fifty percent was chosen as a cut-off because it excluded homographic homophones and heterographic

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[8] There are nine related semantic representations for this one unrelated semantic representation of *tag*. Only one of these nine related semantic representations is listed above, but the defining characteristics were selected from all nine related semantic representations.

homophones that had been labeled biased in previous studies without eliminating those labeled balanced in previous studies (e.g., Folk, 1999; Folk & Morris, 1995). Eliminating heterographic homophones and homographic homophones with one very dominant semantic representation was intended to limit the impact of semantic representation dominance variability and maximize semantic conflict for visual and auditory lexical decisions (e.g., Daneman, Reingold, & Davidson, 1995; Folk, 1999; Folk & Morris, 1995; Pexman et al., 2001; Starr & Fleming, 2001).

Several analyses were conducted to evaluate the validity and reliability of the Internet-based semantic representation frequency estimates. Appendix F provides details on these studies.

3.2.3. Final Stimulus Word Lists

Sixty-seven heterographic homophone sets (148 orthographic representations) met the criteria above. From these, seven heterographic homophone sets were randomly eliminated as they shared a root word with another heterographic homophone, leaving 60 homophone sets with 134 different orthographic representations. Accordingly, 60 homographic homophones (146 unrelated semantic representations) were randomly selected from the 513 eligible homographic homophones (1,206 unrelated semantic representations) and 60 control words were randomly selected from the 3,389 eligible control words.

3.2.3.1. Creating the Auditory Stimuli

For recording, the phonetically transcribed stimuli were read in lists by a native English-speaking female from the Pittsburgh, PA area who was an expert in phonetic transcription. From among the available recorded tokens of each stimulus, a clear and intelligible exemplar that did not occur at the end of a list was selected by the investigator for presentation. Stimuli were evaluated for clarity by a group of doctoral students in communication science and disorders.

The auditory stimuli were digitally recorded via a single channel at a sampling rate of 44,100 Hz with 16 bits per sample using Cool Edit Pro® using a head-mounted microphone (Radio Shack 33-3003) set approximately 6-inches from the speaker's mouth. Each stimulus was spliced from the entire stimulus set and saved as a separate digital *.*wav file. After editing, stimulus files were equated for overall root mean square (RMS) amplitude using Cool Edit Pro® to ensure that the stimuli were similar in average intensity. The acoustic duration of the individual word and nonword files were measured using Multispeech®, Model 3700 software (Kay Elemetrics).

3.2.3.2. Descriptive Characteristics of the Stimulus Words

The heterographic homophone, homographic homophone, and control word stimuli are listed along with their descriptive characteristics in Appendix E. The three stimulus word sets did not differ significantly with respect to semantic representation frequency estimates ($F(2, 335)$ < 0.01, $p = 1.00$), number of graphemes ($F(2, 177) = 1.17$, $p = 0.31$), or acoustic duration as measured with Multispeech®, Model 3700 software (Kay Elemetrics) ($F(2, 177) = 2.11$, $p = 0.13$; see Table 8 for descriptive statistics). In addition, the heterographic homophone and homographic homophone stimulus word groups did not differ significantly with respect to semantic dominance scores ($t(254.77) = -1.51$, $p = 0.13$).

For each heterographic homophone, the orthographic representations to be visually presented were selected randomly after the stimulus words were identified. This procedure does not place assumptions about the orthographic representation(s) recognized by participants in auditory lexical decision or about the unrelated semantic representation(s) of homographic homophones recognized by participants in visual or auditory lexical decision. (The visually presented orthographic representation for each heterographic homophone set is indicated in Appendix E.)

An additional 180 monosyllabic nonwords were created using the body-rime correspondences from the 180 stimulus words (Appendix G). To create a nonword, onsets (null, consonant, or consonant blend) were pseudo-randomly assigned to each body-rime correspondence. This increased the odds that the nonwords were not only word-like but also orthographically and phonologically similar to the stimulus words; two characteristics that increase the probability of semantic processing (e.g., Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Pexman et al., 2001). No nonword appeared in Wordsmyth as a word, a prefix, or a suffix, and no nonword was a pseudohomophone (e.g., *phan*).

Table 8. Characteristics of Heterographic homophone, Homographic homophone, and Control Word Stimuli

	Homographic homophones	Heterographic homophones	Control Words	Total	Statistic
	Semantic Representation Frequency Estimate *df* (2, 355)				
M	2,752,174.20	2,716,071.40	2,700,764.80	2,728,735.40	$F < 0.01$
SD	3,680,737.49	3,802,749.57	4,176,433.77	3,809,211.32	*ns*
	Number of Letters *df* (2, 177)				
M	4.73	4.55	4.80	4.69	$F = 1.17$
SD	0.97	0.89	0.92	0.93	*ns*
	Acoustic Duration (ms) *df* (2, 177)				
M	528.45	562.40	547.71	546.19	$F = 2.11$
SD	91.74	79.22	100.32	91.40	*ns*
	Semantic Dominance *df* (254.77)				
M	41.67%	44.78%	--	--	$t = -1.51$
SD	15.16	18.93	--	--	*ns*

3.3. Procedures

Screening and experimental procedures occurred in a single session in a sound-isolated room at the Department of Communication Science and Disorders at the University of Pittsburgh. First, the screening and experimental procedures were described to participants and the informed consent was discussed and signed. Second, each participant filled out a brief background history questionnaire (Appendix C). Third, hearing was screened binaurally using pure-tone signals at 25 dB HL for 1,000 Hz, 2,000 Hz, and 4,000 Hz (American Speech-

Language-Hearing Association Audiologic Assessment Panel 1996, 1997). After the screening

procedures, a random numbers table (www.randomizer.org) was used to randomly assign

qualifying participants to either the visual condition, in which participants read items, or the

auditory condition, in which participants listened to items.

In response to each item, participants were directed to indicate whether they thought it

was a word or a nonsense word by a button press as described below (see directions in Appendix

H). They were instructed to use the hand they found most comfortable and were not allowed to

change hands during the experiment. The experimenter then demonstrated how to use the

keyboard and participants were given an opportunity to ask questions before beginning 30

practice trials. They received feedback about their speed and accuracy on the computer screen.

Following the practice trials, participants again could ask questions before continuing the

experimental task. During the experimental task, participants were required to respond to each

stimulus item and did not receive feedback about speed and accuracy.

Stimuli were presented randomly without replacement using E-Prime$^{®}$ (version 1.1;

Schneider, Eschmann, & Zuccolotto, 2002) on a Toshiba Satellite Intel Pentium III processor and

lexical decision latencies were collected using button presses. Each trial began with a symbol

(+) displayed in the center of the screen for 500 ms followed by a blank screen for 100 ms. A

stimulus (word or nonword) was presented on the screen or via headphones as appropriate. On

each trial, the stimulus (word or nonword) was presented until the participant responded by

pressing either the letter *g* button on the left, labeled WORD, or the letter *j* button on the right,

labeled NONWORD. After a response, the screen cleared and there was an intertrial interval of

1,000 ms.

A one-to-one ratio of words to nonwords was used in order to limit response biases (Galanter, 1962). Thus, each participant responded to 360 items, which required approximately 40 minutes. For visual lexical decision, the stimuli were presented in the center of a color monitor set approximately 40 cm from each participant in black Arial letters about 0.50 cm high (18-point) on a white background. For auditory lexical decision, a calibration noise band, created with Cool Edit Pro®, was played via E-prime® (Schneider et al., 2002) at the beginning of each session to ensure that the amplitude settings within the computer and experimental program were the same across sessions. The calibration sound file was created to match the mean RMS of the sound files. On each trial a stimulus was presented binaurally at 65 dB SPL, which is analogous to normal conversation at three feet (Martin, 1994), via Kenwood personal monitor headphones (Model KPM-510).

4.   Statistical Analyses

Participant mean lexical decision latencies were analyzed using a mixed 2 (Visual and Auditory) by 3 (heterographic homophones, homographic homophones, control words) Analysis of Variance (ANOVA) with repeated measures on the second factor. Post-hoc pairwise Bonferroni *t*-test comparisons were conducted as appropriate within each modality. A sample size of 48 participants (24 in the visual modality and 24 in the auditory) was calculated with power at 0.80, Cohen's *d* at 0.50, and alpha at 0.05.

In addition to the analyses by participants, item analyses were conducted. Item mean lexical decision latencies were analyzed using a 2 (Visual and Auditory) x 3 (heterographic homophones, homographic homophones, and control words) ANOVA. Item analyses were included in an effort to address the generalizability of findings across a similar population of randomly selected items (e.g., Cleland, Gaskell, Quinlan, & Tamminen, 2006; De Moor, Verguts, & Brysbaert, 2005; Huck & Cormier, 1996; McLennan & Luce, 2005). A sample size of 53 stimulus words for each word type was calculated with power at 0.80, Cohen's *d* at 0.50, and alpha at 0.05.

Even though word types were carefully controlled, there were several variables that could pose threats to validity. Accordingly, supplemental Analyses of Covariance (ANCOVA) were planned with the covariates semantic representation frequency estimate, acoustic duration, and number of letters. Predictor variables were first correlated with the lexical decision latencies; those with correlations exceeding ±0.20 were included as covariates (Huck & Cormier, 1996).

5. Results

5.1. Exclusions

Data were excluded for six participants whose mean response accuracy for stimuli (words and nonwords) was 2 *SDs* or more below the overall mean response accuracy within each condition; such participants may have had a non-detected disability or may have been uncooperative during the session. One participant was excluded due to technical difficulties (see Table 9). Thus, data from 76 participants (38 participants per modality) were eligible for statistical analysis.

Table 9. Number of participants excluded by criteria

	Technical Difficulty	Accuracy Outliers	Total
Visual (*n* = 40)	0	2 (5.00%)	2 (5.00%)
Auditory (*n* = 43)	1 (2.33%)	4 (9.30%)	5 (11.63%)
Overall (*n* = 83)	1 (1.20%)	6 (7.22%)	7 (8.43%)

Note. The percentage is in parentheses.

After participant exclusions had been made, items with lexical decision latencies ± 3 *SD*s from a participant's mean within each word type and inaccurate lexical decisions were excluded from the analyses. Exclusions from visual lexical decision data left 5,899 data points (86.24%) eligible for analyses. Exclusions from auditory lexical decision data left 5,770 data points (84.36%) eligible for analyses.

Table 10 shows the number of trials excluded as lexical decision latency outliers as a function of word type and modality. There were no significant differences between the number of lexical decision latency outliers in the visual condition or the auditory condition; there were no significant differences between the lexical decision latency outliers as a function of word types by participant. Table 11 shows the number of trials excluded due to inaccurate lexical decisions (errors) to words by condition as a function of word type. There were significant differences in the number of inaccurate lexical decisions between word types within the visual

and auditory conditions ($F(1.67, 68.22) = 75.58$, $p < 0.01$, $MSE = 6.07$, $SS = 917.07$, Cohen's $d = 1.78$ and $F(2, 74) = 72.19$, $p < 0.01$, $MSE = 7.02$, $SS = 519.14$, Cohen's $d = 1.54$ respectively).

The effect sizes were substantial for the inaccuracy differences as a function of word type in each modality ranging from Cohen's d 1.44 to 1.93. See Appendix E for mean response accuracy by stimulus word as a function of modality. The number of inaccurate responses within each word type by participants suggests that power for the item analyses may have be somewhat less than anticipated.

Table 10. Total Number of Lexical Decision Latency Outliers across Participants and Descriptive Statistics

Word Type	Total	*Mn*	*SD*	95% Confidence Interval
Visual Lexical Decision ($n = 38$)				
Heterographic Homophones	48	1.26	0.60	1.07 - 1.46
Homographic Homophones	41	1.08	0.59	0.89 - 1.27
Control Words	41	1.08	0.54	0.90 - 1.26
Auditory Lexical Decision ($n = 38$)				
Heterographic Homophones	34	0.89	0.61	0.70 - 1.09
Homographic homophones	29	0.76	0.75	0.52 - 1.01
Control Words	34	0.89	0.61	0.70 - 1.09

Table 11. Total Number of Inaccurate Lexical Decisions across Participants and Descriptive Statistics

Word Type	Total	*Mn*	*SD*	95% Confidence Interval
Visual Lexical Decision ($n = 38$)				
Heterographic Homophones	342	9.00_a	4.20	7.62 - 10.38
Homographic Homophones	118	3.11_b	2.37	2.33 - 3.88
Control Words	351	9.24_a	2.98	8.26 - 10.22
Auditory Lexical Decision ($n = 38$)				
Heterographic Homophones	221	5.82_a	3.45	4.68 - 6.95
Homographic homophones	270	7.11_a	3.75	5.87 - 8.34
Control Words	482	12.68_b	4.42	11.23 - 14.14

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

5.2. Primary Analyses

Table 12 shows descriptive statistics by Word Type and Modality. The 2 (Visual vs.

Auditory) x 3 (heterographic homophone, homographic homophone, and control word)

ANOVAs yielded a significant main effect of word type and an interaction between modality and

word type by participants but not by items (Table 13). This interaction shows that patterns of

lexical decision latencies differed within each modality as a function of word type.

Table 12. Lexical Decision Latencies by Participants and Items as a Function of Word Type and Modality

Word Type	Mn	SD	95% Confidence Interval
Participants (N = 76)			
Heterographic Homophones	897.42	194.36	864.96 - 929.89
Homographic Homophones	886.79	206.28	853.59 - 919.99
Control Words	915.67	220.31	877.80 - 953.55
Visual	758.40	208.59	710.49 - 806.39
Auditory	1,041.53	209.53	993.62 - 1089.43
Items (N = 360)			
Heterographic Homophones	910.80	166.66	890.04 - 931.55
Homographic Homophones	892.97	172.94	872.22 - 913.73
Control Words	943.40	199.49	922.65 - 964.16
Visual	777.86	126.90	759.43 - 796.28
Auditory	1,053.59	106.54	1033.14 – 1069.04

Table 13. Analysis of Variance Results for Lexical Decision Latencies by Participants and Items

Variable	df	SS	MS	F	d	Power
Participants (N = 76)						
Main effect of word type	2	32,435.35	16,217.67	11.37**	0.16	0.99
Main effect of modality	1	1,523,082.74	1,523,082.74	69.35**	2.34	1.00
Modality x Word Type	2	8,799.29	4,399.63	3.09*	0.08	0.59
Within-cells error	148	211,047.64	1,426.00			
Between-cells error	74	41,625,333.87	21,963.97			
Items (N = 360)						
Main effect of word type	2	156,944.52	78,472.26	5.87**	0.23	0.87
Main effect of modality	1	6,842,472.20	6,842,472.20	511.99**	1.87	1.00
Modality x Word Type	2	26,318.28	26,318.28	0.99	0.34	0.23
Within-cells error	354	4,731,048.32	13,364.54			

Note. *$p < 0.05$, **$p < 0.01$

The follow-up one-way ANOVAs illustrated significant main effects of word type for

both visual lexical decision (Table 14) and auditory lexical decision (Table 15). Table 16 shows

descriptive statistics for visual lexical decision latencies by participants and items. Both heterographic homophones and control words had significantly longer lexical decision latencies than homographic homophones by participants (Cohen's $d = 0.08$ and Cohen's $d = 0.10$ respectively). These results suggest a small advantage for homographic homophones relative to both heterographic homophones and control words. By contrast, the item analyses indicated a significant homographic homophone advantage only compared with control words (Cohen's $d = 0.46$).

Table 14. Analysis of Variance Results for Visual Lexical Decision Latencies by Participants and Items

Variable	df	SS	MS	F	d	Power
Participants ($n = 38$)						
Main effect of word type	2	19,159.86	9,579.93	7.58**	0.08	0.94
Within-cells error	74	93,537.48	1,264.02			
Items ($n = 180$)						
Main effect of word type	2	104,988.13	52,494.07	3.35*	0.38	0.63
Within-cells error	177	2,777,415.89	15,691.62			

Note. $*p < 0.05$ $**p < 0.01$

Table 15. Analysis of Variance results for Auditory Lexical Decision Latencies by Participants and Items

Variable	df	SS	MS	F	d	Power
Participants ($n = 38$)						
Main effect of word type	2	22,074.75	11,037.38	6.95**	0.20	0.92
Within-cells error	74	117,510.16	1,587.98			
Items ($n = 180$)						
Main effect of word type	2	78,274.66	39,137.33	3.55*	0.39	0.65
Within-cells error	177	1,953,632.43	11,037.47			

Note. $*p < 0.05$ $**p < 0.01$

Table 16. Visual Lexical Decision Latencies as a Function of Word Type

Variable	Mn	SD	95% Confidence Intervals
Participants ($n = 38$)			
Heterographic homophones	764.63$_a$	160.01	712.03 - 817.22
Homographic homophones	740.35$_b$	147.11	692.00 - 788.70
Control Words	770.22$_a$	174.12	712.98 - 827.45
Items ($n = 180$)			
Heterographic homophones	784.17$_{ab}$	128.43	752.26 - 816.09
Homographic homophones	745.63$_a$	83.05	713.72 - 777.55
Control Words	803.77$_{ab}$	153.90	771.86 - 835.68

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

Table 17 shows descriptive statistics for auditory lexical decision latencies by participants and items. In the participant analyses, both heterographic homophones and homographic homophones had significantly faster auditory lexical decision latencies than control words (Cohen's $d = 0.22$ and Cohen's $d = 0.20$ respectively). These results suggest an advantage for heterographic and homographic homophones relative to control words. By contrast, the item analyses did not indicate any significant differences between word types.

Table 17. Auditory Lexical Decision Latencies as a Function of Word Type

Word Type	*Mn*	*SD*	*95% Confidence Interval*
Participants ($n = 38$)			
Heterographic homophones	1,030.22$_a$	121.44	990.30 - 1,070.14
Homographic homophones	1,033.23$_a$	143.40	986.10 - 1,080.37
Control Words	1,061.13$_b$	156.88	1,009.56 - 1,112.70
Items ($n = 180$)			
Heterographic homophones	1,037.42$_a$	83.16	1,010.65 - 1,064.19
Homographic homophones	1,040.32$_a$	96.28	1,013.55 - 1,067.08
Control Words	1,083.03$_a$	130.10	1,056.27 - 1,109.00

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

5.3.   Covariate Analyses

Because acoustic duration and semantic representation frequency estimates met the specified criteria, they were used in the ANCOVA on the item means (Tables 18, 19, & 20). Including these covariates yielded only one difference: significantly faster auditory lexical decision latencies for heterographic homophones over control words. Thus, with the covariates, the auditory lexical decision findings by items more closely paralleled those by participants. Appendix I illustrates details of the ANCOVA analyses. Figures 3 and 4 illustrate the similarities between item lexical decision latencies with and without covariate adjustments.

Table 18. Correlations (r_s) between Item Characteristics and Lexical Decision Latencies

Measure	1	2	3	4
1. Lexical decision latencies	--			
2. Acoustic duration	0.14**	--		
3. Semantic representation frequency estimate	-0.30**	-0.13*	--	
4. Number of letters	0.09	0.27**	-0.29**	--

Note. Spearman's rho correlations were used because lexical decision latencies did not meet the hypothesis of normality ($W(360) = 0.97$, $p < 0.01$). ** $p < 0.01$, * $p < 0.05$

Table 19. Correlations (r_s) between Item Characteristics and Visual Lexical Decision Latencies

Measure	1	2	3	4
1. Lexical decision latencies	--			
2. Acoustic duration	0.07	--		
3. Semantic representation frequency estimate	-0.69**	-0.13	--	
4. Number of letters	0.15*	0.27**	-0.27**	--

Note. Spearman's rho correlations were used. ** $p < 0.01$, * $p < 0.05$

Table 20. Correlations (r_s) between Item Characteristics and Auditory Lexical Decision Latencies

Measure	1	2	3	4
1. Lexical decision latencies	--			
2. Acoustic duration	0.46**	--		
3. Semantic representation frequency estimate	-0.35**	-0.13	--	
4. Number of letters	0.16*	0.28**	-0.30**	--

Note. Spearman's rho correlations were used. ** $p < 0.01$, * $p < 0.05$
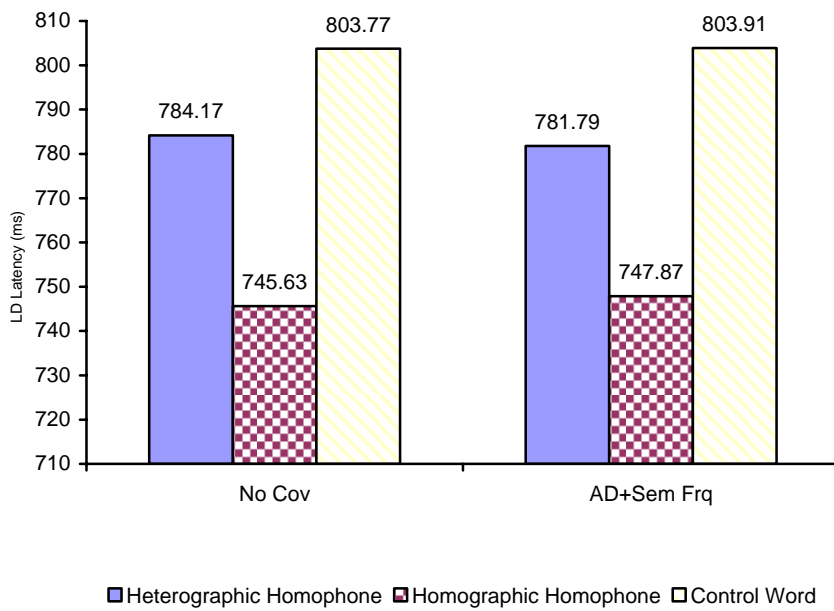
Figure 3. Mean visual lexical decision latencies by word type, with and without covariates (AD = Acoustic Duration; SemFrq = Semantic Representation Frequency Estimate).
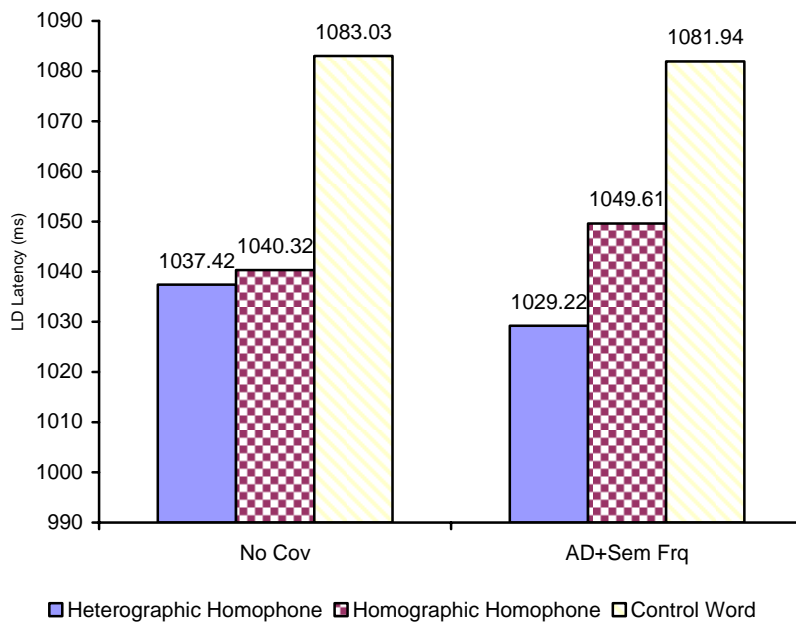
Figure 4. Mean auditory lexical decision latencies by word type, with and without covariates (AD = Acoustic Duration; SemFrq = Semantic Representation Frequency Estimate).

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5.4.   Additional Analyses

Because of the unanticipated interaction between modality and word type, two other

factors were examined for their potential impact on the results. First, data were analyzed with

item accuracy outliers excluded. Item accuracy outliers were defined as those with accuracy 2

*SD*s below the mean accuracy for words by condition. In the visual condition, 13 stimulus words

(7.22%) were classified as item accuracy outliers and in the auditory condition, 11 stimulus

words (6.11%) were classified as item accuracy outliers. See Table 21 for the item accuracy

outliers disaggregated by word type and modality. Excluding item accuracy outliers did not

change the results (see Appendix J).

Table 21. Item Accuracy Outliers by Modality and Word Type with Accuracy and *SD*s below Mean

Visual Lexical Decision			Auditory Lexical Decision		
Stimulus	Accuracy	*SDs* Below *Mn*	Stimulus	Accuracy	*SDs* Below *Mn*
Heterographic homophones					
Yon	11%	-4.00			
Flue	26%	-3.22			
Firs	34%	-2.81			
Mote	39%	-2.55			
Lute	47%	-2.12			
Homographic homophones					
			Bisque	45%	-2.38
			Lore	47%	-2.26
Control Words					
Doffed	18%	-3.64	Doffed	5%	-4.72
Swum	24%	-3.33	Hone	21%	-3.78
Domed	26%	-3.22	Swum	24%	-3.61
Flub	32%	-2.91	Flub	32%	-3.14
Skeet	32%	-2.91	Fames	34%	-3.02
Chafe	34%	-2.80	Slots	37%	-2.85
Bouts	37%	-2.65	Dens	42%	-2.56
Hone	47%	-2.13	Skeet	47%	-2.26
			Bouts	50%	-2.09

Note. Shaded items are item accuracy outliers in both modalities.

Second, results were examined with morphologically different heterographic

homophones excluded (i.e., *bard/barred*, *bruise/brews*, *gaze/gays*, *hoard/horde/whored*,

clod/clawed, *nose/knows/noes*, *ode/owed*, *prince/prints*, *tide/tied*, and *wade/weighed*). Excluding

morphologically different homophones did not change the results. See Appendix K for a complete summary of these results.

6.   Discussion

In this study lexical decision latencies were compared for heterographic homophones, homographic homophones, and control words in the visual and auditory modalities. As hypothesized, lexical decision latencies differed significantly as a function of word type, but the pattern of differences was not the same in the two modalities. In the visual modality, there was a significant advantage for homographic homophones over both heterographic homophones and control words, which did not differ. In the auditory modality, by contrast, there was a significant advantage for both heterographic homophones and homographic homophones over control words.

As noted in the Introduction, most research in the visual modality has shown that inconsistency between phonology-to-orthography inconsistency slows response latencies (i.e., there is a heterographic homophone disadvantage). Contrary to the past findings indicating a heterographic homophone disadvantage relative to control words (e.g., Holden, 2002; Pexman & Lupker, 1999), the present results showed no evidence of a disadvantage for heterographic homophones relative to control words. With respect to homographic homophones, past findings are more difficult to interpret due to poor definition of word stimuli in this category. The present study showed an advantage for homographic homophones which is consistent with findings from Pexman and colleagues (2004), but not with findings from Rodd and colleagues (2002).

In the auditory modality, evidence at the whole-word grain-size is available only for homographic homophones, which Rodd and colleagues (2002) showed were processed more slowly than control words. Results of the present study contradicted Rodd and colleagues (2002) as homographic homophones showed a significant advantage relative to control words. No previous study has examined heterographic homophones in the auditory modality; this study showed a heterographic homophone advantage relative to control words. In short, effects of

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inconsistency were neither additive nor identical across the two modalities, contrary to what might have been predicted based on the existing literature.

6.1.   Orthographic, Phonologic, and Semantic Influences on Visual and Auditory Lexical Decision

Based on the present visual lexical decision latency results, global resonance among orthographic, phonologic, and semantic information coheres faster for homographic homophones than for heterographic homophones or control words. This suggests that the local resonance between orthographic and semantic information is a strong facilitator of the speed with which the global resonance will cohere. Both homographic homophones and heterographic homophones had more than one unrelated semantic representation feeding activation back to phonology and orthography; however, only homographic homophones had significantly faster lexical decision latencies compared with control words and heterographic homophones. For heterographic homophones, more than one unrelated semantic representation may have been activated by phonologic information; however, because there was no advantage for heterographic homophones over control words it appears that only one semantic representation cohered with the presented orthographic representation. Thus, more than one unrelated semantic representation that feeds activation back to a single orthographic representation appears to cohere a strong local resonance between orthographic and semantic information that can speed global resonance allowing a rapid response.

The auditory lexical decision latency results, on the other hand, suggest that global resonance among orthographic, phonologic, and semantic information coheres faster for both heterographic homophones and homographic homophones than for control words. Both heterographic homophones and homographic homophones had more than one unrelated semantic representation feeding information back to one phonologic representation and both had faster

auditory lexical decision latencies than control words. This suggests that increased semantic activation resulting from the local resonance between phonology and semantics is a strong facilitator of the speed with which global resonance will cohere in the auditory modality.

As noted in the Introduction, most models of word recognition explicitly address only one modality, but it appears that most models, whether parallel, distributed, serial, or localist, could be modified to reflect the different patterns of visual and auditory lexical decision latencies observed in the present study. One way to accomplish this in a fully interactive model would be to allow input modality to influence the weights of local connections between orthographic, phonologic, and semantic information. The next section illustrates how one such model, the Harm and Seidenberg (2004) Cooperative Division of Labor Model of Word Recognition, could be modified to accommodate the results of this study.

6.2. Modifying the Cooperative Division of Labor Model of Word Recognition

The Cooperative Division of Labor Model of Word Recognition is a well-specified and computationally realized model that focuses on the acquisition of skilled reading, i.e., orthographic processing that leads to semantic access (see Figure 5; Harm & Seidenberg, 2004). This model was trained initially to compute semantic information from phonologic inputs, and then to process orthographic inputs. The model uses distributed representations and allows presented stimuli to activate orthographic, phonologic, and semantic information in parallel via recurrent networks using backpropagation of error through time with attractor dynamics. Attractor basins cohere activated nodes between information sources into a response (Harm & Seidenberg, 2004). In addition to the attractors, there are clean-up units and hidden units: clean-up units are used to repair noisy, partial, or degraded patterns to allow coherence within an information source and hidden units are placed between information sources to help map

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information from one information source to another. Changes in connection strength are believed to reflect reading acquisition (e.g., Frost, 1998; Harm & Seidenberg, 2004; Van Orden, Bosman et al., 1997) and the connection weights are equal between orthographic, phonologic, and semantic information (see Figure 5). Of interest in the present context, the model allows a direct route from orthographic input to semantic output without accessing phonologic information, which the investigators found to be helpful when introducing subordinate members of heterographic homophone sets to the model. This increased both the speed and accuracy of processing subordinate members of heterographic homophone sets. Even then, the local connections between orthographic and semantic information were supplemental to the interactions to orthographic, phonologic, and semantic information.

The Cooperative Division of Labor Model of Word Recognition (Harm and Seidenberg, 2004) was not designed to account for visual or auditory lexical decision, but with a few modifications the model can account for the present results. The first modification would allow connection strengths to vary in the visual and auditory modality. Another modification would facilitate the realization of the implementation by including a contact point to identify whether the information is computed as input or output phonologic information (see Figures 6 and 7). In a modified account of visual lexical decision, the weights are the same on the connections between orthography and output phonology and between orthography and semantics (see Figure 6). Such a model would predict the homographic homophone advantage in the visual modality because the single orthographic input is strongly associated its phonologic representation and strongly associated with its multiple unrelated semantic representations. The output phonologic representation enhances these associations by also being strongly associated with the multiple unrelated semantic representations. These strong associations with semantics yield faster visual

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lexical decision latencies to homographic homophones than to control words or heterographic homophones. A heterographic homophone does not receive the same benefit from the strong association between its single phonologic representation and multiple semantic representations, as suggested by the lack of a heterographic homophone advantage compared with control words. The difference arises from the number of semantic representations associated with the orthographic input, i.e., heterographic homophones have just one semantic representation for each orthographic representation and homographic homophones have multiple unrelated semantic representations for each orthographic representations. For a heterographic homophone, multiple unrelated semantic representations associated with the phonologic representation of a heterographic homophone do not remain activated because the orthographic input only activates one of these semantic representations, which depletes any activation for the other semantic representations. Accordingly, when orthographic input is used to focus activation, as in visual lexical decision, heterographic homophones are processed similarly to control words.

In a modified account of auditory lexical decision, by contrast, the strongest weights are on the connections between input phonology and semantics followed by the connections between input phonology and orthography, and finally by the connections between orthography and semantics (see Figure 7). When one phonologic input activates multiple unrelated semantic representations and the task is lexical decision, there is rapid coherence between the phonologic input and semantic nodes. This reinforces the other local relationships and focuses them to cohere into global resonance. This model would predict that heterographic homophones and homographic homophones would have faster auditory lexical decision latencies than control words. Thus, in both modalities, if the input representation, orthographic or phonologic, is associated with multiple semantic representations, then global resonance among orthographic,

phonologic, and semantic representations will cohere quickly promoting faster lexical decision latencies.
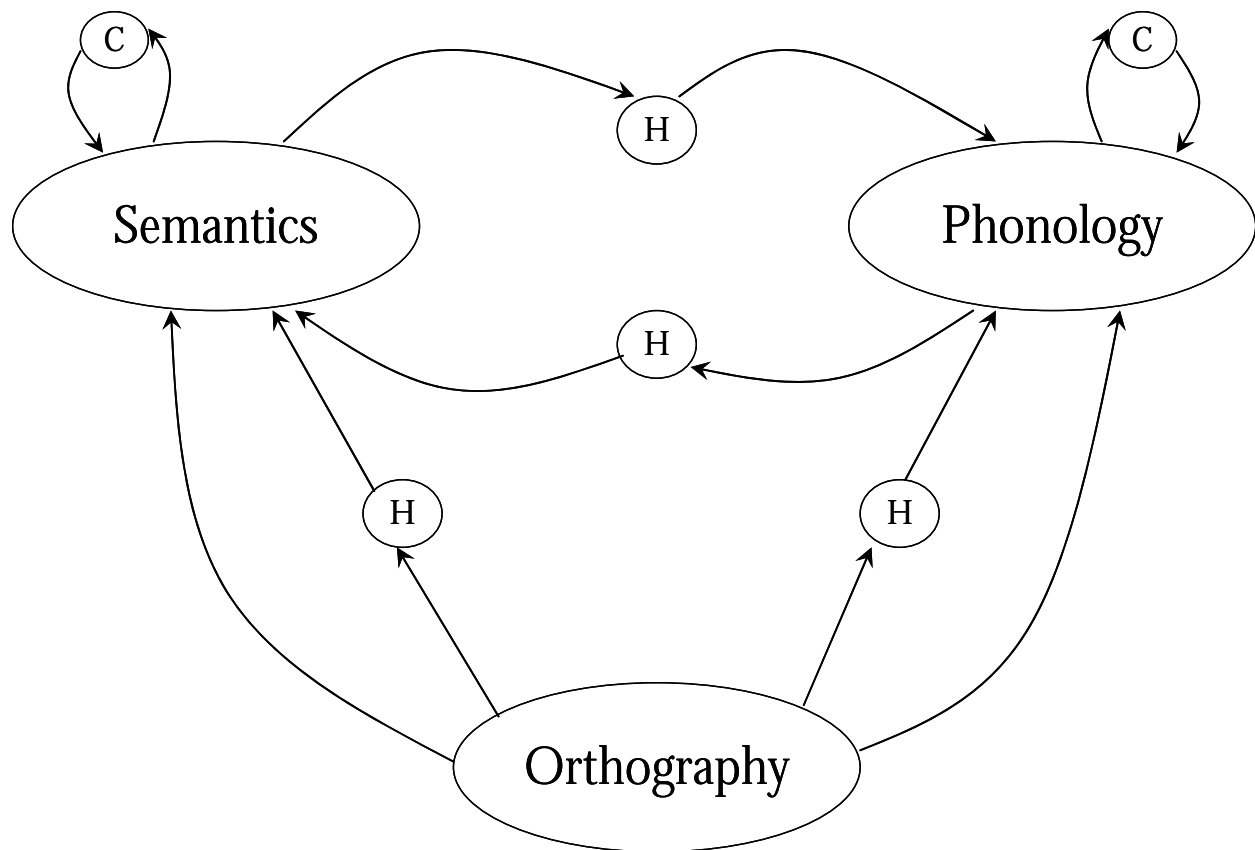
Figure 5. Figure of model from Harm and Seidenberg (2004). The authors eventually added feedback from semantics to orthography to allow "spelling verification".

C = Clean-up Units; H = Hidden Units
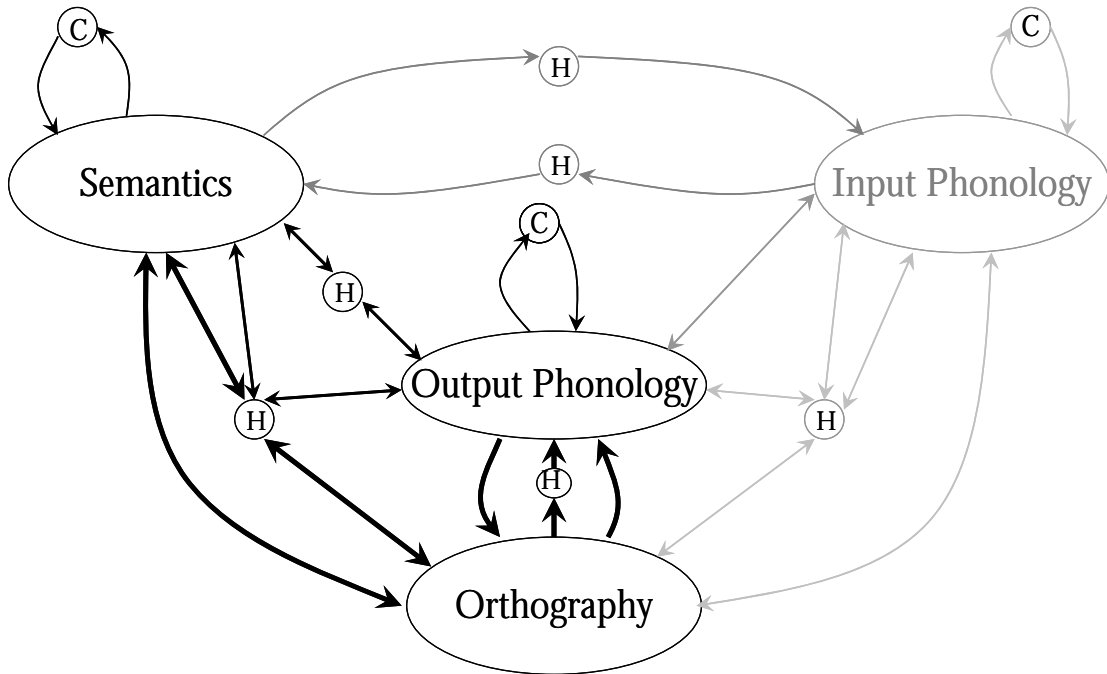
Figure 6. Connection strengths for visual word recognition in the extended Cooperative Division of Labor Model.

Connection strength is illustrated by line thickness and color. Information sources and lines connected with input phonology are in gray because this information does not interact unless there is a spoken presentation. C = Clean-up units; H = Hidden Units. Adapted from Harm and Seidenberg (2004).
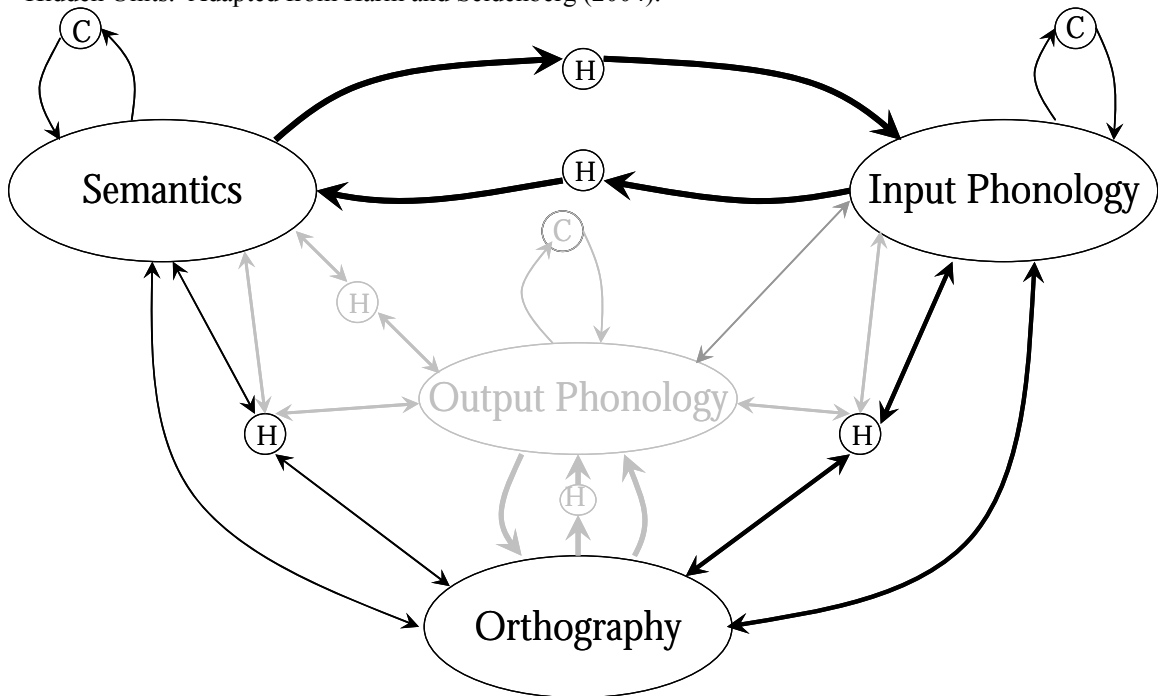
Figure 7. Connection strengths for spoken word recognition in the extended Cooperative Division of Labor Model.

Connection Strength is illustrated by line thickness and color. Output phonology and its connections are in gray because unless generation of phonologic information is necessary, output phonology is not in use. C = Clean-up units; H = Hidden Units. Adapted from Harm and Seidenberg (2004).

These modifications to the Cooperative Division of Labor Model (Harm & Seidenberg, 2004) should allow it to account for the present results in both the visual and auditory modalities. Of course, a computational instantiation of the model would be necessary to evaluate its adequacy in predicting behavioral results (Harm & Seidenberg, 2004).

6.3. Limitations

Limitations of the present study include undetected variation in participants and stimuli. With respect to participants, reading skill and vocabulary were not measured directly, although past research has shown different patterns of responses for participants at different reading and vocabulary levels (e.g., Bell & Perfetti, 1994; Folk, 1999; Folk & Morris, 1995; Unsworth & Pexman, 2003; Starr & Fleming, 2001). The absence of a heterographic homophone disadvantage relative to control words during visual lexical decision might suggest that the participants in the present study were more skilled with reading than participants in other studies (e.g., Bell & Perfetti, 1994; Unsworth & Pexman, 2003). For example, Unsworth and Pexman (2003) found that high-skilled and low-skilled readers exhibited a heterographic homophone disadvantage for visual lexical decision latencies, but high-skilled readers did not exhibit the same disadvantage for response accuracy unlike the low-skilled readers. By contrast, the present study did not find evidence of a heterographic homophone disadvantage for visual lexical decision latencies or for response accuracy compared with control words. An overt measure of reading skill was not used in the present study because reading skill was not a variable of interest. In fact, many lexical decision studies indirectly measure reading skill in the manner of the present study by excluding participants according to some response accuracy level. Differences in reading skill could contribute to the different findings across studies: Studies focusing on the visual modality that use highly skilled readers may not find effects that arise

from inconsistent orthographic information because their experience with computing meaning from orthographic information might diminish the need for phonologic information to guide meaning access. Conversely, readers less skilled with orthographic information might rely more heavily on phonologic than orthographic information to guide meaning access.

Similarly, without a direct measure of the participants' vocabulary knowledge, it is impossible to know whether their vocabularies included at least two unrelated semantic representations for the homographic homophones and at least two orthographic representations with unrelated semantic representations for the heterographic homophones. The main control placed on participant knowledge was the exclusion of inaccurate responses. An indirect control comes from the validity study for the semantic representation frequency estimates using the homographic homophones (see Appendix F). In this study, 22 native English-speaking participants from the University of Pittsburgh rated the frequency of occurrence for at least two semantic representations of homographic homophones and their ratings of perceived semantic representation frequency were within 2 *SD*s of the Internet-based semantic representation frequency estimates. Direct evidence that the participants in the visual and auditory condition were similar with respect to reading skill and vocabulary knowledge would further strengthen the results of this study.

Additional possible limitations center on the stimulus items, the use of Internet-based semantic representation frequency estimates and list context effects. With respect to stimulus items, it is possible that uncontrolled systematic differences among word types could have contributed to the results. For example, orthographic and phonologic neighborhood density have been argued to influence word recognition latencies, although recent investigations have shown that orthographic neighborhood size accounts for negligible amounts of variability in visual and

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auditory lexical decision (e.g., Balota et al., 2004; Ziegler, Muneaux, & Grainger, 2003). These factors could not be controlled while maintaining the other necessary stimulus features for this investigation, but their potential influence cannot be discounted.

Internet-based estimates were used in an effort to equate the word types for semantic representation frequency because there were problems with the use of word association norms to measure semantic representation frequency for homographic homophones (de Groot, 1989; Gilhooly & Logie, 1980; Griffin, 1999). In past studies, researchers (e.g., Pexman & Lupker, 1999; Rodd et al., 2002) used objective frequency counts to match frequencies between homographic homophones and control words without accounting for the potential difference between the semantic representation frequency estimates for homographic homophones and control words.

Because semantic dominance was based on the semantic representation frequency estimates, there may have been a difference between participant perceived dominance and actual dominance, which could have led to a reduced chance of finding the homographic homophone and heterographic homophone disadvantages. The correlation between Internet-based semantic dominance scores and participant-based semantic dominance estimates was $r = 0.71$ ($p < 0.01$) for homographic homophones, which is significant and strong but only accounts for 49.70% of the variance. Although the mean semantic dominance scores did not differ significantly for heterographic homophones and homographic homophones, 20% (12) of the heterographic homophones have semantic dominance scores within 10% of each other versus 36.67% (22) of the homographic homophones. A greater number of homographic homophones that are closely balanced should have enhanced the chance of finding either a homographic homophone advantage or disadvantage for visual and auditory lexical decision latencies by allowing each

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semantic representation equal opportunity to influence responses (Folk & Morris, 1995). A brief analysis of the stimulus words by semantic dominance subtype within each modality did not reveal significant differences (Fs < 1). However, power was between 0.38 and 0.35 for this variable in the visual and auditory modalities for homographic homophones. Although it would be ideal to control this factor in the future, doing so would be impossible while maintaining the other controls.

Stimulus words can yield list context effects, which are likely associated with loading the lists with items that have extreme values along the targeted dimensions, which becomes implicitly or explicitly apparent to the participants yielding strategic responses (Balota et al., 2004). For example, visual lexical decision latencies to words presented with pseudohomophonic nonwords are longer than those to words presented with pronounceable nonwords (e.g., Pexman et al., 2001). This effect is argued to suggest that pseudohomophonic nonwords attune participants to the orthographic information of the stimulus. In the present study several participants mentioned that there was something different about the orthographic representations of the stimulus words. Participants could have been influenced by the preponderance of semantically ambiguous words because two-thirds of the words were heterographic homophones and homographic homophones. This would provide a fast and accurate way to classify these word types, thus yielding faster responses to homophones than control words in both visual and auditory lexical decision. However, this possibility is mitigated by the different responses to homographic and heterographic homophones.

6.4.   Directions for Future Research

The present study has several important implications for future research. Researchers need to be careful when selecting and classifying all stimulus words. Removing the cross-

classification of words within each word type presented a different picture for the present study: there was not a heterographic homophone disadvantage relative to control words and there was a homographic homophone advantage. In fact, there was an advantage for heterographic homophones over control words in the auditory modality. The modality difference is important to note because researchers often conduct experiments on language-based effects in the visual modality, assuming that results will generalize to the auditory modality (Frost, 1998). The present study suggests the need for caution in such generalization.

The present results also suggest that reading skill and vocabulary knowledge should be measured directly, perhaps by a recognition-based vocabulary quiz for the representations of heterographic and homographic homophones. In addition, differences in frequency of word occurrence in visual as compared with spoken language may be an important variable. For example, homographic homophones *bisque* and *lore* were item accuracy outliers in the auditory condition but not in the visual condition. This suggests participants may have read these two words more frequently than they heard them. Conversely, five heterographic homophones were item accuracy outliers in the visual condition, *yon*, *flue*, *firs*, *mote*, and *lute*, but none of these were item accuracy outliers in auditory lexical decision. For such words, their frequency within each modality may influence their speed of coherence.

Furthermore, it would be very interesting to extend stimulus word sets to include homographic heterophones (e.g., *bow* → bo͞u and ba͞u) to better understand the role of phonologic inconsistency and clarify whether activation is excitatory or inhibitory among the phonologic information nodes and the role of the connection between orthographic information and semantic information. Finally, it is unknown whether these results would generalize to other language processing tasks. For example, patterns of performance have been reported to differ in

visual lexical decision vs single-word oral reading as well as in auditory lexical decision vs oral

shadowing tasks (e.g., Balota et al., 2004; Ziegler et al., 2003). Information about the influence

of orthographic, phonologic, and semantic information sources across all language-based tasks is

a prerequisite to fully specified models of language processing.

APPENDIX A

Models of Word Recognition

Models of Word Recognition

Several models of word recognition are presented in this appendix and described using

the following characteristics. The label is first, followed by the description of the information in

each row:

1.   Primary concern(s): What is/are the primary effects that the model was designed to
      explain?

2.   Modality: Which modality was the model designed to account for?

3.   Basic Format: Connectionist vs. Dynamical vs. Dual-Route. A model can take more than
      one approach.

4.   Computational: *Has the model been implemented computationally?*

5.   Information Processing: Does the model assume information processing occurs in serial,
      in parallel, or in both ways?

6.   Information Sources: Orthography, phonology, and semantics. Which information
      source(s) are implemented and/or hypothesized to operate in the model?

7.   Type of Representations: What type(s) of representations does the model use? i.e.,
      Distributed representations include a set of units and each unit participates in the
      representation of many words. Localist representations use individual units to represent
      the orthography, phonology, and semantics of a word or the word's lexical entry.

8.   Routes: How many are there? Describe.

9.   Interactivity: Does the model assume interactivity?

10.   Homogeneous or Heterogeneous: Homogeneous means all computations involve the
      same kinds of structures. Heterogeneous means computations involve different structures.

11.   Hidden Units: Does the model use hidden units? Describe.

12.   Connection weights: Describe any connection weights.

13.   Connection Strength(s) and Mapping Ease: Do the connection strengths and/or ease of
      mapping(s) between information sources vary? Describe.

14.   Attractors/Attractor basins: Does the model use attractors or attractor basins?

15.   Learning: Description of learning if it exists.

16. Developmental Explanation: Describe the account for the development trajectory of learning.

17. Design Constraints: Are there any constraints on the system? How do these occur?

18. Model Limitations: What limits the model from changing?

19. Related Model(s): List a few related models if any exist.

Connectionist Networks: General Principles (Rueckl, 2002)

Design	Characteristics
Primary concern(s):	Overview of dynamical systems approach to visual word recognition
Modality:	Discussed in terms of VWR, but theoretically could account for SWR
Basic Format:	Connectionist and Dynamical
Computational:	Some
Information Processing:	Parallel
Information Sources:	Orthography, phonology, & semantics
Type(s) of Representations:	Distributed but can be localist at smallest grain-size of theoretical importance
Routes:	N/A
Interactivity:	Most exhibit some amount of interactivity
Homogeneous or Heterogeneous:	Primarily homogeneous
Hidden Units:	Model dependent
Connection Weights:	• Coupling parameters control the interactions among nodes • These are determined by learning process tuning the network to environment and task demands • Weights contain the internal constraints and act to ensure that the states of a network's components are mutually consistent
Connection Strength and Mapping Ease:	Network dependent
Attractors/Attractor Basins:	• Self-organizing attractor dynamics • Over time a model's pattern of activation moves toward a stable state • Upon reaching attractor state the network remains there until input changes (i.e., perturbation) • State space includes fixed points of attractors and repellers • Positions of attractors in state space are organized to reflect similarities in orthography, phonology, and semantics • When properly trained, each word has a unique attractor
Learning Occurs:	Learning algorithm is used to adjust connection strengths such that activation flow is tailored to structure and task demands of environment
Developmental Explanation	Model dependent
Design Constraints:	• State of a dynamical system characterized by one or more state parameters varying across model • <u>Self-causal</u>: Changes in system state are a

Design	Characteristics
	consequence of state dependent processes
	• Control parameters (e.g., weights & external input) determine the structure of the flow field
	• External constraints on the dynamics of word identification reflect optical push that seeing orthography exerts on lexical system
	• Self-organizing on 2 time scales: faster time scale is equal to reading rate and slower time scale is the connectivity pattern which adjusts weights to tune network to structure of environment and task demands
	• Parametric control includes potentially many options to accommodate strategy effects
Model Limitations:	N/A
Related Models:	• Harm and Seidenberg (2004) • Plaut et al. (1996) • Resonance model by Van Orden and colleagues • Connectionist Dual-Process Model (e.g., Zorzi, 2000)

Computing Meanings of Words in Reading: Cooperative Division of Labor between

Visual and Phonological Processes (Harm & Seidenberg, 2004)

Design	Characteristics
Primary concern(s):	• Model of meaning computation based on principles explored in previous work and allowing both pathways to activate semantics (Primary) • Feasibility of orthography to semantics pathway • Developmental trajectory from language acquisition to skilled reading • Heterographic homophone and pseudohomophone processing • Effect(s) of masking on lexical processing
Modality:	Designed to account for VWR, but theoretically could account for SWR
Basic Format:	Connectionist and Dynamical
Computational:	Yes – Modified backpropagation
Information Processing:	Parallel
Information Sources:	Orthography, phonology, & semantics
Type(s) of Representations:	Distributed
Routes:	N/A
Interactivity:	• Interactive • Feedback is overtly represented between phonology and semantics • Feedback is overtly represented between orthography and semantics in the last adaptation of the model
Homogeneous or Heterogeneous:	Homogeneous
Hidden Units:	• Yes • Mediate computations • Assist with encoding complex relations between codes • Individual hidden units are *not* dedicated to individual words
Connection Weights:	• Weights on connections between units are used to process all words • *Cooperative division of labor:* contribution of one set of weights to output depends on contribution of other set of weights • Adjusted by backpropagation of error through the network and moving each weight in a direction that minimizes the error • Regularities are encoded in the weights
Connection Strength and Mapping Ease:	• Orthography → Phonology & Orthography → Semantics connections differ in degree vs. kind

Design	Characteristics
	• System learns the regularities from the training corpus and encodes as weights • Orthography → phonology are correlated with each other • Phonology → Semantics is known • Orthography → Semantics is difficult to learn *but* faster to compute
Attractors/Attractor Basins:	• Add a time-varying component to processing • Network can change state in response to own state & external input
Learning Occurs:	• Variant of *backpropagation* for training attractor networks to settle into patterns over time • A letter pattern is presented to the model and it computes semantic output which is compared to correct target • Discrepancy used to make small adjustments to weights • Across experiences, weights gradually assume values yielding accurate performance
Developmental Explanation	• Learning to read is central to the model • Approximates some aspects of children's knowledge • Models learning phonology → semantics before adding orthography • Does not account for explicit learning which occurs in classrooms
Design Constraints:	• Minimal assumptions about nature of orthographic, phonologic, and semantic codes, but incorporates strong assumptions about the relationships among these • Phonology develops as an underlying representation mediating between production and comprehension of spoken language • Pretrained component on relationships between phonologic and semantic patterns for words was in place when orthographic patterns were introduced • Semantic representations were composed of meanings with elements recurring in many words and meanings with different representations • Capacity to encode letter strings • Assumes that the readers should compute meanings quickly and accurately which demands maximum activation from all available resources; network was penalized for incorrect *or* slow responses and error was injected early to encourage quick ramp up of activity • Orthography → phonology → semantics peaks and increased accuracy of intact model is due to additional

Design	Characteristics
	learning in orthography → semantics • System responds to task assigned and division of labor shifts as skill acquired with orthography → semantics becoming more efficient
Model Limitations:	• Phonological representations do not capture all aspects of phonological knowledge • Has not attempted to simulate course of phonological acquisition • Does not account for visual or auditory lexical decision
Related Models:	• Plaut et al. (1996) • Resonance model by Van Orden and colleagues

Dual-Route Cascaded Model of Visual Word Recognition and Reading Aloud (DRC;

Coltheart et al., 2001)

Design	Characteristics
Primary concern(s):	• Computational realization of the dual-route theory of reading • Introduce cascaded processing into the dual-route view
Modality:	VWR
Basic Format:	Dual-route model with cascaded processing
Computational:	Yes
Information Processing:	• Predominantly serial with position-specific coding at the feature layer, letter layer, and phoneme layer • Parallel processing at the letter unit level and phoneme level
Information Sources:	Orthography, phonology, & semantics[9]
Type(s) of Representations:	• Localist • Units represent the smallest individual symbolic parts of the model
Routes:	• Lexical nonsemantic route • Grapheme-to-Phoneme Conversion Route • Lexical semantic route (not computationally implemented at this time)
Interactivity:	• Units at the same level may interact via lateral inhibition • Adjacent layers of the model communicate fully in both excitatory and inhibitory ways • *Exceptions:* (1) Communication between the orthographic lexicon units and phonologic lexicon units are only excitatory and only one-to-one, except in relation to heterographic homophones and homographic heterophones; (2) Communication between feature and letter layers is in one direction only (features to items) as in Interactive Activation Model • Although the nonlexical route is not interactive in the current instantiation, this route may theoretically be bidirectional and was examined as part of spelling
Homogeneous or Heterogeneous:	• Heterogeneous • Each route is composed of a number of interacting layers that contain units which represent the smallest individual symbolic parts of the model

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[9] Although semantics is theoretically described, it is not implemented in the computational model.

Design	Characteristics
Hidden Units:	None mentioned
Connection Weights:	• Constant weights associated with the communications between two units • Remain same for all connected units for any two communications between units in two adjacent layers
Connection Strength and Mapping Ease:	• Hardwired to be sensitive to computationally generated GPC rules • Hardwired to be frequency-sensitive • Hardwired with phonotactic rules and morphophonemic rules
Attractors/Attractor Basins:	N/A
Learning Occurs:	Hardwired by the authors using past research
Developmental Explanation	Does not overtly account for reading acquisition, but claims that learning to read can be understood in the context of the model via rule learning.
Design Constraints:	• Operates with words up to 9 letters long • Added a blank-letter detector to each set of 26 letter detectors that is activated when there is no letter in that particular position in the letter string • Feature, letter, and phoneme layers have position-specific coding and different subsets of units for each position in the input or output string • Heterographic homophones have separate units in the orthographic lexicon but a common unit in the phonologic lexicon • Homographic heterophones have a single unit in the orthographic lexicon but separate units in the phonologic lexicon for each pronunciation • *Lexical Nonsemantic Route:* Generates pronunciation of a word via sequential processes; units in the orthographic lexicon are frequency sensitive • *GPC Route:* Uses GPC rules selected on statistical grounds and context sensitive grounds to convert a letter string into a phoneme string; serial processing from left-to-right using rules • *Lexical Semantic Route:* to be implemented later • Weak phonology theory for all tasks • Claims to account for spelling-to-dictation of words because of feedback from the phoneme level to the letter level in the lexical route, but admits must adapt to allow the model to spell regular words, irregular words, and nonwords

Design	Characteristics
	• Extensions made for spelling-to-dictation are argued to allow the model to account for auditory lexical decision results • Pathway that readers use to recognize words may change to accommodate task demands • Reliance on assembled phonology may be reduced or eliminated when the stimulus set includes pseudohomophone foils because readers shift processing away from nonlexical assembled phonology and rely on lexical processing because these distinguish them from words • Predicts a null or reduced regularity effect when pseudohomophone foils are included in lexical decision
Model Limitations:	• Predicts a frequency by regularity interaction, not found by Jared (2002) • Restricted to monosyllabic words and acknowledges need for rules for assigning stress and vowel reduction • Does not accurately account for masking research because masking indicates a role for early phonologic influences on processing • Does not consider orthographic body a level of representation and if shown to be then DRC will be refuted • Crude lexical decision process, but the model was not designed to account for lexical decision • Not developed to explain consistency effects, but claims these are part of neighborhood consistency • Accounting for strange words (e.g., *weird*) because does not allow *a priori* subcategories of exception words • No limits because researchers can always propose extra components and pathways to accommodate unexpected main effects (Gibbs & Van Orden, 1998) • Questionable utility for understanding the flexibility of human performance (Gibbs & Van Orden, 1998)
Related Models:	• Interactive-Activation and Competition Model: McClelland & Rumelhart (1981) and Rumelhart & McClelland (1982)

Connectionist Models of Word Reading: PMSP96

(Plaut, McClelland, Seidenberg, & Patterson, 1996)

Design	Characteristics
Primary concern(s):	• Connectionist account of knowledge representation and cognitive processing in quasi-regular domains • Specific context of normal and impaired word reading
Modality:	VWR; theoretically, it could account for SWR
Basic Format:	Connectionist
Computational:	Yes
Information Processing:	Yes
Information Sources:	Orthography, phonology, & semantics[10]
Type(s) of Representations:	• Distributed • Graphotactic and Phonotactic specifications
Routes:	N/A
Interactivity:	• Interactive • Componential attractors • Uses an abstraction of a recurrent implementation
Homogeneous or Heterogeneous:	• Homogeneous
Hidden Units:	• Yes • Networks containing hidden units ca overcome the limitations of having only input and output units • Sensitivity to higher order combinations of input units • Tend to make similar responses to similar inputs and can respond to input pattern with nonstandard phonologic representation, yielding an inconsistency disadvantage
Connection Weights:	Weight changes were modified using the training procedure for frequencies of occurrence of words
Connection Strength and Mapping Ease:	• Mapping between semantics and phonology develops before reading acquisition • Orthography → semantics can be acquired when learning to read, like orthography → phonology • Orthography → phonology is more structured and degree of learning within semantics is likely sensitive to frequency with which words are encountered • Strength of semantic contribution to phonology in reading increases gradually over time and is stronger

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[10] Semantics is always in the theoretical model, but is not implemented in the computational model until Simulation 3.

Design	Characteristics
	for high-frequency words
Attractors/Attractor Basins:	• Componential attractors are developed in learning to map orthography to phonology • Substructure that reflects common sublexical correspondences between orthography and phonology • Applies to most words and nonwords, providing correct pronunciations • Attractors for exception words are less componential
Learning Occurs:	• Backpropagation over time adapted for continuous units • Continuous propagation of error backwards • If targets remain constant over time, output units will attempt to reach their targets quickly and remain there
Developmental Explanation	• Demonstration of development is beyond scope of work • Makes assumptions about the system's inputs and outputs even thought these are learned internal representations • Attempted to make these broadly consistent with relevant developmental and behavioral data
Design Constraints:	• Based on a number of principles of information processing (e.g., GRAIN) • 2 simulations are feedforward which do not account for interactivity and randomness • Phonologic and semantic pathways must work together to support normal skilled reading
Model Limitations:	• Not designed to account for development • Different results from human data in Jared (2002) for Simulations 1 and 4
Related Models:	• Seidenberg & McClelland (1989) • Fully interactive models (e.g., Resonance model by Van Orden and colleagues and Recurrent feedback models)

The TRACE I & II Model of Speech Perception (McClelland, 1991; McClelland &

Elman, 1986a, 1986b)

Design	Characteristics
Primary concern(s):	Apply ideas embodied in interactive activation model of word perception to speech perception
Modality:	SWR
Basic Format:	Connectionist
Computational:	Interactive Activation
Information Processing:	Activates successive units in time, but this spreads activation throughout system
Information Sources:	Phonology (feature level, phoneme level, & word level)
Type(s) of Representations:	• Localist • One independent processing unit devoted to each representational unit in each level • Units are repeated in each time slice
Routes:	N/A
Interactivity:	• Interactive • Perceptual processing of older portions of the input continues even as newer portions being processed • Excitatory activation between levels • Inhibitory activation among nodes within a level • Model can anticipate the word with each time slice of phonetic information
Homogeneous or Heterogeneous:	• Homogeneous whenever possible • Heterogeneous in that units are repeated in each time slice
Hidden Units:	N/A
Connection Weights:	• Not in original versions • Weight modulation by adjacent time slices
Connection Strength and Mapping Ease:	Hard-wired by the authors
Attractors/Attractor Basins:	Network can change state in response to own state & external input
Learning Occurs:	Hard-wired by creators
Developmental Explanation	Not an objective and not accounted for
Design Constraints:	• At the *feature level* there are banks of feature detectors, one for each of several dimensions of speech sounds • At the *phoneme level* there are phoneme detectors • At the *word level* there are detectors for every word • Entire network of units referred to as the *trace* because the pattern of activation remaining from a spoken input is a trace of the analysis of the input at each of the three processing levels

Design	Characteristics
	• Processing elements continue to interact as processing continues • Competition vs. phoneme-to-word inhibition: phoneme units have excitatory connections to all word units with which they are consistent • Word units compete with each other • Items with successive phoneme in sequence dominate others • Without perfect match, a word providing a close fit to phoneme sequence can eventually win over words providing less adequate matches • Weaker activation for large cohort sets
Model Limitations:	• Frequency effects are not addressed • Learning cannot generalize from one part of Trace to another • Insensitive to global parameters such as speaking rate • Fails to account for repetition presentation • Views selection of word candidates as a parallel localist process of competition • Small set size in each level
Related Models:	• Interactive-Activation and Competition Model: McClelland & Rumelhart (1981) and Rumelhart & McClelland (1982)

Resonance Model/Recurrent Feedback Model

(Stone & Van Orden, 1994; Stone et al., 1997; Van Orden, 2002; Van Orden &

Goldinger, 1994; Van Orden, Bosman et al., 1997; Van Orden, Jansen op de Haar, &

Bosman, 1997)

Design	Characteristics
Primary concern(s):	Phonology is fundamental to reading and spelling
Modality:	VWR & some SWR
Basic Format:	Connectionist & Dynamical
Computational:	No
Information Processing:	Parallel
Information Sources:	Orthography, phonology, & semantics
Type(s) of Representations:	• Distributed, subsymbolic • Finest grain-size of orthographic-phonologic-semantic correspondences that correlate with performance
Routes:	N/A
Interactivity:	• Interactive • Recurrent feedback/Resonance • Governed by sigmoid (nonlinear) signal function • Cooperative interactions included • Feedback from phonologic information rapidly organizes perception, mediating local competitions to organize the visual stimulus
Homogeneous or Heterogeneous:	• Homogeneous
Hidden Units:	N/A
Connection Weights:	• Depends on consistency and inconsistency of mappings • Frequency of mappings and words
Connection Strength and Mapping Ease:	• *Phonologic coherence hypothesis:* orthographic-phonologic resonances cohere before orthographic-semantic resonances • Primacy of orthographic-phonologic is guaranteed because statistical and strengthened by frequency • For high frequency or regular words, resonance between letters and phonemes may occur so rapidly that perception appears direct yielding ceiling effects • Phonologic-semantic relationship is stronger than orthographic-semantic relationship because we speak before we read; asymmetry self-perpetuates because reading strengthens phonologic-semantic representations because phonology functions
Attractors/Attractor Basins:	• Well-learned patterns for meaningful words • Develop as a consequence of learning

Design	Characteristics
	• Within the attractor basin, dynamics move encodings toward respective attractor point • Distance traveled in attractor basin between initial encoding and attractor point is positively correlated with response time
Learning Occurs:	• *Covariant learning principle* • System behavior should reflect the cumulative statistical relationships between inputs and outputs • Model uses vectors to limit cross-talk • High frequency words are less influenced by cross talk • The closer the actual output is to the correct output, the faster the model generates a response • Implicit process cleans up cross talk and more cross talk leads to more clean-up time • Inconsistent cross talk increases competition for resonance which increases response latencies
Developmental Explanation	Uses *covariant learning principle*
Design Constraints:	• Units begin mutual activation simultaneously, but cannot support response until achieve resonance • Every node in the orthography, phonology, and semantic group of nodes is bidirectionally connected every node in the other two groups • *Interactivity assumption* leads to prediction that visual and spoken word recognition should be influenced by orthography-to-phonology inconsistency and phonology-to-orthography inconsistency • Nodes are fully interdependent • After initial spread of activation, cooperating-competitive dynamics begin among all subsymbol groups and coherent structures emerge as relatively stable feedback loops • Flexible change in patterns of activation and adaptation to task and context • A naming response is specified when orthographic and phonologic subsymbols cohere in resonance; first, the strongest pronunciation may be activated and if incorrect it will be unstable and weaker pronunciation is activated because more stable • A lexical decision response occurs when the system state for word stimuli can be distinguished from that for nonword stimuli; if no semantic context, orthographic-phoneme connections should cohere first because graphemes and phonemes tightly covary; because nonwords also activate semantic nodes, initial activation is not enough to distinguish words from nonwords; words

Design	Characteristics
	are distinguished as their stable feedback loops build on initial activation and inhibit spurious activation
	• *Mismatch index* is an estimate of overall coherence which is the difference between feedforward activation on orthographic nodes and feedback patterns. Illegal & legal nonwords entail more mismatch than pseudohomophones because they generate less semantic activity
	• In context, orthographic-phonologic covariation still exerts role in perception, but in highly predictive context, semantic resonance may cohere quickly optimizing reading
	• Involves parametric control to accommodate strategy effects
Model Limitations:	• Hidden units will be necessary for this model to operate quickly and allow combination of information
	• Assumption of recurrent feedback does not naturally accommodate the assumption of pathway selection
Related Models:	• Interactive-Activation and Competition Model: McClelland & Rumelhart (1981) and Rumelhart & McClelland (1982)
	• Plaut et al (1996)
	• Harm and Seidenberg (2004)

Connectionist Dual-Process Model

(Zorzi, 2000; Zorzi, Houghton, & Butterworth, 1998)

Design	Characteristics
Primary concern(s):	• Model of reading that maintains the uniform computational PDP style without rigid commitment to single route • Separating different knowledge into different systems yields successful modeling of surface dyslexia
Modality:	VWR
Basic Format:	Connectionist
Computational:	Yes – standard backpropagation learning algorithm
Information Processing:	Parallel
Information Sources:	Orthography & Phonology
Type(s) of Representations:	• Distributed • *Direct pathway*: extracts sublexical spelling-sound relationships • *Mediated pathway*: forming word-specific representations that are distributed via backpropagation training
Routes:	Two: mediated and direct
Interactivity:	• Interactive • Task demands interact with initial network architecture
Homogeneous or Heterogeneous:	Homogeneous
Hidden Units:	• Form intermediate representations in mapping from orthography to phonology • In mediated pathway act to inhibit the wrong phoneme candidates activated by the direct connections and reinforce correct phoneme units
Connection Weights:	Error signals used to change weights on direct and mediated pathways in parallel
Connection Strength and Mapping Ease:	• Self-organization of the system emerges from the interaction of task demands with an initial pattern of connectivity permitting direct and mediated interactions • Consistency yields greater strength/ease of mapping
Attractors/Attractor Basins:	N/A
Learning Occurs:	• Sublexical route learns typical spelling-to-sound correspondences via a 2-layer network • Lexical route converts print to speech via direct activation of the word's phonologic representation learned in a 3-layer network containing orthographic input, hidden units, and phonologic output
Developmental Explanation	N/A
Design Constraints:	• Does not implement an orthographic lexicon: print

Design	Characteristics
	directly activates the word's phonologic representation • Two sources of information feeding output • Backpropagation is used in the mediated pathway but not in the direct pathway
Model Limitations:	• Lacks semantic information • GPC rules in spite of body-rime primacy for English
Related Models:	• Plaut et al (1996) • DRC Coltheart et al. (2001)

Independent Activation Meaning Model
(Dixon & Twilley, 1999a, 1999b; Twilley & Dixon, 2000)

Design	Characteristics
Primary concern(s):	• Lexical ambiguity resolution • Provide a framework for much existing data on ambiguity resolution and incorporate several common approaches to ambiguity resolution as special cases • Influence of context on comprehension in many domains
Modality:	VWR, but theoretically could account for SWR
Basic Format:	Connectionist formulation with some nonlinearity
Computational:	Yes
Information Processing:	Parallel
Information Sources:	• Semantics • Input/perceptual piece which may be orthography or phonology
Type(s) of Representations:	• Distributed • Large sets of microfeatures used for word meanings • One meaning can be written as a vector of activations
Routes:	N/A
Interactivity:	• Independent • Information flows unidirectionally from one process to another • Presumes feedback is slow but access and integration inputs combine to determine activation level for word meanings • Weak influence of implicit feedback loop between the level of word meanings and integration input • Weak potential for interactive feedback among word meanings
Homogeneous or Heterogeneous:	Homogeneous
Hidden Units:	N/A
Connection Weights:	Simple incremental learning algorithms are used to learn connection weights associating a word in context with one meaning
Connection Strength and Mapping Ease:	Appear modulated by meaning frequency
Attractors/Attractor Basins:	N/A
Learning Occurs:	Hard-wired
Developmental Explanation	N/A
Design Constraints:	• Feedback is slow and any influences processing weakly • Input from access processes is determined by perceptual encoding and varies over time

Design	Characteristics
	• Different semantic senses have different but overlapping representations in terms of features and the contexts in which these senses are appropriate overlap with features • Semantic nodes have reading activation levels and receive input from access and integration processes • Semantic nodes for homographic homophones increase activation above resting level when perceiving homographic homophones • Lexical system is embedded in a larger comprehensive system including perceptual processes, working memory, and long-term memory • Construction of working memory representations provides input to lexical system which can influence the activation of subsequent semantic representations as they are encountered and can provide a major contribution to integration input that can be positive or negative • Semantic representation activation is calculated by summing the inputs to each semantic representation and then scaling into range 0-1 • Integration input is determined by prior contexts and is relatively constant throughout course of meaning resolution • Symmetric processes occur as prior context disambiguates semantic representations of homographic homophones enhancing the appropriate and suppressing the inappropriate
Model Limitations:	• Not designed to explain heterographic homophone effects, leaves to other models • Not designed to explain inconsistency effects or most other word recognition effects • Views as piece of larger system
Related Models:	N/A

Merge Model

(Norris et al., 2000a, 2000b)

Design	Characteristics
Primary concern(s):	• Create a model where lexical and prelexical information can jointly determine phoneme identification responses • Model should be fully autonomous
Modality:	SWR
Basic Format:	Feedforward only
Computational:	Simple competition-activation network with same basic dynamics as Shortlist
Information Processing:	Yes
Information Sources:	Phonology
Type(s) of Representations:	Localist
Routes:	N/A
Interactivity:	• States non-interactive, no feedback • Allows bidirectional inhibition
Homogeneous or Heterogeneous:	Heterogeneous
Hidden Units:	N/A
Connection Weights:	N/A
Connection Strength and Mapping Ease:	Hard-wired
Attractors/Attractor Basins:	N/A
Learning Occurs:	Word with largest activation can suppress the activation of competitors
Developmental Explanation	N/A
Design Constraints:	• Prelexical processing provided continuous information in a strictly feedforward manner to lexical level which allows activation of compatible lexical candidates • This information is also available for explicit phonemic decision making which continuously accepts input from lexical level to merge the two sources • Activation from nodes at both phoneme and lexical level is fed to a set of phoneme-decision units that decide which phonemes are actually present in input and are susceptible to facilitatory influences from the lexicon and inhibitory effects • Not necessary to wait for a route to produce a clear answer since output of these is constantly combined • Lexical information cannot influence prelexical processing • Facilitatory connections are unidirectional and

Design	Characteristics
	inhibitory connections are unidirectional
	• Lexical network is created dynamically: word nodes are not permanently connected to decision nodes
Model Limitations:	• Claim phonology-to-orthography inconsistency disadvantage is an effect of type frequency
	• Prelexical phoneme level duplicated at the phoneme decision stage
	• Feedforward models accumulate *ad hoc* explanations each time they confront a new feedback phenomenon
	• Fails with respect to parsimony
	• Cannot account for context-sensitive speech data
	• Unnatural explanation for decisions
Related Models:	Shortlist (Norris, 1994)

Modeling the Effects of Semantic Ambiguity in Word Recognition

(Rodd et al., 2002, 2004)

Design	Characteristics
Primary concern(s):	• Implications of semantic ambiguity for connectionist word recognition models • Illustrate the related semantic representation advantage and the unrelated semantic representation disadvantage
Modality:	VWR
Basic Format:	Connectionist
Computational:	Yes
Information Processing:	Yes
Information Sources:	Orthography & Semantics
Type(s) of Representations:	Distributed semantic representations
Routes:	N/A
Interactivity:	• Feedforward from orthography to semantics • Recurrent connections between semantic representations
Homogeneous or Heterogeneous:	Homogeneous
Hidden Units:	N/A
Connection Weights:	Weights are set by the connection strength between the units
Connection Strength and Mapping Ease:	Connection strengths were learned via an error-correcting learning algorithm
Attractors/Attractor Basins:	• Unrelated semantic representations of homographic homophones correspond to separate attractor basins in different regions of semantic space and process of moving away from blend state makes these words more difficult to recognize • Related semantic representations of polysemous words correspond to the overlapping regions in semantic space which broadens the attractor basin • Related semantic representation benefit should be restricted to lexical decision
Learning Occurs:	• Connection strengths were initially set to 0 • Network presented with a single training pattern • Error-correcting learning algorithm changed connection strengths for feedforward connections from orthographic to semantic units and recurrent connections between semantic units
Developmental Explanation	N/A
Design Constraints:	• No feedback from semantics to orthography • Attractor space

Design	Characteristics
Model Limitations:	• No role for phonologic information • Not designed to account for all types of semantic ambiguity effects (e.g., Heterographic homophones) • Restricted to lexical decision
Related Models:	N/A

APPENDIX B

Word Recognition Models and Influences on Word Recognition

Word Recognition Models and Influences on Word Recognition

Model	VWR Naming					
	Frequency: HF words < LF words latencies	Orthographic length: Long > Short latencies	OP Inconsistency disadvantage for latencies	Pseudohomophone advantage for latencies	Heterographic homophone disadvantage latencies	Homographic homophone advantage latencies
Division of Labor (H&S2004)	+	+	+	+	+[c]	+[c]
DRC (Coltheart et al., 2001)	+	+	+ (neighborhood consistency)	+	-	+
PMSP96	+	+	+	+	+[c]	+
TRACE II	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Resonance Model	+	+	+	+	+[c]	+
Connectionist Dual-Process Model	+	+	+	+	-	+[c]
Independent Activation Meaning Model	+	-[b]	-[b]	-[b]	-[b]	+
Merge	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Rodd et al., 2004	-[b]	-[b]	-[b]	-[b]	- (cannot because separate orthographic representation for each unrelated semantic representation would yield different result)	- (claims should be disadvantage)

Note. OP = orthography-to-phonology; PO = phonology-to-orthography; + = accounts for; - = cannot account for; p-g = phoneme-to-grapheme; r-b = rime-body; b-r = body-rime [a]not designed to account for this modality; [b]model is supplemental to other word recognition models for this effect; [c]Did not mention this result, but theoretically could account for

Model	VWR Lexical Decision						
	Frequency: HF words < LF words latencies	OP Regularity disadvantage: Irregular > Regular latencies	PO Inconsistency disadvantage at p-g for latencies	PO Inconsistency disadvantage at r-b for latencies	Heterographic homophone disadvantage latencies	Homographic homophone advantage latencies	Homographic homophone disadvantage latencies
Division of Labor (H&S2004)	+	+[c]	+[c]	+[c]	+[c]	+[c]	+[c]
DRC (Coltheart et al., 2001)	+	-, Predicts null or reduced when pseudohomophones included	-	-	-	+	-
PMSP96	+	+[c]	+[c]	+[c]	+[c]	+	+[c]
TRACE II	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Resonance Model	+	+	+	+	+[c]	+	+
Connectionist Dual-Process Model	+	-	-	-	+	+	-
Independent Activation Meaning Model	+	-[b]	-[b]	-[b]	-[b]	+	-
Merge	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Rodd et al., 2004	-[b]	-[b]	-[b]	-[b]	- (separate ortho rep per unrelated semantic rep would yield different result)	-	+

Note. OP = orthography-to-phonology; PO = phonology-to-orthography; + = accounts for; - = cannot account for; p-g = phoneme-to-grapheme; r-b = rime-body; b-r = body-rime, [a]not designed to account for this modality; [b]model is supplemental to other word recognition models for this effect; [c]Did not mention this result, but theoretically could account for

Model	VWR Lexical Decision		Auditory Lexical Decision				
	Pseudo-homophone disadvantage: Latencies	Polysemy advantage: Latencies	PO Inconsistency disadvantage at r-b for latencies	Heterographic homophone advantage latencies	Many Phono Neighbors less accurate than few	Homographic homophone advantage latencies	Homographic homophone disadvantage latencies
Division of Labor (H&S2004)	+	+	+[c]	+[c]	+[c]	+[c]	+[c]
DRC (Coltheart et al., 2001)	+	+	-[a]	-[a]	-[a]	-[a]	-[a]
PMSP96	+	+[c]	+[c]	+[c]	+[c]	+[c]	+[c]
TRACE II	-[a]	-[a]	-[a]	-[a]	+[a]	-	-
Resonance Model	+	+	+	+	+[c]	+	+
Connectionist Dual-Process Model	+	-	-	-	-[a]	-[a]	-[a]
Independent Activation Meaning Model	-	+	-[b]	+[c]	-[b]	+[c]	-
Merge	-[a]	-[a]	- (claims a type consistency effect)	-[a]	-[a]	-[a]	-[a]
Rodd et al., 2004	-[b]	+	-[b]	-[c]	-[b]	-	+

Note. OP = orthography-to-phonology; PO = phonology-to-orthography; p-g = phoneme-to-grapheme; r-b = rime-body; b-r = body-rime; + = accounts for; - = cannot account for; [a]not designed to account for this modality; [b]model is supplemental to other word recognition models for this effect; [c]Did not mention this result, but could account for theoretically

APPENDIX C

Background History Form

Participant # _____

BACKGROUND QUESTIONNAIRE

Age_____

Major _____

Circle 1 for each of the following

Highest grade completed: high school diploma/GED

       College year completed: freshman   sophomore   junior   senior   graduate school

Gender: male   female

Race: African-American   Hispanic   Caucasian   Asian   American Indian

       Other:_____

Is your native language English?

      YES   NO

Do you have any physical limitations that may affect your ability to push buttons with either of your hands (e.g., paralyzed or weak hand)?

      YES   NO

Do you have normal or corrected-to-normal vision with or without corrective lenses (20/25)?

      YES   NO

Have you ever taken a course in phonetic transcription or do you know how to phonetically transcribe?

      YES   NO

Have you ever been diagnosed with a learning disability (e.g., dyslexia, reading disability, language learning disability, central auditory processing disorder, etc.) or a neurological impairment (e.g., seizures, epilepsy, ADHD/ADD, traumatic brain injury, etc.)?

      YES   NO

Did you ever receive special education or resource services, tutoring for reading or language difficulties, or speech-language therapy?

      YES   NO

APPENDIX D

Directions for Selecting Words to Obtain Semantic Representation Frequency Estimates

Directions for Choosing Words to Obtain Semantic Representation Frequency Estimates

1. Co-occurrences define an orthographic representation's semantic context, which includes its related semantic representations in Wordsmyth (i.e., the definitions included in a single dictionary entry)

2. Select the co-occurrence words using no more than 10 of the following, selected across the related definitions

    a. The defining characteristics (i.e., single content words in the definitions that characterize the meaning of the word)
    b. Synonyms listed in the dictionary entry
    c. Near synonyms listed in the dictionary entry
    d. Related words listed in the dictionary entry

        i. *NOTE* – sometimes the related definitions refer to different aspects of words so make sure to use at least one word from each 'distinct' definition
        ii. e.g., *yield* contains several related definitions including "to give forth or produce" and "to give up; surrender; relinquish" which are distinct and require different words to capture the majority of its senses
        iii. Co-occurrence words should be chosen that encompass a majority of the related definitions of the words
    e. Feel free to use different morphological inflections of words as co-occurrence (e.g., *warn* and *warning*) because sometimes the word being searched for occurs with both at some point.

3. **Special case – Homographic homophones**

    a. Because homographic homophones have one orthographic representation for one phonologic representation and more than one unrelated semantic representation (as represented by having more than one dictionary entry in Wordsmyth) it is necessary to make sure that the co-occurrence words selected for these stimuli do NOT overlap.
    b. That is, a co-occurrence word for these stimuli must be specific to each unrelated semantic representation. If it *could* overlap with the two of the unrelated semantic representations then it may NOT be included as a co-occurrence word for either unrelated semantic representation.
    c. *Suggestion:* Do the homographic homophones first and then the other words because this will solidify the co-occurrence word criteria.

4. **Examples**

    a. *Control words* – e.g., *beep*

beep
Browse the words alphabetically around "beep"
See entries that contain "beep"

Syllables: beep Parts of speech: noun , intransitive verb , transitive verb ⬆Part of Speech noun ❓ Pronunciation

bip

Definition**1.**a short, usu. high-pitched warning signal.

🔼Part of Speech intransitive verb   Inflected Forms beeped, beeping, beeps   Definition**1.**to emit a short warning signal.   Example The microwave oven will beep when the food is ready.

🔼Part of Speech transitive verb   Definition**1.**to cause to emit a short warning signal.   Example He beeped his car horn at the dog in the road.

For this you might select the co-occurrence words of warning, signal, horn, car, short, warn

b.   *Heterographic homophones* would be the same as control words.

c.   *Homographic homophones* – e.g., *tag*

tag[1]

  Syllables: tag Parts of speech: noun , transitive verb , intransitive verb 🔼Part of Speech noun ❓ Pronunciation taeg

Definition**1.**a piece of cardboard, thin metal, plastic, or other material that identifies, labels, or shows the price of that to which it is attached.   Synonyms tab (1) , label (1) , ticket (3)
Similar Words docket , stub , sticker
Definition**2.**any of various distinctive ends, esp. of something hanging loose, as a shoelace or an animal's tail.
Synonyms trailer (1) , tail (1,2)
Similar Words train , end
Definition**3.**a floppy or ragged tatter or projection.
Synonyms tail (4) , flap (1) , tatter (1)
Similar Words lappet , stub , shred , lap[2]
Definition**4.**a phrase, speech, or the like that serves as an ending or summation.
Synonyms appendix (1) , annex (2)
Similar Words postscript , codicil , summation , rider
Definition**5.**a phrase, nickname, or the like that serves to characterize someone or something.
Synonyms name (2) , nickname (1) , label (2)
Similar Words term , sobriquet , epithet
Related Words name , appendix , appendage , adjunct , appellation , affix

🔼Part of Speech transitive verb   Inflected Forms tagged, tagging, tags   Definition**1.**to attach a tag or tags to, as one or more items for sale.   Synonyms ticket (2) , label (1)   Similar Words tab
Definition**2.**to identify or characterize, esp. with a word or phrase.   Example She tagged him as an egotist.
Synonyms nickname , label (2) , call (10) , term
Crossref. Syn. mark , label
Similar Words dub[1] , designate
Definition**3.**to add or append.
Example The lawyer tagged an extra fee on my bill.
Synonyms tack on {tack (vt 2)} , affix (2) , suffix (2) , append (1) , annex (1)   Crossref. Syn. tack
Similar Words attach
Related Words add , style , mark , stamp , title , call , label , price , ticket

🔼Part of Speech intransitive verb
Definition**1.**(informal) to follow or accompany someone closely (usu. fol. by after or along).
Example Being curious, he tagged along with us.
Synonyms trail (2) , tail (2)
Similar Words follow , pursue , dog (vt)

Derived Forms taglike, adj.

tag^2
Browse the words alphabetically around "tag^2"
See entries that contain "tag^2"
  Syllables: tag Parts of speech: noun , transitive verb

Part of Speech noun   Pronunciation
taeg
   Definition**1.**a children's game in which one player chases the others until he or she touches one of them, who then becomes the pursuer.
Definition**2.**in baseball, an act or instance of tagging.

Part of Speech transitive verb   Inflected Forms tagged, tagging, tags
Definition**1.**to touch (a player) in the game of tag, or in a similar game.
Definition**2.**in baseball, to touch (a runner) with the ball or with the hand or glove holding it.

For tag^1 you might choose the co-occurrence words label, price, cardboard, add, name, speech, sale, sell. For tag^2 you might choose the co-occurrence words game, player, chase, touch.

5. *What I need from you –*
    a. For each related definition of a word, provide me a list of no more than 10 co-occurrence words for focusing a web search.
    b. All of the definitions, synonyms, near synonyms, cross-reference synonyms, and related words are attached.
    c. Just write the words you would select for each item in the space provided.

APPENDIX E

Word Stimuli

Heterographic homophones

General Properties of Heterographic Homophones							Visual		Auditory		
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
/ɑrk/	arc	any curved line; anything shaped like a bow or curve	3,510,000	69.37%	3	454.81	759.77	0.95	931.00	0.97	
	ark	(sometimes cap.) according to the Old Testament, a large boat built by Noah to preserve life during the Flood	1,550,000	30.63%	3						x
/bɑrd/	bard	a poet	261,000	44.54%	4	515.66	980.58	0.84	1,028.33	0.58	
	barred	protected with bars, as a window	325,000	55.46%	6						x
/baɪt/	bight	the loop or slack part of a rope, as opposed to the ends	18,800	0.28%	5	504.76	1,139.90	0.56	961.86	0.92	
	bite	to seize with the teeth	3,140,000	46.60%	4						
	byte	in computers, a basic unit of operation, usu. equal to eight binary digits or bits	3,580,000	53.13%	4						x
/bruz/	brews	to make beer or ale, esp. as an occupation	164,000	51.57%	5	642.32	705.61	1.00	1,034.38	0.95	
	bruise	to wound or damage without causing a break or rupture	154,000	48.43%	6						x
/dir/	dear	regarded fondly; expensive	5,920,000	74.94%	4	477.08	683.39	1.00	857.95	1.00	
	deer	any of a family of large, swift, hoofed mammals, such as the white-tailed deer or the reindeer, the males of which usu. have antlers that grow and are shed yearly	1,980,000	25.06%	4						x
/doʊ/	doe	the female of certain mammals, such as deer and related animals, rabbits and hares, and goats	622,000	37.65%	3	471.99	712.09	0.97	1,000.31	0.95	
	dough	a thick mixture of flour or meal and a liquid such as	1,030,000	62.35%	5						x

| | General Properties of Heterographic Homophones | | | | | | Visual | | Auditory | | |
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
		water or milk that is prepared for baking into bread, cake, or the like									
/ɛrz/	airs	the tasteless, odorless, and colorless mixture of nitrogen, oxygen, and other gases that forms the earth's atmosphere	99,700	19.38%	4	672.78	972.56	0.92	1,176.52	0.89	
	errs	to make a mistake	66,800	12.98%	4						
	heirs	a person who receives or has the right to receive, upon another's death, that person's rank or property	348,000	67.64%	5						x
/fɝz/	firs	any of numerous cone-bearing evergreen trees related to the pines	102,000	30.91%	4	716.89	1,178.62	0.34	1,124.55	0.84	x
	furs	the soft thick hair that covers the bodies of certain animals, such as the mink or fox	220,000	66.67%	4						
	furze	one of a group of low, spiny shrubs of the legume family, bearing yellow flowers; gorse	7,990	2.42%	5						
/flɛr/	flair	an innate ability; knack	596,000	63.88%	5	614.73	717.97	0.97	1,027.37	0.92	
	flare	to blaze or burn brightly, esp. suddenly (often fol. by up)	337,000	36.12%	5						x
/fli/	flea	any of an order of tiny wingless insects that move by jumping, and feed by sucking the blood of warm-blooded animals	642,000	60.45%	4	559.04	715.97	0.92	967.62	0.97	x
	flee	to escape by moving rapidly away; run away	420,000	39.55%	4						
/flu/	flew	a past tense of fly1	1,450,000	50.35%	4	593.99	776.13	0.22	992.29	0.92	

		General Properties of Heterographic Homophones					Visual		Auditory		
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	**Mn LD Lat.**	**Mn Acc.**	**Mn LD Lat.**	**Mn Acc.**	**Visually Presented**
	flu	influenza	1,280,000	44.44%	3						
	flue	a duct, pipe, or other passage through which hot or cold air, smoke, or steam may be evacuated	150,000	5.21%	4						
/forθ/	forth	forward or onward in time or location	7,500,000	44.78%	5	343.27	840.62	0.92	987.94	0.89	x
	fourth	indicating rank or position between third and fifth	9,250,000	55.22%	6						
/geɪz/	gays	a homosexual person, esp. male; of or in a happy, joyous mood; festive; merry	1,660,000	68.43%	4	546.02	827.19	0.86	1,000.92	0.97	x
	gaze	to look intently	766,000	31.57%	4						
/haɪ/	hi	(informal) Greetings!; Hello!	9,900,000	40.98%	2	531.44	650.11	1.00	907.56	0.97	
	hie	to go speedily; hurry	57,400	0.24%	3						
	high	of great vertical extent; elevated; tall	14,200,000	58.78%	4						x
/heɪ/	hay	grass, clover, alfalfa, or the like that is cut, dried, and stored for animal food	3,130,000	29.92%	3	531.03	713.68	0.97	1,075.30	0.97	
	hey	used to draw attention or to show surprise, mild delight, or annoyance	7,330,000	70.08%	3						x
/hir/	hear	to perceive with the ears	9,360,000	36.34%	4	502.78	652.89	1.00	999.52	0.68	x
	here	in, at, or to this specific place or location	16,400,000	63.66%	4						
/houl/	hole	an opening or hollow cavity in something	6,690,000	33.47%	4	474.29	664.05	0.97	1,077.09	0.92	x
	whole	comprising the entire extent or amount	13,300,000	66.53%	5						
/hord/	hoard	a collection or supply of something that is hidden, stored, or guarded, as for use at a later time or to keep	141,000	32.87%	5	495.93	1,069.06	0.49	1,021.57	0.95	

	General Properties of Heterographic Homophones						Visual		Auditory		
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	***Mn* LD Lat.**	***Mn* Acc.**	***Mn* LD Lat.**	***Mn* Acc.**	**Visually Presented**
		it from being stolen; cache									
	horde	a large number, group, or crowd; throng; multitude	282,000	65.74%	5						x
	whored	to engage in prostitution, as the seller or buyer of sexual acts	5,980	1.39%	6						
/jɑn/	yawn	to open the mouth involuntarily while breathing in deeply, usu. as a sign of tiredness, boredom, or the like	175,000	57.19%	4	670.97	940.25	0.11	1,001.09	0.92	
	yon	from this location to another, esp. to a place at a great distance	131,000	42.81%	3						x
/dʒinz/	genes	a section of a chromosome that determines the structure of a single protein or part of one, thereby influencing a particular hereditary characteristic, such as eye color, or a particular biochemical reaction	3,780,000	48.65%	5	659.28	773.71	0.92	973.45	1.00	x
	jeans	(pl.) pants made from a heavy, often blue, twilled cotton cloth	3,990,000	51.35%	5						
/jo͞uk/	yoke	a device used to join together a pair of draft animals, usu. comprising a crossbar with two U-shaped loops, each fitted around the head of an animal	296,000	63.25%	4	464.27	749.91	0.94	939.06	0.89	
	yolk	the yellow nutritive substance in an egg, consisting of protein and fat, that is involved directly in the formation of the embryo	172,000	36.75%	4						x

						Visual		Auditory		
General Properties of Heterographic Homophones										
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	**Mn LD Lat.**	**Mn Acc.**	**Mn LD Lat.**	**Mn Acc.**	**Visually Presented**
/kæʃ/	cache	a hiding place for treasures or supplies, esp. in the ground	3,120,000	25.66%	5	649.00	933.37	0.71	1,046.16	0.84	x
	cash	money in exchangeable form, such as bills, coins, or checks; payment in such form	9,040,000	74.34%	4						
/klɑd/	clawed	to scratch, tear, dig, or pull something with or as if with claws	83,400	63.33%	6	557.44	765.78	1.00	1,265.95	0.57	x
	clod	a lump of earth or clay	48,300	36.67%	4						
/kor/	core	the center part of certain fruits, containing hard material and seeds	7,100,000	62.61%	4	525.30	738.09	0.86	1,002.63	0.97	
	corps	a branch of the military that has a specialized function	4,240,000	37.39%	5						x
/litʃ/	leach	to extract (soluble matter) by means of a percolating liquid	236,000	69.62%	5	547.77	777.68	0.97	1,053.79	0.89	
	leech	any of various primarily aquatic bloodsucking or carnivorous worms, one species of which was formerly used medicinally to bleed patients	103,000	30.38%	5						x
/lut/	loot	valuables taken by pillaging or plundering, usu. in wartime; spoils	174,000	51.18%	4	530.92	852.78	0.47	1,137.22	0.71	
	lute	an ancient stringed instrument having a bent, fretted neck and a pear-shaped body	166,000	48.82%	4						x
/morn/	morn	morning or dawn	132,000	32.27%	4	560.67	763.45	0.63	955.54	0.97	x
	mourn	to feel or show deep sorrow or grief, esp. for the dead; grieve	277,000	67.73%	5						

		General Properties of Heterographic Homophones					Visual		Auditory		
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	***Mn* LD Lat.**	***Mn* Acc.**	***Mn* LD Lat.**	***Mn* Acc.**	**Visually Presented**
/mo͞ut/	moat	a deep trench dug for defense around a castle, fort, medieval town, or the like, and usu. filled with water	204,000	71.83%	4	529.60	1,070.07	0.38	1,130.77	0.70	
	mote	a fine particle of dust; speck	80,000	28.17%	4						x
/mus/	moose	a large North American hoofed, cud-chewing mammal with humped shoulders, the males of which bear broad, flattened antlers	334,000	42.23%	5	557.82	706.86	0.97	949.05	1.00	x
	mousse	a light, molded dessert made with whipped cream, flavoring such as fruit or chocolate, and sometimes gelatin	457,000	57.77%	6						
/no͞uz/	knows	to have knowledge, perception, or understanding	9,120,000	72.83%	5	568.28	657.16	1.00	915.95	1.00	
	noes	an occurrence, in speech or writing, of the word "no"	102,000	0.81%	4						
	nose	the structure at the front of the face in people and certain animals that contains nostrils, organs of smell, and a passageway for breathing	3,300,000	26.35%	4						x
/o͞ud/	ode	a long, elaborate, usu. rhymed lyrical poem, often in praise or celebration of something or someone, and usu. in a lofty and enthusiastic style	357,000	30.25%	3	454.19	971.17	0.65	1,054.93	0.81	x
	owed	to be in debt	823,000	69.75%	4						
/pe͞ɪlz/	pails	a steep-sided container with a handle; bucket	102,000	53.63%	5	622.13	930.04	0.64	1,149.59	0.75	
	pales	to make or become pale	88,200	46.37%	5						x

| General Properties of Heterographic Homophones | | | | | | | Visual | | Auditory | | |
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
/pɛrd/	paired	to separate persons or items into groups of two (often fol. by off)	628,000	73.71%	6	553.25	905.43	0.55	1,019.30	1.00	
	pared	to cut off the outer layer or ends from	224,000	26.29%	5						x
/pis/	peace	a state of freedom from war or hostility	6,980,000	38.39%	5	406.12	600.53	1.00	932.39	0.95	x
	piece	a section or part separated from the whole	11,200,000	61.61%	5						
/preɪ/	pray	to petition, praise, or invoke (God or some object of worship)	2,820,000	74.39%	4	504.04	743.33	0.97	910.49	1.00	
	prey	the object of a hunt or pursuit, usu. one animal caught and eaten by another	971,000	25.61%	4						x
/prɪnᵗs/	prince	the son or grandson of a monarch	4,740,000	48.92%	6	562.88	667.30	0.97	954.00	1.00	x
	prints	to produce a shape, design, or text using a machine or other device, esp. as an occupation or trade	4,950,000	51.08%	6						
/raɪt/	right	in accordance with what is fair and morally good	17,700,000	59.41%	5	502.71	662.25	0.97	1,028.03	0.89	
	rite	a formal or ceremonial act or ritual prescribed or customary for a specific occasion, as in religious worship	627,000	2.10%	4						
	wright	a worker at or creator of something (usu. used in combination)	464,000	1.56%	6						
	write	to form (letters, words, symbols, or characters) on a surface with a pen, pencil, typewriter, or other instrument	11,000,000	36.92%	5						x

		General Properties of Heterographic Homophones					Visual		Auditory		
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
/rɑt/	rot	to decompose or decay, as organic matter	689,000	40.08%	3	594.35	778.25	0.86	1,053.20	0.81	x
	wrought	a past tense and past participle of work	1,030,000	59.92%	7						
/reɪnd/	rained	to come down as water from the clouds	233,000	59.05%	6	603.27	864.67	0.89	1,200.11	0.71	
	reigned	to exercise the authority of a monarch; act as an absolute ruler	114,000	28.89%	7						x
	reined	(usu. pl.) a set of leather straps attached to both ends of a bridle bit by which a driver or rider can control an animal such as a horse	47,600	12.06%	6						
/roʊlz/	roles	the character played by an actor or actress	4,000,000	52.42%	5	597.26	677.89	0.97	1,016.71	0.82	x
	rolls	to move by rotating or turning over repeatedly	3,630,000	47.58%	5						
/sɝfs/	serfs	in feudal societies, a person who is held in servitude on a lord's land and who may be sold or otherwise transferred with the land	54,300	53.98%	5	707.76	896.79	1.00	1,182.22	0.84	
	surfs	to ride on the waves of the sea with a surfboard	46,300	46.02%	5						x
/sɛlz/	cells	a microscopic unit of plant or animal life, containing a nucleus and surrounded by a very thin membrane	5,110,000	55.66%	5	629.78	832.43	0.95	1,106.58	0.87	
	sells	to be involved in selling anything	4,070,000	44.34%	5						x
/sɛnt/	cent	a monetary unit of numerous countries, including the United States and Canada; a hundredth part of certain currencies	5,670,000	30.22%	4	503.82	669.43	0.97	992.00	0.97	x

General Properties of Heterographic Homophones							Visual		Auditory		
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	***Mn* LD Lat.**	***Mn* Acc.**	***Mn* LD Lat.**	***Mn* Acc.**	**Visually Presented**
	scent	a characteristic odor, esp. a pleasant one	1,090,000	5.81%	5						
	sent	past tense and past participle of send	12,000,000	63.97%	4						
/sin/	scene	the place where any event occurs	8,930,000	44.58%	5	578.01	664.11	1.00	1,043.78	0.95	x
	seen	past participle of see1	11,100,000	55.42%	4						
/slēɪ/	slay	to kill or murder deliberately and usu. violently	174,000	39.82%	4	623.32	789.75	0.97	1,122.97	0.95	x
	sleigh	a light horse-drawn cart on runners that is used to carry people over snow and ice	263,000	60.18%	6						
/stilz/	steals	to practice or commit theft	434,000	66.16%	6	759.94	751.74	0.73	1,197.42	0.97	
	steels	a hard, strong metal alloy composed of iron and carbon, and used for making machines, tools, knives, and the like	222,000	33.84%	6						x
/sʌn/	son	a person's male offspring, either natural or adopted	7,080,000	45.53%	3	549.50	640.68	1.00	976.21	1.00	x
	sun	the central star of the solar system around which the earth and other planets revolve and from which heat and light issue	8,470,000	54.47%	3						
/swit/	suite	several things that collectively form a set or series	8,950,000	58.34%	5	616.02	666.55	1.00	1,003.92	0.97	
	sweet	having a flavor like that of sugar or honey; not bitter, salty, or sour in taste	6,390,000	41.66%	5						x
/tāɪd/	tide	the periodic change, occurring about every twelve hours, in the height of the surface of oceans and	2,060,000	50.61%	4	523.61	744.58	1.00	1,067.12	0.89	

General Properties of Heterographic Homophones							Visual		Auditory		
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
		bodies of water near or feeding into them, caused by the gravitational pull of the moon and sun									
	tied	to form a connection or bond	2,010,000	49.39%	4						x
/teɪl/	tail	an animal's rearmost part, usu. an appendage and extension of the spinal column, that projects from the rear of the trunk	3,490,000	42.30%	4	541.88	626.32	1.00	989.17	0.95	x
	tale	an account of the details of a real or fictional occurrence; story	4,760,000	57.70%	4						
/θroʊn/	throne	the seat occupied by a ruler or high secular or religious official on ceremonial occasions or when holding audience	1,040,000	44.07%	6	624.92	794.67	0.97	1,048.28	0.95	x
	thrown	to hurl, cast, or fling something	1,320,000	55.93%	6						
/vaɪl/	vial	a small, sometimes stoppered bottle of glass or plastic used for small amounts of liquid medicine, chemicals, perfume, or the like	299,000	43.65%	4	678.01	773.31	0.83	1,086.75	0.95	x
	vile	extremely bad, disgusting, or unpleasant	304,000	44.38%	4						
	viol	any of a group of stringed instruments of the sixteenth and seventeenth centuries having fretted necks and usu. six strings, and played with a curved bow	82,000	11.97%	4						
/veɪl/	vale	a valley	483,000	40.69%	4	649.79	813.22	0.61	1,133.03	0.84	x

General Properties of Heterographic Homophones							Visual		Auditory		
Phono	Ortho	Semantic Representation	Semantic Rep Freq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.	Visually Presented
	veil	a thin piece of fabric or netting, usu. worn over the head, shoulders, and face	704,000	59.31%	4						
/veɪn/	vain	not leading to a desirable or lasting effect; futile; fruitless	632,000	37.49%	4	672.44	729.28	0.95	1,095.11	0.95	x
	vane	a device mounted so that it rotates freely in the wind, indicating the wind's direction; weather vane	142,000	8.42%	4						
	vein	one of the many small vessels that transport blood to the heart	912,000	54.09%	4						
/wɑrn/	warn	to put on guard or give notice	1,050,000	33.02%	4	531.38	707.16	0.97	1,034.05	1.00	x
	worn	past participle of wear	2,130,000	66.98%	4						
/weɪd/	wade	to walk in water or another substance that partially envelops one's legs, thereby hindering movement	1,230,000	62.60%	4	570.32	680.34	1.00	1,121.61	0.94	
	weighed	to have weight or a particular amount of weight	735,000	37.40%	7						x
/wɛr/	ware	(usu. pl.) manufactured products or other articles of commerce, including salable skills, knowledge, or the like; goods	2,930,000	35.65%	4	516.86	547.71	0.69	986.00	0.97	x
	wear	to carry on one's person as a covering or ornament	4,960,000	60.35%	4						
	weir	a fence, as of brush, set in a stream to catch fish	329,000	4.00%	4						
/weɪts/	waits	to keep oneself inactive or in one place until an anticipated event occurs (often fol. by for or until)	1,320,000	43.85%	5	577.84	700.11	1.00	1,084.73	0.89	x
	weights	the heaviness of an object,	1,690,000	56.15%	7						

		General Properties of Heterographic Homophones					Visual		Auditory		
Phono	**Ortho**	**Semantic Representation**	**Semantic Rep Freq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	***Mn* LD Lat.**	***Mn* Acc.**	***Mn* LD Lat.**	***Mn* Acc.**	**Visually Presented**
		esp. as expressed in terms of a recognized system of measurement									
/we͞ɪvd/	waived	to forgo or give up (a right, claim, or privilege)	590,000	67.43%	6	579.21	659.21	1.00	1,019.41	0.97	
	waved	to move freely up and down or back and forth; flutter	285,000	32.57%	5						x

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Homographic Homophones

General Characteristics of Homographic Homophones								Visual		Auditory	
Ortho	**Phono**	**# Unrelated Sem Reps**	**Semantic Representations**	**Semantic Rep Frq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	*Mn* **LD Lat.**	*Mn* **Acc.**	*Mn* **LD Lat.**	*Mn* **Acc.**
arms	/ɑrmz/	2	either of the two upper limbs of the human body, between the shoulders and the wrists	8,090,000	57.10%	4	655.59	643.54	1.00	902.47	1.00
			to become prepared for a state of war	5,320,000	42.90%						
bisque	/bɪsk/	2	a thick cream soup made with shellfish, meat, or strained vegetables	108,000	43.37%	6	450.59	886.04	0.74	1,085.06	0.43
			clay or porcelain that has been fired but not glazed	141,000	56.63%						
bounds	/baʊndz/	4	held by bonds; tied	1,080,000	22.45%	6	584.14	774.26	1.00	1,165.48	0.68
			on the way to; headed (usu. fol. by for)	1,300,000	27.03%						
			to leap; spring	1,260,000	26.20%						
			to adjoin or border	1,170,000	24.32%						
buck	/bʌk/	4	a fully grown male of certain animal species such as the deer, goat, rabbit, and sheep	2,640,000	28.76%	4	349.50	797.82	0.89	1,094.36	0.61
			an object such as a buckhorn knife that was formerly placed before a player in a poker game to indicate the responsibility to deal	2,560,000	27.89%						
			a structure used to hold wood for sawing; sawhorse	2,350,000	25.60%						
			of a horse or similar animal, to leap off the ground and come down with stiff forelegs in order to throw off a rider	1,630,000	17.76%						

General Characteristics of Homographic Homophones								Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
chop	/tʃɑp/	4	to cut by hitting repeatedly, esp. with an ax or other sharp tool (often fol. by down or off)	807,000	45.90%	4	456.03	727.86	1.00	1,072.30	0.97
			to suddenly shift direction; swerve, esp. with the wind	581,000	33.05%						
			(usu. pl.) the jaws, cheeks, or mouth	370,000	21.05%						
clips	/klɪps/	2	to cut off, cut out, or trim something	4,850,000	55.75%	5	572.43	673.00	1.00	1,022.39	0.84
			a device that holds, grasps, or fastens, as a paper clip or hair clip	3,850,000	44.25%						
date	/deɪt/	2	a specific day or point in time, usu. described by indicating the month, day, and year	17,600,000	64.83%	4	364.11	641.32	0.97	847.63	1.00
			the edible fruit of the date palm tree of the Middle East	9,550,000	35.17%						
drilled	/drɪld/	3	to produce a hole or holes in something, as by the use of a drill	561,000	51.00%	7	565.33	797.65	1.00	1,025.71	1.00
			a sturdy twilled fabric, usu. of cotton	157,000	14.27%						
			to plant seeds in drills	382,000	34.73%						
dubbed	/dʌbd/	3	to award the title of knight to by tapping or striking lightly on the shoulder, usu. with a sword	719,000	43.21%	6	379.38	815.71	0.78	1,008.03	0.76
			sounds that are added to or that replace sounds on a recording, such as a film	577,000	34.68%						
			to push, poke, or thrust at	368,000	22.12%						

General Characteristics of Homographic Homophones								Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
fan	/fæn/	2	a mechanical apparatus, usu. driven by electricity, that creates an air current by moving several vanes or blades in rotation	5,970,000	43.45%	3	497.13	668.35	0.97	1,031.33	0.95
			an enthusiastic follower of an activity such as a sport or a performing art, or of a person or persons who engage in that activity	7,770,000	56.55%						
flag	/flæg/	4	a piece of cloth, usu. rectangular or triangular, bearing any of various colors and designs and used for signaling or as the symbol or emblem of a country, organization, or the like; banner; pennant	5,140,000	40.86%	4	583.44	659.76	1.00	1,072.17	0.76
			any of a variety of plants characterized by long, flat, pointed leaves, such as the iris, blue flag, or cattail	2,100,000	16.69%						
			to lose energy, strength, or interest	3,100,000	24.64%						
			a type of broad, flat stone used for covering surfaces such as a patio; flagstone	2,240,000	17.81%						
flats	/flæts/	2	in a horizontal position; level to the ground	922,000	48.30%	5	642.13	764.78	0.97	1,115.84	0.51
			a group of rooms forming a residence on one floor of a house; apartment	987,000	51.70%						
flushed	/flʌʃt/	3	to flow or gush quickly and heavily	369,000	38.32%	7	501.73	755.97	0.97	996.45	0.89
			to start up from cover or take flight, as a game bird	221,000	22.95%						

Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
								Visual		**Auditory**	
General Characteristics of Homographic Homophones											
			so as to be on the same plane or in the same line; level or even	373,000	38.73%						
jade	/dʒeɪd/	2	one of two hard, translucent, usu. green minerals, nephrite or jadeite, or the carved and polished jewelry or decorative objects made from them	1,600,000	55.94%	4	586.47	761.39	0.97	1,103.57	0.97
			an old, worthless, or ill-tempered horse; nag	1,260,000	44.06%						
jerked	/dʒɝkt/	2	to make a sudden or unexpected and uneven motion	254,000	57.47%	6	464.76	704.76	0.97	901.62	1.00
			to cure (meat that has been cut into thin strips) by drying	188,000	42.53%						
keys	/kiz/	2	a notched or grooved object, usu. metal, that can open or close locks	5,690,000	67.82%	4	545.47	638.29	1.00	924.08	0.97
			a low island near shore, as off the southern coast of Florida	2,700,000	32.18%						
leave	/liv/	3	to depart or go away from	10,300,000	38.20%	5	496.63	693.66	1.00	966.97	0.92
			to grow leaves, as a tree	7,390,000	27.41%						
			permission	9,270,000	34.38%						
light	/laɪt/	3	electromagnetic radiation, esp. from the sun, that enables one to see	11,100,000	34.13%	5	461.12	644.26	1.00	970.00	0.86
			not heavy, full, intense, or forceful	9,320,000	28.66%						
			to set down after motion; land after flight	12,100,000	37.21%						

			General Characteristics of Homographic Homophones					Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
line	/laɪn/	2	a thin unbroken mark, as made on a surface	12,400,000	51.45%	4	527.77	703.54	0.97	1,178.61	0.82
			to cover the inside of	11,700,000	48.55%						
loaf	/loʊf/	2	a usu. oblong or rectangular mass of bread or cake, shaped and baked in that form	276,000	60.13%	4	410.50	680.46	0.95	1,085.37	0.79
			to spend time in a lazy, aimless manner; idle	183,000	39.87%						
lore	/lor/	2	that which is known or believed about a subject, esp. that transmitted by tradition, oral means, or obscure writings	629,000	61.79%	4	545.59	886.19	0.74	1,175.33	0.47
			the portion of a bird between its eye and beak, or an analogous portion of a fish or reptile	389,000	38.21%						
lug	/lʌg/	2	to move with a great effort, esp. by pulling or lifting	371,000	47.63%	3	507.96	917.96	0.76	1,250.57	0.78
			an earlike projection used to support or hold something, such as a machine	408,000	52.37%						
match	/mætʃ/	2	a slender strip of wood or cardboard with a combustible material on the end that is ignited by friction	6,370,000	38.21%	5	607.65	662.05	0.97	1,072.81	0.97
			a person or thing that is identical to or like another	10,300,000	61.79%						
miss	/mɪs/	2	to fail to hit, catch, reach, cross, or in any way touch or contact (a particular object)	7,710,000	42.81%	4	494.77	663.64	0.95	993.20	0.95

General Characteristics of Homographic Homophones								Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
			the traditional title of an unmarried woman, preceding the surname, and currently often replaced by "Ms."	10,300,000	57.19%						
mush	/mʌʃ/	2	a thick, soft cereal, usu. of corn meal boiled in water or milk	118,000	50.21%	4	531.33	856.26	0.82	1,080.25	0.84
			to travel over snow by means of a dog sled	117,000	49.79%						
palms	/palmz/	2	the inner surface of the hand, between the wrist and the base of the fingers	1,180,000	44.03%	5	607.53	696.89	1.00	1,084.70	0.89
			any of numerous mainly tropical evergreen plants, usu. an unbranched tree having a crown of large divided leaves, or fronds	1,500,000	55.97%						
pelt	/pɛlt/	2	to attack by hurling missiles or by repeated blows	74,700	47.88%	4	454.27	848.76	0.71	1,100.29	0.82
			the skin or hide of an animal, usu. fur-bearing	91,300	52.12%						
perch	/pɝtʃ/	2	a rod, branch, or the like on which birds sit	363,000	52.99%	5	434.42	845.83	0.97	976.97	0.92
			any of various edible freshwater fishes that have spiny fins	322,000	47.01%						
pike	/paɪk/	4	any of several large freshwater fishes with elongated, flattened snouts, that are caught for food or sport	1,150,000	31.79%	4	405.33	882.40	0.83	1,032.57	0.74
			a long pole with a sharp head, formerly used by foot soldiers as a weapon	816,000	22.56%						

General Characteristics of Homographic Homophones								Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
			a road on which a toll is charged; turnpike	1,400,000	38.71%						
			any sharp point, as on an arrow.	251,000	6.94%						
pit	/pɪt/	2	a comparatively wide and deep hole dug or existing in the ground	2,290,000	68.98%	3	376.88	713.95	1.00	903.63	0.95
			the hard seed at the center of an apricot, cherry, plum, or certain other fruits	1,030,000	31.02%						
pitch	/pɪtʃ/	2	to throw or toss	2,590,000	51.49%	5	425.64	731.11	1.00	945.41	0.97
			a dark sticky substance	2,440,000	48.51%						
plots	/plɑts/	2	to form secret plans for an illegal or hostile purpose	1,600,000	57.97%	5	620.33	783.16	0.97	1,212.79	0.65
			a small piece of land, esp. one used for a specific purpose	1,160,000	42.03%						
poached	/poʊtʃt/	2	to hunt, fish, or trap illegally or on another's land	87,900	45.81%	7	473.14	832.06	0.95	878.97	0.95
			to cook by boiling or simmering in water or other liquid	104,000	57.14%						
posed	/poʊzd/	2	to take or hold a bodily position, as in modeling clothing or having one's portrait made	1,440,000	52.94%	5	611.66	897.00	0.97	1,178.41	0.97
			to puzzle or embarrass with a difficult problem or question	1,280,000	47.06%						
pound	/paʊnd/	3	to strike repeatedly and heavily	2,500,000	37.91%	5	573.30	640.33	0.97	972.35	0.97
			a shelter for confining or housing homeless animals	755,000	11.45%						

			General Characteristics of Homographic Homophones					Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
			a unit of weight equal to sixteen ounces or 453.592 grams in the avoirdupois weight system, and equal to twelve ounces or 373.242 grams in the apothecaries' and troy weight systems. (abbr.: lb.)	3,340,000	50.64%						
press	/prɛs/	2	to bear down on as if to crush or squeeze	12,400,000	71.84%	5	429.74	737.92	1.00	951.22	0.86
			to force into military service; impress	4,860,000	28.16%						
prop	/prɑp/	3	a physical object, such as a heavy beam, stick, or stone, used to support and hold something in place	1,940,000	57.23%	4	424.14	879.41	0.86	950.73	0.87
			a piece of furniture or other article used for a theatrical presentation or the like; stage property	1,080,000	31.86%						
			(informal) a propeller, as on an airplane or boat	370,000	10.91%						
prunes	/prunz/	2	the dried or partially dried fruit of any of various common plums	113,000	55.80%	6	682.72	823.58	0.87	1,084.11	0.97
			to cut or remove dead or unwanted branches, twigs, or the like from; trim	89,500	44.20%						
punch	/pʌntʃ/	3	a hard, quick blow with the fist	1,260,000	26.25%	5	403.92	645.08	0.97	850.53	0.97
			a sweet drink comprising a mixture of ingredients such as fruit juices, soda, spices, or the like, often with wine or liquor added	1,610,000	33.54%						

Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	Mn LD Lat.	Mn Acc.	Mn LD Lat.	Mn Acc.
								Visual		Auditory	
			a tool or machine used for making small holes or indentations or for impressing a design, as in leather	1,930,000	40.21%						
rakes	/rēɪks/	3	to use a rake or similar tool	42,300	56.56%	5	675.00	833.28	0.97	1,037.54	0.95
			one who shamelessly carries on improper or immoral behavior; profligate; libertine	26,800	35.83%						
			to slant away from a vertical or horizontal line; incline	5,690	7.61%						
rock	/rɑk/	2	a large mass of hard mineral matter that lies under the earth's soil or forms a cliff, mountain, or the like.	5,580,000	35.14%	4	411.53	612.92	1.00	964.62	0.78
			to sway strongly back and forth or from side to side	10,300,000	64.86%						
scaled	/skēɪld/	2	to flake off	367,000	35.02%	6	656.43	740.38	0.92	1,118.20	0.92
			to climb, progress, or ascend, esp. in stages	681,000	64.98%						
sheds	/ʃɛdz/	2	a simple, usu. one-story structure used for storage or shelter, or as a workshop, and either free-standing or attached to another building	466,000	58.99%	5	591.86	837.63	0.89	1,032.88	0.92
			to cast off, take off, or let fall (a covering or growth)	324,000	41.01%						
slips	/slɪps/	2	to move smoothly or with ease	771,000	37.59%	5	606.04	825.92	0.97	1,087.58	1.00
			a cutting from a plant, intended for propagation	1,280,000	62.41%						
spat	/spæt/	4	a short, insignificant quarrel	246,000	34.36%	4	562.71	869.60	0.95	1,102.19	0.82

			General Characteristics of Homographic Homophones					Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
			a past tense and past participle of spit1	280,000	39.11%						
			(often pl.) a short cloth or leather covering worn over the top of the shoe and around the ankle, and usu. fastened with a strap under the shoe; gaiter	177,000	24.72%						
			a young oyster or other shellfish	12,900	1.80%						
spell	/spɛl/	3	to name or write the letters of (a word) in order	1,870,000	70.20%	5	595.88	669.95	0.97	1,103.65	0.82
			a word, phrase, or the like used to bewitch or enchant; charm; incantation	198,000	7.43%						
			a brief, undefined period or interval of time	596,000	22.37%						
spoke	/spoʊk/	2	to have said, the past tense of "to speak"	4,630,000	69.00%	5	589.94	706.18	1.00	1,013.82	1.00
			a rod or bar radiating from the center of a wheel and connected to the outer rim	2,080,000	31.00%						
spray	/spreɪ/	2	water or another liquid flying or falling in fine droplets, as from the nozzle of a hose	3,930,000	56.63%	5	703.11	702.95	0.97	1,065.13	1.00
			a single shoot or branch that has leaves, flowers, or berries	3,010,000	43.37%						
stalks	/stɑlks/	2	a plant's main stem	182,000	55.83%	6	696.04	735.51	0.95	1,219.37	0.95
			to walk in a stiff, arrogant, or threatening manner	144,000	44.17%						
stem	/stɛm/	3	the main axis of a plant, usu. above ground, from which branches, leaves, flowers, or fruits may arise	2,710,000	43.49%	4	587.81	721.11	0.97	1,065.08	0.95

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			General Characteristics of Homographic Homophones					Visual		Auditory	
Ortho	**Phono**	**# Unrelated Sem Reps**	**Semantic Representations**	**Semantic Rep Frq Est**	**Semantic Dominance Score**	**# Letters**	**Acoustic Duration**	***Mn* LD Lat.**	***Mn* Acc.**	***Mn* LD Lat.**	***Mn* Acc.**
			an upright, usu. curved beam at the bow of a nautical vessel, into which the side timbers are jointed	752,000	12.07%						
			to stop the flow of; dam up; stanch	2,770,000	44.45%						
stoop	/stup/	2	to bend the body forward and downward, as to pick up something	135,000	44.55%	5	614.12	828.09	0.86	1,207.94	0.92
			a large step or small porch at the entrance to a home, often reached by a short flight of steps	168,000	55.45%						
studs	/stʌdz/	2	a nail or rivet with a protruding and often rounded knob or head, fixed in a surface as a protective or ornamental device	608,000	36.02%	5	656.58	823.24	0.92	1,108.17	0.97
			a domesticated male animal, such as a racehorse, that is kept for breeding	1,080,000	63.98%						
tend	/tɛnd/	2	to have an inclination or disposition to do something; be inclined	2,980,000	46.64%	4	550.25	683.59	0.97	1,180.68	0.78
			to care for or maintain; look after (a person or thing)	3,410,000	53.36%						
tipped	/tɪpt/	4	the extreme end, esp. of something slender, tapered, or pointed	370,000	21.49%	6	449.17	757.49	0.97	907.86	0.95
			a light touch; tap	338,000	19.63%						
			to give someone a tip	470,000	27.29%						
			to lean; slant; tilt	544,000	31.59%						
toast	/toʊst/	2	bread that has been sliced and browned in an oven,	1,200,000	63.49%	5	512.16	658.97	1.00	941.21	1.00

			General Characteristics of Homographic Homophones					Visual		Auditory	
Ortho	Phono	# Unrelated Sem Reps	Semantic Representations	Semantic Rep Frq Est	Semantic Dominance Score	# Letters	Acoustic Duration	*Mn* LD Lat.	*Mn* Acc.	*Mn* LD Lat.	*Mn* Acc.
			toaster, or the like								
			a call on other people to drink in honor of someone or something, or a short verbal salute preceding this call	690,000	36.51%						
top	/tɑp/	3	the uppermost area, point, or surface	17,500,000	58.53%	3	517.21	655.86	0.97	1,029.42	0.95
			a children's toy in the shape of a cone that is made to spin on its point	12,400,000	41.47%						
trace	/treɪs/	2	a visible mark or evidence of a past event or thing	4,510,000	68.44%	5	566.84	678.19	1.00	943.54	0.97
			one of two ropes, chains, or straps used to harness a draft animal to a cart, carriage, or the like	2,080,000	31.56%						
wake	/weɪk/	2	to emerge from sleep (often fol. by up)	5,240,000	51.83%	4	446.86	707.18	1.00	991.97	0.97
			the track of waves left by something that is moving through water	4,870,000	48.17%						
waxed	/wækst/	2	a solid yellowish substance that is pliable when melted and is secreted by bees for constructing their honeycombs; beeswax	154,000	52.20%	5	559.70	717.62	0.97	1,069.08	0.95
			to increase gradually in quantity, strength, volume, or the like	141,000	47.80%						
zip	/zɪp/	2	a sudden, sharp whizzing noise, such as that of an arrow or bullet in flight	5,450,000	45.64%	3	450.25	644.26	1.00	980.53	0.95
			to fasten or unfasten by closing or opening a zipper	6,490,000	54.36%						

Control Words

General Characteristics of Control Words						Visual		Auditory	
Ortho	Phono	Semantic Representation	Semantic Rep Freq Est	# Letters	Acoustic Duration	*Mn* LD Lat	*Mn* Acc	*Mn* LD Lat	*Mn* Acc
beep	/bip/	a short, usu. high-pitched warning signal	300,000	4	433.16	756.13	1.00	946.25	0.95
belched	/bɛltʃt/	to expel gas from the stomach through the mouth, in a spasmodic, noisy burst, as after eating or drinking	32,200	7	483.66	926.29	0.84	965.66	0.92
bouts	/baʊts/	an athletic match, as between wrestlers or boxers	172,000	5	503.36	1,421.36	0.31	1,156.44	0.49
broom	/brum/	a device for sweeping, consisting of a bundle of straw or bristles attached to a long handle	278,000	5	469.39	710.03	0.97	943.79	1.00
cease	/sis/	to stop or come to an end	1,410,000	5	561.20	837.91	0.95	1,224.39	0.82
chafe	/tʃeɪf/	to abrade, irritate, or wear away by rubbing	47,200	5	392.05	973.15	0.34	1,121.50	0.76
crust	/krʌst/	the hard browned dough on the outside of baked goods such as bread or pies	689,000	5	518.26	706.11	0.95	969.50	1.00
deaf	/dɛf/	partly or totally lacking the sense of hearing	1,600,000	4	332.72	723.97	0.97	967.74	0.71
deeps	/dips/	to or at a great depth	66,700	5	478.11	715.04	0.64	1,029.38	0.57
dens	/dɛnz/	the resting place or retreat of a large predatory wild animal, such as a wolf or lion; lair	170,000	4	529.09	848.54	0.72	1,192.50	0.42
doffed	/dɑft/	to take off (clothing)	25,900	6	495.09	1,158.20	0.14	1,390.00	0.03
domed	/doʊmd/	to rise or swell in the shape of a dome	154,000	5	541.18	1,461.00	0.26	1,052.83	0.62
dragged	/drægd/	to pull along with force; haul	591,000	7	624.77	660.56	1.00	983.58	0.95
dull	/dʌl/	lacking in interest, originality, or liveliness; boring	987,000	4	450.90	714.63	1.00	994.32	0.74
fames	/feɪmz/	widespread recognition; public esteem; renown	8,390	5	621.80	826.47	0.53	1,404.54	0.34
flub	/flʌb/	(informal) to do badly; botch; bungle	13,400	4	467.56	830.45	0.30	1,042.09	0.30
forced	/forst/	involuntary; imposed	7,440,000	6	531.74	728.37	1.00	1,009.49	0.97
ghouls	/gulz/	an evil demon, esp. one of Islamic legend that eats people and corpses	95,600	6	508.50	1,010.34	0.81	1,118.96	0.76

General Characteristics of Control Words						Visual		Auditory	
Ortho	Phono	Semantic Representation	Semantic Rep Freq Est	# Letters	Acoustic Duration	*Mn* LD Lat	*Mn* Acc	*Mn* LD Lat	*Mn* Acc
glowed	/gloʊd/	to shine with bright light, as something very hot but flameless	145,000	6	531.08	857.85	0.92	1,066.78	0.64
grove	/groʊv/	a small wooded area, esp. one with little ground cover	4,070,000	5	595.74	805.89	0.92	1,178.69	0.86
grudge	/grʌdʒ/	a feeling of resentment harbored against someone because of a real or imagined injustice	156,000	6	492.21	764.22	0.97	995.13	0.84
hedged	/hɛdʒd/	to avoid commitment to a position or opinion by qualifying or evading; equivocate	81,400	6	492.08	860.80	0.83	1,063.10	0.53
hens	/hɛnz/	a female bird, esp. a chicken	241,000	4	462.42	799.89	0.97	976.06	0.87
hoax	/hoʊks/	an act of deception, esp. a humorous or mischievous trick	247,000	4	527.93	805.14	0.97	1,054.43	0.79
hone	/hoʊn/	a fine-textured whetstone used to sharpen knives, razors, and other cutting tools	333,000	4	426.26	1,074.75	0.44	1,108.50	0.21
hope	/hoʊp/	an optimistic sense or feeling that events will turn out well	11,700,000	4	355.12	632.24	1.00	1,027.69	0.91
jut	/dʒʌt/	to project or extend sharply outward; protrude (often fol. by out)	84,200	3	374.20	960.59	0.47	998.00	0.68
lair	/lɛr/	a wild animal's shelter; den	664,000	4	439.49	780.07	0.79	1,071.64	0.66
lifts	/lɪfts/	to rise, as a plane or balloon	1,440,000	5	525.05	756.78	0.97	969.77	0.72
lymph	/lɪmf/	a transparent, usu. yellowish liquid produced by body tissues that is rich in white blood cells	5,270,000	5	478.22	940.15	0.87	1,161.48	0.76
men	/mɛn/	pl. of man	11,300,000	3	533.73	647.14	0.95	936.13	1.00
mugs	/mʌgz/	to use physical force on or assault, usu. with the intent to rob, and usu. on the street or in some other public place	1,060,000	4	628.43	749.34	1.00	1,087.46	0.95
note	/noʊt/	a brief written record or reminder	14,200,000	4	521.69	638.34	1.00	1,051.16	0.97
nouns	/naʊnz/	in grammar, a word that names a person, place, thing, condition, or quality, that usu. has plural and possessive forms, and that functions as the subject of a sentence or as the object of a verb or preposition	314,000	5	629.80	750.46	0.97	1,072.68	0.97
part	/part/	a separate portion or segment of a whole	15,000,000	4	436.83	661.61	1.00	971.25	0.95

General Characteristics of Control Words						Visual		Auditory	
Ortho	Phono	Semantic Representation	Semantic Rep Freq Est	# Letters	Acoustic Duration	*Mn* LD Lat	*Mn* Acc	*Mn* LD Lat	*Mn* Acc
patch	/pætʃ/	a small piece of material, esp. fabric, applied to a larger piece of the same or similar material to cover a hole or tear, or to strengthen a weakened place	4,710,000	5	590.82	726.71	1.00	1,127.83	0.95
plugs	/plʌgz/	(informal) to work in a uniform, often uninspired way (often fol. by away or along)	1,510,000	5	545.80	729.94	0.97	1,058.10	0.79
pure	/pjur/	composed of only one substance, element, or quality; not mixed	8,870,000	4	500.47	625.76	1.00	950.76	0.89
rice	/raɪs/	a grass that is widely cultivated in warm, wet areas, esp. in India and China	4,880,000	4	472.22	655.58	1.00	918.76	1.00
robes	/roʊbz/	a long, loose gown or outer garment, such as one worn by certain officials or during certain ceremonies	526,000	5	594.35	858.29	0.92	1,051.93	0.78
score	/skor/	the record of the total points earned in a competition or test	7,290,000	5	665.66	622.66	1.00	1,065.32	0.97
shame	/ʃeɪm/	emotional pain brought about by the knowledge that one has done something wrong, embarrassing, or disgraceful	2,730,000	5	710.07	684.94	0.95	1,105.89	0.97
shelf	/ʃɛlf/	a thin, flat, usu. rectangular piece of wood, metal, or glass attached horizontally to a wall or in a cabinet, case, or the like for things to be kept upon	3,660,000	5	528.36	689.00	1.00	1,098.53	0.97
sips	/sɪps/	to drink slowly and a little at a time	109,000	4	529.30	798.24	0.89	998.87	1.00
skeet	/skit/	a form of trapshooting in which targets are thrown at different heights and speeds to simulate birds in flight	142,000	5	626.89	1,024.17	0.32	1,388.47	0.43
slots	/slɑts/	a long, narrow indentation or opening into which something may be put	3,590,000	5	719.13	799.33	0.97	1,483.92	0.35
smear	/smir/	to spread or apply (a sticky, oily, or greasy substance) on or over a surface	239,000	5	670.96	716.62	0.92	1,022.68	0.92
smudged	/smʌdʒd/	to become stained or dirtied; smear	38,800	7	738.41	841.56	0.91	1,152.24	1.00
sphere	/sfir/	a round, three-dimensional geometric figure in which every point on the surface is an equal distance from the center	1,580,000	6	721.94	697.24	1.00	1,047.39	0.95
spun	/spʌn/	past tense and past participle of spin	690,000	4	634.05	835.19	0.97	1,319.07	0.78

General Characteristics of Control Words						Visual		Auditory	
Ortho	Phono	Semantic Representation	Semantic Rep Freq Est	# Letters	Acoustic Duration	*Mn* LD Lat	*Mn* Acc	*Mn* LD Lat	*Mn* Acc
squirm	/skwɝm/	to twist about; writhe; wriggle	92,100	6	797.67	835.19	0.97	1,119.08	0.97
store	/stor/	a place where merchandise is sold	11,100,000	5	797.67	826.65	0.97	1,151.11	1.00
swum	/swʌm/	past participle of swim	50,700	4	716.78	662.62	0.97	1,417.83	0.17
text	/tɛkst/	the body of a printed work as distinguished from its title, headings, notes, and the like	13,900,000	4	660.73	1,043.33	0.17	1,111.70	0.83
twirl	/twɝl/	to cause to spin or revolve quickly; rotate	90,300	5	504.31	588.66	1.00	976.53	0.97
urge	/ɝdʒ/	to push or drive forward or onward	1,640,000	4	631.04	732.08	1.00	963.28	0.95
veered	/vird/	to turn aside or away from a particular course; change direction; swerve	105,000	6	616.25	965.86	0.76	1,138.15	0.89
went	/wɛnt/	past tense of go1	11,000,000	4	520.31	683.38	0.97	968.09	0.95
worm	/wɝm/	any of numerous related invertebrates with long, thin, flexible, round or flat bodies and no limbs	2,430,000	4	532.32	768.59	0.97	942.03	0.97
zoom	/zum/	to move quickly or rapidly while making a low-pitched humming sound	5,430,000	4	695.07	694.89	0.97	1,097.18	0.89

APPENDIX F

Reliability and Validity of Semantic Representation Frequency Estimates

Reliability and Validity of Semantic Representation Frequency Estimates

Reliability was calculated for the Internet frequency estimates for unrelated semantic representations (Nixon et al, in prep). A reliability rater was provided with directions (Appendix D) for selecting co-occurrence words related to semantic representations from the Wordsmyth Internet Dictionary entries for a randomly selected subset of the stimulus words. The independent rater was asked to provide co-occurrence words for 13 heterographic homophone sets with all orthographic representations, 13 homographic homophone sets with all of its semantic representations, and 13 control words. Intra-class correlations were calculated between the semantic representation frequency estimates obtained using the co-occurrence words provided by the reliability rater and the semantic representation frequency estimates obtained by the author. The Intra-class Correlation Coefficient (ICC) between the independent rater's and the author's semantic representation frequency estimates was large, positive and significant at 0.95 ($p < .001$), and these ratings did not differ significantly ($F(1, 65) = 0.13$, $p = .73$). Accordingly, the independent rater was able to obtain similar semantic representation frequency estimates for words when provided with the directions (Appendix D) and the same definitions used by the original author.

One validity check consisted of calculating correlations between the semantic representation frequency estimates and both the HAL corpus frequency counts[11] (Balota et al., 2002) and the Spelling Dictionary frequency counts (Rondthaler & Lias, 1986).[12] Because the HAL corpus and the Spelling Dictionary do not have frequency of occurrence for unrelated

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[11] The HAL (Hyperspace Analogue to Language) Corpus consists of words gathered from Usenet newsgroups. HAL corpus word frequencies provided better predictors of lexical decision latencies than the Kučera and Francis (1967) word frequency counts (for a complete discussion see Burgess & Livesay, 1998).
[12] The Spelling Dictionary frequency counts updated the Kučera and Francis (1967) word frequency counts using words from the then current Merriam-Webster list of most used words, a similar McGraw-Hill list, the WES dictionary, and several lists of newer words. This yielded a vocabulary of almost 45,000 words. Frequency counts were adjusted for word use in other types of writing with a search of 100,000 words from personal and business correspondence (Rondthaler & Lias, 1986).

semantic representations, the semantic representation frequency estimates were summed across all unrelated semantic representations for each homographic homophone. Of the stimulus words, five did not have HAL frequency counts and were excluded from the correlation between HAL frequency counts and semantic representation frequency estimates; and, 13 did not have Spelling Dictionary frequency counts and were excluded from the correlation between Spelling Dictionary frequencies and semantic representation frequency estimates. None of the word frequency measures met the hypothesis of normality according to the Shapiro-Wilk test (W_{238} (Internet) = 0.25, $p < .05$; W_{238} (HAL) = 0.35, $p < .05$; W_{238} (Sp. Dic.) = 0.33, $p < .05$). The nonparametric correlation coefficient, Spearman's rho (r_s) was used to test these associations. Correlations of primary interest were large and significant: r_s equaled 0.93 ($p < .05$) between semantic representation frequency estimates and HAL frequency counts and 0.80 ($p < .05$) between semantic representation frequency estimates and Spelling Dictionary frequency counts. Thus, semantic representation frequency estimates summed across orthographic representations appear to be valid estimators of direct word frequency counts.

To validate semantic representation frequency estimates as measures of semantic representation use, correlations were calculated between the semantic representation frequency estimates of each word type and objective frequencies from the CELEX (Baayen, Piepenbrock, & van Rijn, 1993) and Wall Street Journal (WSJ; Marcus, Santorini, & Marcinkiewicz, 1993) databases. The correlations between semantic representation frequency estimates and objective frequency measures for heterographic homophones and control words should be positive and larger than the correlation between semantic representation frequency estimates and objective frequency measures for homographic homophones. Objective frequency measures should overestimate homographic homophone semantic representation frequencies because objective

frequency measures are based on the frequency of occurrence for each orthographic

representation versus for each unrelated semantic representation within an orthographic

representation.[13] The non-parametric correlation coefficient, Spearman's *rho*, was used to test

these relationships because the frequency measures did not meet the hypothesis of normality.

Correlations between semantic representation frequency estimates and objective frequency

counts from the CELEX and WSJ databases are listed in Table 22 by word type. As predicted,

correlations between semantic representations frequency estimates of homographic homophones

and objective frequencies from the CELEX and WSJ databases were slightly weaker than the

other correlations. For example, CELEX (Baayen et al., 1993) objective frequencies account for

67.24% of the variance in semantic representation frequency estimates for control words but only

36.00% of the variance in semantic representation frequency estimates for homographic

homophones. This suggests that the semantic representation frequency estimates are valid

measures of semantic representation use frequency.

Table 22. Correlations between Semantic Representation Frequency Estimates and Objective Frequency Measures

Word Type	CELEX	WSJ
Control Words	.82**	.86**
Heterographic homophones	.72**	.77**
Control Words +	.84**	.86**
Heterographic homophones		
Homographic homophones	.60**	.68**

Note. WSJ = Wall Street Journal
**Correlation is significant at .01 level (2-tailed)

To validate that Internet semantic dominance scores reflected subjective judgments of

semantic dominance, 22 participants from the University of Pittsburgh between the ages of 18

and 23 ($M = 18.77$, $SD = 1.34$) were recruited to estimate the relative frequency with which they

encountered each semantic representation of 90 homographic homophones in written and spoken

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[13] Griffin (1999) used a similar procedure to determine whether subjective frequencies for specific semantic
representations of heterographic homophones, homographic homophones, and control words reflected frequency of
semantic representation use or objective frequency counts.

language. It was determined *a priori* that Internet semantic dominance scores would be considered valid reflections of subjective ratings of semantic dominance if r_s was greater than or equal to 0.66. This value was selected based on studies comparing Internet-based and objective frequency counts for heterographic homophones (words with a single pronunciation but more than one spelling, such as bite/byte), which can be compared directly due to their different spellings. Spearman's rho correlations among objective frequency counts from the CELEX (Baayen et al., 1993), WSJ (Marcus et al., 1993), and Zeno et al (1995) corpora ranged from 0.69 to 0.84. In addition, Spearman's rho correlations[14] between objective frequency-based meaning dominance scores and Internet-based meaning dominance scores ranged from 0.66 to 0.73. These values were consistent with correlations among three objective corpora, Caroll, Davies, and Richman (1971), Kučera and Francis (1967), and Zeno et al (1995), which range from 0.73 to 0.84 (Lee, 2003). Because objective frequency counts vary from corpus to corpus, it is reasonable to expect that meaning dominance scores will vary to this degree as well.

Participants were asked to assign a relative percentage of occurrence scores to each semantic representation of a homographic homophone (Nixon et al., in preparation). After obtaining the subjective ratings, difference scores were calculated by subtracting the Internet semantic dominance score from the mean subjective semantic dominance score for each semantic representation. Using these difference scores, four homographic homophone sets were identified as outliers, which had at least one semantic representation with a difference score ±2 *SD*s from the mean difference score. After removing these four outlying stimulus sets from the

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[14] Spearman's *rho* correlations were used because the word frequency data did not meet the assumptions of normality.

analyses,[15] 86 homographic homophone sets remained with 198 unrelated meanings. The correlation between subjective estimates of semantic dominance and Internet semantic dominance scores was positive, large, and significant at $r_s = 0.71$, $p < 0.01$. The correlation reached the expected level and accounted for 49.70% of the variance providing further evidence of the validity of the Internet-based measures. The remaining variability can likely be explained by differences in the texts accessed on the Internet and/or by differences in personal experience with particular words and meanings.

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[15] Of the 4 outliers, 3 were in the original stimulus set of 60 homonyms to be used in the lexical decision study. Accordingly, these were replaced with additional homonyms used in the validation study that were not outliers but met the other criteria for stimulus words in the dissertation study.

APPENDIX G

Nonword Stimuli

Nonwords

General Characteristics				Visual		Auditory	
ortho	phono	# letters	acoustic duration	*Mn* LD lat	*Mn* Acc	*Mn* LD lat	*Mn* Acc
baved	/lɪtʃ/	5	543.26	908.34	0.89	1,123.81	0.42
baxed	/bækst/	5	523.33	836.35	0.89	1,176.82	0.89
beace	/bis/	5	429.96	919.34	1.00	1,144.92	0.68
bedged	/bɛʤd/	6	517.51	973.77	0.95	1,101.53	0.86
bext	/bɛkst/	4	525.16	779.03	0.92	960.82	0.87
bips	/bɪps/	4	516.11	869.71	0.95	946.14	0.97
bley	/blēɪ/	4	495.32	773.16	1.00	1,197.72	0.78
blirm	/blɝm/	5	557.23	842.87	1.00	1,124.51	1.00
blouns	/bla͞ʊnz/	6	687.88	791.26	1.00	1,205.91	0.92
boffed	/bɑft/	6	519.85	867.71	1.00	1,009.61	0.95
bomed	/bo͞ʊmd/	5	496.95	1,120.65	0.94	1,187.13	0.65
bosed	/bozd/	5	585.68	947.47	0.86	1,279.33	0.87
brame	/brēɪm/	5	509.00	903.64	0.95	1,150.15	0.87
brend	/brɛnd/	5	511.74	914.15	0.87	1,175.77	0.79
bress	/brɛs/	5	544.15	923.22	0.97	1,305.42	0.32
brince	/brɪnᵗs/	6	500.17	883.08	0.97	1,081.13	0.63
broast	/bro͞ʊst/	6	636.69	1,062.21	0.76	1,207.80	0.66
brone	/bro͞ʊn/	5	544.17	860.37	0.97	1,033.10	0.78
broop	/brup/	5	478.24	825.42	0.95	1,023.39	0.74
brop	/brɑp/	4	475.92	774.43	0.97	1,025.15	0.89
brose	/bro͞ʊz/	5	627.91	840.28	0.95	1,178.00	0.57
brove	/bro͞ʊv/	5	571.37	791.42	0.97	1,127.62	0.55
brum	/brʌm/	4	527.63	852.00	0.95	1,032.84	0.50
bure	/bjur/	4	526.78	855.97	0.97	1,161.84	0.50
burge	/bɝʤ/	5	600.06	1,146.20	0.71	1,288.05	0.57
chakes	/tʃēɪks/	6	616.17	960.54	0.97	1,106.69	0.95
chark	/tʃɑrk/	5	542.20	881.73	0.97	1,194.34	0.92
cheds	/tʃɛdz/	5	608.05	825.74	1.00	1,047.97	1.00
chent	/tʃɛnt/	5	499.96	819.08	1.00	1,063.86	0.97
chod	/tʃɑd/	4	575.37	819.83	0.76	1,119.86	0.95
chot	/tʃɑt/	4	591.41	819.22	0.97	1,109.79	0.89
chough	/tʃo͞ʊ/	6	564.25	1,061.50	0.65	1,213.15	0.94
chun	/tʃʌn/	4	569.61	920.03	0.94	1,117.49	0.95
clagged	/klægd/	7	629.45	920.76	0.89	1,137.62	1.00
clats	/klæts/	5	688.12	869.97	0.97	1,236.36	0.95

General Characteristics				Visual		Auditory	
ortho	phono	# letters	acoustic duration	*Mn* LD lat	*Mn* Acc	*Mn* LD lat	*Mn* Acc
clon	/klɑn/	4	673.59	796.95	0.97	1,181.35	0.97
clore	/klor/	5	567.56	870.17	0.95	1,148.22	0.97
corth	/korθ/	5	467.37	809.16	0.97	1,036.57	0.97
counds	/kaʊndz/	6	662.83	849.03	0.89	1,148.44	0.73
dake	/deɪk/	4	477.66	882.92	0.97	1,144.06	0.92
dalms	/dɑlmz/	5	585.75	837.59	0.97	1,155.21	0.92
darms	/dɑrmz/	5	636.04	840.70	0.97	1,023.57	0.97
darred	/dɑrd/	6	581.44	1,132.86	0.83	1,096.37	0.92
datch	/dætʃ/	5	547.77	872.03	1.00	1,045.20	0.92
dirl	/dɝl/	4	556.62	890.95	1.00	1,152.06	0.86
dit	/dɪt/	3	399.84	954.60	0.95	1,016.47	1.00
dop	/dɑp/	3	451.97	934.22	0.89	1,016.42	0.87
dorced	/dorst/	6	642.72	870.14	0.95	1,164.45	0.87
drales	/drelz/	6	698.44	834.54	0.92	1,213.88	0.89
dreak	/drik/	5	499.32	893.49	0.97	1,022.76	0.97
drock	/drɑk/	5	447.69	854.46	0.92	1,052.87	1.00
durfs	/dɝfs/	5	538.30	855.44	0.94	957.16	1.00
dute	/dut/	4	430.34	819.49	0.92	979.53	0.95
dymph	/dɪmf/	5	381.52	886.80	0.95	1,036.57	0.97
dyte	/daɪt/	4	432.68	870.26	0.95	1,062.94	0.87
eigned	/eɪnd/	6	527.72	940.74	0.97	1,071.35	0.68
feeps	/fips/	5	514.80	807.73	0.97	1,012.60	0.92
fene	/fin/	4	492.87	820.94	0.95	1,176.59	0.46
ferch	/fɝtʃ/	5	562.34	786.76	0.92	1,063.97	0.95
fipped	/fɪpt/	6	529.27	1,441.77	0.37	1,066.51	0.97
flens	/flɛnz/	5	722.51	862.38	0.97	1,147.56	0.92
floke	/floʊk/	5	539.53	881.45	0.82	1,139.74	0.92
flots	/flɑts/	5	681.09	937.03	0.92	1,134.60	0.95
flunes	/flunz/	6	719.24	849.24	0.87	1,157.44	0.95
fope	/foʊp/	4	458.37	794.47	1.00	1,056.62	0.97
frice	/fraɪs/	5	571.80	841.94	0.95	1,182.96	0.68
frip	/frɪp/	4	475.36	795.41	0.97	979.11	0.97
fruise	/fruz/	4	545.72	813.78	0.95	1,297.62	0.76
frun	/frʌn/	6	652.30	753.49	1.00	1,192.10	0.82
frust	/frʌst/	5	676.90	986.15	0.89	1,284.67	0.32
gair	/gɛr/	4	443.57	840.03	0.97	1,034.50	0.89
gan	/gæn/	3	512.11	806.51	0.97	1,089.30	0.97

General Characteristics				Visual		Auditory	
ortho	**phono**	**# letters**	**acoustic duration**	*Mn* **LD lat**	*Mn* **Acc**	*Mn* **LD lat**	*Mn* **Acc**
gart	/gɑrt/	4	427.06	833.53	0.97	1,016.69	0.92
glips	/glɪps/	5	505.69	879.32	0.92	1,095.16	0.66
goaf	/goʊf/	4	365.05	916.97	0.89	1,073.84	1.00
goom	/gum/	4	503.36	1,007.53	0.81	1,047.28	0.95
greered	/grird/	7	558.51	998.11	0.97	1,154.12	0.92
hain	/heɪn/	4	527.68	914.94	0.94	1,191.25	0.11
heech	/hitʃ/	5	487.70	827.66	0.92	1,138.24	0.55
henes	/hinz/	5	664.72	916.24	0.97	1,265.47	0.86
hifts	/hifts/	5	512.33	905.00	1.00	1,066.74	0.84
hoached	/hoʊtʃt/	7	567.96	1,091.21	0.78	1,319.33	0.08
horm	/hɝm/	4	522.04	873.35	0.97	1,020.78	0.25
hote	/hoʊt/	4	531.76	860.82	1.00	1,166.32	0.92
jelt	/dʒɛlt/	4	501.49	964.97	0.83	1,067.73	0.97
jore	/dʒor/	4	546.36	846.30	0.97	1,134.03	0.92
jubbed	/dʒʌbd/	6	551.39	922.00	0.86	1,087.97	0.97
keaf	/kɛf/	4	343.19	796.81	0.95	950.48	0.73
kelched	/kɛltʃt/	7	557.59	866.64	0.92	1,055.59	0.97
kere	/kir/	4	499.06	759.79	1.00	1,056.66	0.92
knelf	/nɛlf/	5	472.99	883.30	0.97	965.00	0.97
knugs	/nʌgz/	5	572.52	819.58	1.00	1,124.12	0.87
litch	/lɪtʃ/	5	568.14	1,127.26	0.61	1,308.97	0.78
meave	/miv/	5	551.54	934.49	0.92	1,190.13	0.81
misque	/mɪsk/	6	569.34	1,013.46	0.73	1,320.00	0.87
moax	/moʊks/	4	587.60	782.24	0.85	1,182.47	0.95
nared	/nɛrd/	5	628.06	939.93	0.76	1,193.56	0.84
nobes	/noʊbz/	5	719.38	943.91	0.92	1,194.00	0.97
nuck	/nʌk/	4	414.71	878.29	0.94	1,060.13	0.86
pames	/peɪmz/	5	668.00	885.24	1.00	1,124.35	0.54
pight	/paɪt/	5	521.29	1,104.26	0.82	1,244.29	0.82
plare	/plɛr/	5	521.29	906.36	0.95	1,106.00	0.92
plear	/plir/	5	502.75	857.43	0.97	1,085.56	0.42
pleep	/plip/	5	436.08	895.08	0.95	1,002.84	0.97
plen	/plɛn/	4	522.40	772.61	1.00	1,216.68	0.97
pline	/plaɪn/	5	550.40	811.44	0.95	1,240.35	0.68
pode	/poʊd/	4	502.99	889.74	0.97	1,132.70	0.97
poom	/pum/	4	521.88	814.49	1.00	1,134.83	0.95
praled	/preɪld/	6	603.52	827.94	0.97	1,185.45	0.97

General Characteristics				Visual		Auditory	
ortho	**phono**	**# letters**	**acoustic duration**	*Mn* **LD lat**	*Mn* **Acc**	*Mn* **LD lat**	*Mn* **Acc**
preet	/prit/	5	509.86	805.00	0.97	1,179.84	0.97
prilled	/prɪld/	7	502.95	808.74	0.92	1,081.59	1.00
proose	/prus/	6	499.98	862.50	0.95	1,074.19	0.95
prots	/prɑts/	5	678.37	750.97	1.00	1,134.42	0.95
ratch	/rætʃ/	5	649.09	979.61	0.82	1,281.92	0.68
reet	/rit/	4	487.05	820.11	0.95	1,240.27	0.68
rike	/rɑɪk/	4	508.02	834.00	0.95	1,137.24	0.89
rolk	/roʊlk/	4	549.26	800.54	0.97	1,212.40	0.68
seirs	/sɛrz/	5	760.94	816.40	0.95	1,287.32	1.00
shate	/ʃeɪt/	5	648.97	949.19	0.97	1,370.39	0.74
shease	/ʃis/	5	563.86	876.73	1.00	1,348.20	0.13
shreys	/ʃriz/	6	688.20	902.56	0.89	1,444.43	0.18
shried	/ʃrɑɪd/	6	722.83	987.48	0.87	1,314.68	0.50
shrolls	/ʃroʊlz/	7	801.87	852.87	1.00	1,301.19	0.72
shugs	/ʃʌgz/	5	630.02	1,130.48	0.82	1,184.22	0.71
sleer	/slir/	5	703.34	900.68	0.92	1,166.08	0.97
slore	/slor/	5	636.70	952.79	1.00	1,190.50	1.00
smeels	/smilz/	6	811.81	930.97	0.94	1,161.97	1.00
smeighed	/smeɪd/	8	732.00	942.22	1.00	1,234.67	0.95
smigh	/smɑɪ/	5	720.96	854.27	0.97	1,272.33	0.97
smole	/smoʊl/	5	753.31	881.06	0.97	1,235.69	0.95
smub	/smʌb/	4	580.94	911.68	0.97	1,114.71	1.00
snace	/sneɪs/	5	734.05	821.89	0.97	1,156.45	1.00
snat	/snæt/	4	649.40	1,012.13	0.86	1,310.26	0.62
snay	/sneɪ/	4	650.67	823.87	0.89	1,179.50	0.97
snirs	/snɝz/	5	809.29	835.51	0.97	1,123.68	0.97
snouls	/snulz/	6	851.56	875.91	0.92	1,276.17	0.95
snue	/snu/	3	771.59	748.72	0.97	1,287.31	0.95
sote	/soʊt/	4	642.18	824.84	0.97	1,280.86	0.97
souts	/saʊts/	5	752.36	832.44	0.94	1,237.17	0.95
spag	/spæg/	4	720.83	823.97	1.00	1,237.27	0.97
spem	/spɛm/	4	693.45	879.65	0.92	1,259.78	0.95
spralks	/sprɑlks/	7	797.33	956.64	0.97	1,153.13	1.00
spround	/sprɑʊnd/	7	750.12	997.22	0.95	1,220.15	0.94
squail	/skweɪl/	6	764.95	1,092.52	0.57	1,279.29	0.80
squarn	/skwɑrn/	6	737.26	910.12	0.94	1,257.90	0.55
squerked	/skwɝkt/	8	781.63	1,032.78	0.84	1,255.40	0.66

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General Characteristics				Visual		Auditory	
ortho	**phono**	**# letters**	**acoustic duration**	*Mn* **LD lat**	*Mn* **Acc**	*Mn* **LD lat**	*Mn* **Acc**
stea	/sti/	4	636.81	959.32	0.97	1,206.71	0.92
stell	/stɛl/	5	650.85	967.86	0.92	1,331.86	0.76
stips	/stɪps/	5	703.30	943.38	0.84	1,334.76	0.76
strale	/strel/	6	720.14	893.76	1.00	1,214.97	0.97
sut	/sʌt/	3	594.58	848.32	0.84	1,150.97	0.91
swone	/swo͞un/	5	691.96	879.51	0.97	1,181.78	0.95
swudged	/swʌʤd/	7	735.61	891.46	0.97	1,210.69	0.97
tache	/tæʃ/	5	575.57	926.94	0.92	1,279.50	0.37
tade	/te͞ɪd/	4	533.35	940.23	0.91	1,277.09	0.86
tays	/te͞ɪz/	4	593.95	866.92	0.97	1,084.64	0.74
thafe	/ðe͞ɪf/	5	475.76	797.92	1.00	1,028.37	0.97
thite	/θɑ͞ɪt/	5	601.71	864.42	1.00	1,214.00	0.22
thop	/θɑp/	4	549.29	830.86	0.95	1,053.81	0.95
tiss	/tɪs/	4	436.22	903.68	0.78	1,098.93	0.71
trowed	/tro͞ud/	6	582.01	862.63	0.79	1,192.29	0.82
truds	/trʌdz/	5	524.74	849.35	0.89	1,054.65	0.61
twey	/twe͞ɪ/	4	484.54	740.49	0.97	1,116.31	0.95
twial	/twɑ͞ɪl/	5	591.11	857.57	0.95	1,161.88	0.86
udge	/ʌʤ/	4	429.74	957.06	0.84	1,069.00	0.79
ushed	/ʌʃt/	5	442.00	1,193.07	0.73	1,061.71	0.92
vaits	/ve͞ɪts/	5	575.42	812.11	0.97	1,134.37	0.73
vens	/vɛnz/	4	651.26	932.76	0.89	1,379.65	0.61
vorde	/vord/	5	551.73	808.40	0.95	1,214.03	0.78
vorn	/vorn/	4	623.79	818.79	0.89	1,188.36	0.76
vull	/vʌl/	4	577.94	777.78	0.95	1,193.35	0.94
wrells	/rɛlz/	6	592.73	801.42	1.00	1,101.39	1.00
wrunch	/rʌntʃ/	6	578.01	923.70	0.97	1,166.06	0.46
yare	/jɛr/	4	588.67	918.15	0.87	1,118.03	0.92
yent	/jɛnt/	4	568.06	888.23	0.95	1,092.73	0.97
yug	/jʌg/	3	521.84	777.41	0.97	982.42	0.95
yush	/jʌʃ/	4	552.86	857.57	0.95	1,056.16	1.00
zay	/ze͞ɪ/	3	555.17	785.05	0.97	1,089.97	0.97
zear	/zir/	4	591.11	803.73	0.89	1,126.40	0.95
zore	/zor/	4	611.76	753.81	0.95	1,084.03	0.92

APPENDIX H

Directions to Participants

Directions to Participants

1. ***Hearing Screening:***

I am going to present several tones to either your left or your right ear. Please raise the hand corresponding to the ear in which you hear each tone. Do you have any questions?

[PRESENT TONES]

2. ***Lexical Decision Task:***

IF THE AUDITORY SAY THE FOLLOWING FIRST: *First I need to set the volume of the headphones and then we will continue.*

You are going to [*SEE/HEAR*] several hundred [*WRITTEN/SPOKEN*] words. Some of the words will be real words and some will be nonsense words. Please [*READ/LISTEN* TO] each item and show whether you think it is a word or a nonsense word by pressing the button on the left marked *word* if the item is a word and pressing the button on the right marked *nonword* if the item is not a word. Please respond using only one hand throughout the entire task – either your right hand or your left hand. You can use 2 fingers, just one hand. Which hand will you be using?

[RECORD RESPONSE]

Please respond as quickly and accurately as possible. You cannot change your response after you press a button. If you are unsure about an item, make your best guess. You must respond to each item. Do you have any questions?

[PRESS SPACEBAR]

Good! Let's try 30 items for practice. While practicing you will receive feedback about your speed and accuracy on the computer screen after you respond to each item. I will remain in the room for the practice trials in case you have any questions. Press the spacebar when you are ready to begin.

Participant goes through the practice trials.

Great! That's the end of the practice trials. Now you will [*SEE/HEAR*] several hundred more items. For these, there won't be any feedback. Please continue using the same hand as you used in the practice items and *only* that hand to respond. Also, continue responding as quickly and accurately as possible and remember that you must respond to every item. Do you have any questions? [WAIT FOR A RESPONSE!]

Okay. After I leave the room and shut the door and when you are ready to begin, press the spacebar.

[LEAVE THE ROOM]

APPENDIX I

Covariate Data

Mean Lexical Decision Latencies Adjusted on Covariates

Descriptive statistics after adjusting for covariates acoustic duration and semantic

representation frequency estimate are in Table 23. The ANCOVA indicated a significant Main

Effect of Word Type (Table 24).

Table 23. Lexical Decision Latencies Adjusted on the Covariates Acoustic Duration and Semantic Representation Frequency Estimate

	Mn	*SD*	*SEM*
Heterographic homophones	905.98	183.59	9.68
Homographic homophones	898.49	183.80	9.69
Control Words	942.70	182.62	9.63
Visual	777.45	149.10	7.86
Auditory	1,054.00	149.10	7.86
Total	915.72	105.44	5.56

Table 24. ANCOVA Results Adjusted for the Covariates Acoustic Duration and Semantic Representation Frequency Estimate

Variable	*df*	*MS*	*F*	*d*	Power
Main effect of word type	2	67,079.12	6.04**	0.28	0.88
Main effect of modality	1	6,882364.19	619.18**	3.03	1.00
Modality and Word Type	2	11,564.86	1.04	0.15	0.23
Within-cells error	352	11,115.30			

Note. *p* < 0.05, **p* < 0.01

Tables 25 and 26 contain the descriptive statistics adjusted for the covariates in the visual

condition and auditory condition respectively. Within the visual and auditory conditions, there

significant Main Effects of Word Type (Tables 27 and 28). Visual lexical decision latencies

were significantly shorter to homographic homophones than to control words (Table 25).

Auditory lexical decision latencies were significantly shorter to heterographic homophones than

to control words and to homographic homophones than to control words (Table 26).

Table 25. Visual Lexical Decision Latencies Adjusted on the Covariates Acoustic Duration and Semantic Representation Frequency Estimates

	Mn	*SD*	*SEM*
Heterographic homophones	781.79ab	188.67	14.06
Homographic homophones	747.87a	188.88	14.08
Control Words	803.91a	187.66	13.99

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

Table 26. Auditory Lexical Decision Latencies Adjusted on the Covariates Acoustic Duration and Semantic Representation Frequency Estimates

	Mn	*SD*	*SEM*
Heterographic homophones	1,029.22a	161.33	12.03
Homographic homophones	1,049.61a	161.49	12.04
Control Words	1,081.94b	160.47	11.96

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

Table 27. One-Way ANCOVAs on Visual Lexical Decision Latencies Adjusted for the Covariates Acoustic Duration and Semantic Representation Frequency Estimate ($n = 180$)

Variable	*df*	*SS*	*MS*	*F*	*d*	Power
Word Type	2	94,639.43	47,317.25	4.03*	0.33	0.71
Error	175	2,053,926.81	11,736.73			

Note. *p* < 0.05 **p <0.01

Table 28. One-Way ANCOVAs on Auditory Lexical Decision Latencies Adjusted for the Covariates Acoustic Duration and Semantic Representation Frequency Estimate ($n = 180$)

Variable	*df*	*SS*	*MS*	*F*	*d*	Power
Word Type	2	84,589.88	42,294.94	4.93**	0.36	0.80
Error	175	1,502,026.74	8,583.01			

Note. *p* < 0.05 **p <0.01

APPENDIX J

Item Accuracy Outliers Removed

Analyses with Item Accuracy Outliers Removed

Response Accuracy Analyses

To determine whether these greater inaccuracy and longer lexical decision latencies for control words reflect token inaccuracy in lexical decision tasks, response accuracy data was submitted to statistical analyses by participants and items across word types. As with the initial analyses, participant and item data are analyzed with 2 (Modality) x 3 (Word Type) ANOVAs and One-way ANOVAs for visual lexical decision and auditory lexical decision. Response accuracy data were submitted for analyses as a proportion (i.e., number correct divided total possible correct).

Overall Response Accuracy Analyses

In sum, overall there were significant differences for response accuracy among word types which were maintained within analyses specific to each modality. As hypothesized, there were more control word accuracy outliers in each modality compared with the other stimulus word types. Such a concentration item accuracy outliers may have skewed the initial results. Accordingly, data are re-analyzed with item accuracy outliers excluded.

Descriptive statistics are presented in Table 29. In the 2 (Modality) x 3 (Word type) there was a significant Main Effect of Word Type by participants ($F_1(2, 148) = 3.92$, $p = 0.02$, $MSE = 1,159.44$, Cohen's $d = 0.06$, Power $= 0.70$; $F_2(2, 330) = 0.62$, $p = 0.54$, $MSE = 8,637.09$, Cohen's $d = 0.10$, Power $= 0.15$) and a significant Interaction between Modality and Word Type by participants ($F_1(2, 148) = 3.07$, $p < 0.05$, $MSE = 1,159.44$, Cohen's $d = 0.05$, Power $= 0.59$; $F_2(2, 330) = 0.44$, $p = 0.65$, $MSE = 8,637.09$, Cohen's $d = 0.06$, Power $= 0.12$).

Table 29. Descriptive Statistics by Participants and Items as a Function of Word Type and Modality

Word Type	*Mn*	*SD*	SEM
Participants (*N* = 76)			
Heterographic Homophones	892.30	195.31	22.40
Homographic Homophones	885.23	205.72	23.60
Control Words	900.68	213.46	24.49
Visual	750.04	204.26	23.43
Auditory	1,035.43	204.26	23.43
Items (*N* = 360)			
Heterographic Homophones	902.64	167.15	8.68
Homographic Homophones	891.42	171.48	8.56
Control Words	903.84	169.36	9.16
Visual	758.08	97.71	7.20
Auditory	1,040.52	87.41	7.17

Descriptive statistics for lexical decision latencies are in Table 30 for the visual condition and in Table 31 for the auditory condition. The One-way ANOVAs on lexical decision latencies yielded a significant main effect of word type by participants in the visual condition ($F_1(2, 74) = 3.30$, $p = .04$ $MSE = 1,077.45$, Cohen's $d = 0.10$, Power $= 0.61$; $F_2(2, 164) = 0.78$, $p = 0.46$, $MSE = 9,572.69$, Cohen's $d = 0.19$, Power $= 0.18$) and in the auditory condition by participants ($F_1(2, 74) = 3.67$, $p = .03$, $MSE = 1,241.42$, Cohen's $d = 0.13$, Power $= 0.66$; $F_2(2, 166) = 0.21$, $p = 0.81$, $MSE = 7,712.77$, Cohen's $d = 0.10$, Power $= 0.08$). Heterographic homophones had significantly longer visual lexical decision latencies than homographic homophones by participants (Table 30). Control words had significantly longer auditory lexical decision latencies than heterographic homophones (Table 31)

Table 30. Visual Lexical Decision Latencies as a Function of Word Type with Item Accuracy Outliers Excluded

Variable	*Mn*	*SD*	*SEM*
Participants (*n* = 38)			
Heterographic homophones	757.48$_a$	159.29	25.84
Homographic homophones	739.10 $_b$	147.04	23.85
Control Words	753.53$_{ab}$	165.85	26.90
Items (*n* = 167)			
Heterographic homophones	767.86	113.21	12.19
Homographic homophones	745.63	83.05	12.63
Control Words	760.75	96.09	13.57

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

Table 31. Auditory Lexical Decision Latencies as a Function of Word Type with Item Accuracy Outliers Excluded

Variable	*Mn*	*SD*	*SEM*
Participants (*n* = 38)			
Heterographic homophones	1,027.12$_a$	120.87	19.61
Homographic homophones	1,031.35$_{ab}$	142.51	23.12
Control Words	1,047.83$_b$	142.76	25.84
Items (*n* = 169)			
Heterographic homophones	1,037.42	83.16	11.34
Homographic homophones	1,037.22	96.07	11.53
Control Words	1,046.93	83.20	12.30

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

APPENDIX K

Morphologically Different Heterographic homophones Removed

Analyses with Morphologically Different Heterographic homophones Excluded

Morphologically different heterographic homophones were excluded from the stimulus set used in the analysis with Item Accuracy Outliers Excluded (Appendix I). In visual lexical decision, 5,256 data points remained of the 6,840 possible data points (76.84%). In auditory lexical decision, 5,315 data points remained of the 6,840 possible data points (77.70%).

Descriptive statistics are shown in Table 32. The 2 (Modality) x 3 (Word type) ANOVAs yielded a significant Main Effect of Word Type by participants ($F_1(2, 148) = 4.07$, $p = 0.02$, $MSE = 1,149.64$, Cohen's $d = 0.09$, Power $= 0.79$; $F_2 (2, 311) = 0.51$, $p = 0.60$, $MSE = 8,294.11$, Cohen's $d = 0.06$, Power $= 0.13$).

Table 32. Lexical Decision Latencies with Morphologically Heterographic Homophones Excluded

Word Type	Mn	SD	SEM
Participants ($N = 76$)			
Heterographic Homophones	888.39	199.54	16.58
Homographic Homophones	886.10	205.58	16.69
Control Words	900.68	213.46	17.75
Visual	748.37	206.07	23.64
Auditory	1,035.08	206.07	23.64
Items ($N = 360$)			
Heterographic Homophones	896.84	168.03	9.30
Homographic Homophones	891.42	171.48	8.39
Control Words	903.84	169.36	8.97
Visual	754.72	94.18	7.29
Auditory	1,040.01	87.14	7.24

Tables 33 and 34 contain descriptive statistics for visual and auditory lexical decision latencies, respectively. In the One-way (word type) ANOVA on visual lexical decision latencies the main effect of word type did not approach significance, $F_1(2, 74) = 1.62$, $p = 0.21$, $MSE = 1,044.34$, Cohen's $d = 0.07$, Power $= 0.33$; $F_2 (2, 155) = 0.41$, $p = 0.67$, $MSE = 8,925.42$, Cohen's $d = 0.14$, Power $= 0.12$. In the One-way (word type) ANOVA on auditory lexical decision latencies, the main effect of word type reached significance by participants, $F_1(2, 74) =$

3.91, $p = 0.02$, $MSE = 1{,}252.94$, Cohen's $d = 0.14$, Power $= 0.69$; $F_2(2, 156) = 0.24$, $p = 0.78$,

$MSE = 7{,}686.85$, Cohen's $d = 0.11$, Power $= 0.09$. Heterographic homophones had significantly

shorter auditory lexical decision latencies than control words by participants (Table 34).

Table 33. Visual Lexical Decision Latencies with Morphologically Different Heterographic Homophones Excluded

Variable	*Mn*	*SD*	*SEM*
Participants ($n = 38$)			
Heterographic homophones	750.72	161.13	26.14
Homographic homophones	740.84	148.39	24.07
Control Words	753.53	165.85	26.90
Items ($n = 158$)			
Heterographic homophones	757.79	105.99	13.93
Homographic homophones	745.63	83.05	12.20
Control Words	760.75	96.09	13.10

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

Table 34. Auditory Lexical Decision Latencies with Morphologically Different Heterographic Homophones Excluded

Variable	*Mn*	*SD*	*SEM*
Participants ($n = 38$)			
Heterographic homophones	$1{,}026.06_a$	125.76	20.40
Homographic homophones	$1{,}031.35_{ab}$	142.51	23.12
Control Words	$1{,}047.83_b$	142.76	23.16
Items ($n = 159$)			
Heterographic homophones	1,035.89	81.29	12.38
Homographic homophones	1,037.22	96.07	11.50
Control Words	1,046.93	83.30	12.26

Note. Within each section of the table, means that differ significantly ($p \leq 0.05$) are given different subscripts.

BIBLIOGRAPHY

American Speech-Language-Hearing Association Audiologic Assessment Panel 1996 (1997). *Guidelines for audiologic screening.* Rockville, MD: Author.

Azuma, T. (1996). Familiarity and relatedness ratings for 110 homographs. *Behavioral Research Methods, Instruments, and Computers*, *28*, 109-124.

Azuma, T. & Van Orden, G. C. (1997). Why SAFE is better than FAST: The relatedness of a word's meanings affects lexical decision times. *Journal of Memory and Language, 36*, 484-504.

Baayen, R. H., Piepenbrock, P., & van Rijn, H. (1993). The CELEX Lexical Database (CD-ROM). Linguistic Data Consortium, University of Pennsylvania, Philadelphia, PA.

Balota, D. A., Cortese, M. J., Hutchison, K. A., Neely, J. H., Nelson, D., Simpson, G. B., & Treiman, R. (2002). The English lexicon project: A web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords. HTTP://elexicon.wustl.edu

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133* (2), 283-316.

Bell, L. C. & Perfetti, C. A. (1994). Reading skill: Some adult comparisons. *Journal of Experimental Psychology, 86* (2), 244-255.

Blair, I. V., Urland, G. R., & Ma, J. E. (2002). Using internet search engines to estimate word frequency. *Behavioral Research Methods, Instruments, and Computers, 34* (2), 286-290.

Borowsky, R. & Masson, M. E. J. (1996). Semantic ambiguity effects in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22* (1), 63-85.

Brown, G. D. & Watson, F. L. (1987). First in, first out: Word learning age and spoken frequency as predictors of word familiarity and word naming latency. *Memory and Cognition, 15* (3), 208-216.

Burgess, C. & Livesay, K. (1998). The effect of corpus size in predicting reaction time in a basic word recognition task: Moving on from Kučera and Francis. *Behavior Research Methods, Instruments, and Computers, 30* (2), 272-277.

Carroll, J. B., Davies, P., & Richman, B. (1971). *Word Frequency Book*. Boston: Houghton Mifflin.

Cleland, A. A., Gaskell, M. G., Quinlan, P. T., & Tamminen, J. (2006). Frequency effects in spoken and visual word recognition: Evidence from dual-task methodologies. *Journal of Experimental Psychology: Human Perception and Performance, 32* (1), 104-119.

Coltheart, M. (2004). Are there lexicons? *The Quarterly Journal of Experimental Psychology, 57A* (7), 1153-1171.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A Dual Route Cascaded Model of visual word recognition and reading aloud. *Psychological Review, 108* (1), 204-256.

Daneman, M., Reingold, E. M., & Davidson, M. (1995). Time course of phonological activation during reading: Evidence from eye fixations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21* (4), 884-898.

Davelaar, E., Coltheart, M., Besner, D., & Jonasson, J. T. (1978). Phonological recoding and lexical access. *Memory and Cognition, 8*, 195-209.

de Groot, A. M. B. (1989). Representational aspects of word imageability and word frequency as assessed through word association. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*, 824-845.

De Moor, W., Verguts, T., Brysbaert, M. (2005). Testing the Multiple in the multiple read-out model of visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31* (6), 1502-1508.

Dixon, P. & Twilley, L. C. (1999a). An integrated model of meaning and sense activation and disambiguation. *Brain and Language, 68*, 165-171.

Dixon, P. & Twilley, L. C. (1999b). Context and homograph meaning resolution. *Canadian Journal of Experimental Psychology, 53* (4), 335-346.

Dobbs, A. R., Friedman, A., & Lloyd, J. (1985). Frequency effects in lexical decisions: a test of the Verification Model. *Journal of Experimental Psychology: Human Perception and Performance, 11* (1), 81-92.

Edwards, J. D., Pexman, P. M., & Hudson, C. E. (2004). Exploring the dynamics of the visual word recognition system: Homophone effects in LDT and naming. *Language and Cognitive Processes, 19* (4), 503-532.

Fiez, J. A., Balota, D. A., Raichle, M. E., & Petersen, S. E. (1999). Effects of word frequency, spelling-to-sound regularity, and lexicality on the functional anatomy of word reading. *Neuron, 24*, 205-218.

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

Folk, J. R. & Morris, R. K. (1995). Multiple lexical codes in reading: Evidence from eye movement, naming time, and oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21* (6), 1412-1429.

Frost, R. (1998). Toward a strong phonological theory of Visual word recognition: True issues and false tails. *Psychological Bulletin, 123* (1), 71-99.

Frost, S. J., Fowler, C. A., & Rueckl, J. G. (2003). *Bidirectional orthographic-phonological consistency effects on auditory word perception and production.* Manuscript submitted for publication.

Galanter, E. G. (1962). Contemporary psychophysics. In R. Brown, E. Galanter, E. H. Hess, & G. Mandler (Eds.), *New Directions in Psychology* (pp. 89-114). New York: Holt, Rinehart, & Winston.

Gaskell, M. G. & Marslen-Wilson, W. D. (1997). Integrating for and meaning: A distributed model of speech perception. *Language and cognitive processes, 12* (5/6), 613-656.

Gaskell, M. G. & Marslen-Wilson, W. D. (2002). Representation and competition in the perception of spoken words. *Cognitive Psychology, 25,* 220-266.

Gibbs, P. & Van Orden, G. C. (1998). Pathway selection's utility for control of word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24* (4), 1162-1187.

Gilhooly, K. J. & Logie, R. H. (1980). Meaning-dependent ratings of imagery, age of acquisition, familiarity, and concreteness for 387 ambiguous words. *Behavior Research Methods & Instrumentation, 12* (4), 428-450.

Goldinger, S. D. (1996). Auditory lexical decision. *Language and Cognitive Processes, 11* (6), 559-567.

Gottlob, L. R., Goldinger, S. D., Stone, G. O., & Van Orden, G. C. (1999). Reading homographs: Orthographic, phonologic, and semantic dynamics. *Journal of Experimental Psychology: Human Perception and Performance, 25* (2), 561-574.

Griffin, Z. M. (1999). Frequency of meaning use for ambiguous and unambiguous words. *Behavior Research Methods, Instruments, and Computers, 31* (3), 520-530.

Grossberg, S. (2000). The complementary brain: Unifying brain dynamics and modularity. *Trends in Cognitive Sciences, 4* (6), 233-246.

Harm, M. W. & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111* (3), 662-720.

Hino, Y., Lupker, S. J., & Pexman, P. M. (2002). Ambiguity and synonymy effects in lexical decision, naming, and semantic categorization tasks: Interactions between orthography, phonology, and semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28* (4), 686-713.

Hobbs, J. B. (1999). *Homophones and homographs: An American dictionary* (3rd ed.). Jefferson, NC: McFarland & Company, Inc.

Holden, J. G. (2002). Fractal characteristics of response time variability. *Ecological Psychology, 14* (1-2), 53-86.

Huck, S. W. & Cormier, W. H. (1996). *Reading Statistics and Research* (2nd ed.). New York, NY: Longman.

Jared, D. (2002). Spelling-sound consistency and regularity effects in word naming. *Journal of Memory and Language, 46* (4), 723-750.

Jared, D., Levy, B. A., & Rayner, K. (1999). The role of phonology in the activation of word meanings during reading: Evidence from proofreading and eye movements. *Journal of Experimental Psychology: General, 128* (3), 219-264.

Kawamoto, A. H., Farrar, W. T., & Kello, C. T. (1994). When two meanings are better than one: Modeling the ambiguity advantage using a recurrent distributed network. *Journal of Experimental Psychology: Human Perception and Performance, 20* (6), 1233-1247.

Kellas, G., Ferraro, F. R., & Simpson, G. B. (1988). Lexical ambiguity and the time course of attentional allocation in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 14* (4), 601-609.

Klein, D. E. & Murphy, G. L. (2001). The representation of polysemous words. *Journal of Memory and Language, 45*, 259-282.

Klepousniotou, E. (2002). The processing of lexical ambiguity: Homonymy and polysemy in the mental lexicon. *Brain and Language, 81*, 205-223.

Kučera, H. & Francis, W. N. (1967). *Computational Analysis of Present-Day American English.* Providence, RI: Brown University Press.

Lee, C. J. (2003). Evidence-based selection of word frequency lists. *Journal of Speech-Language Pathology and Audiology, 27*, 170-173.

Lewellen, M. J., Goldinger, S. D., Pisoni, D. B., & Greene, B. G. (1993). Lexical familiarity and processing efficiency: Individual differences in naming, lexical decision, and semantic categorization. *Journal of Experimental Psychology: General, 122* (3), 316-330.

Luce, P. A., Goldinger, S. D., Auer, E., & Vitevitch, M. S. (2000). Phonetic priming, neighborhood activation, and PARSYN. *Perception and psychophysics, 62* (3), 615-625.

Luce, P. A. & Pisoni, D. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*, 1-36.

Marcus, M. P., Santorini, B., & Marcinkiewicz, M. A. (1993). Building a large annotated corpus of English: The Penn treebank. *Computational Linguistics*, *19* (2), 313-330.

Martin, F. N. (1994). *Introduction to Audiology* (5th ed). Englewood Cliffs, NJ: Prentice-Hall, Inc.

McClelland, J. L. (1991). Stochastic interactive processes and the effect of context on perception. *Cognitive Psychology, 23*(1), 1-44.

McClelland, J. L. & Elman, J. L. (1986a). The TRACE Model of Speech Perception. *Cognitive Psychology, 18*, 1-86.

McClelland, J. L. & Elman, J. L. (1986b). Interactive processes in speech perception: The TRACE Model. In J. A. Feldman, P. J. Hayes, & D. E. Rumelhart (Eds.), *Parallel Distributed Processing: Explorations in the microstructure of cognition. Psychological and Biological Models (Vol. 2).* Cambridge, MA: The MIT Press.

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88* (15), 375-407.

McLennan, C. T. & Luce, P. A. (2005). Examining the time course of indexical specificity effects in spoken word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31* (2), 306-321.

Montant, M. (2000). Feedback: A general mechanism in the brain. *Behavioral and Brain Sciences, 23* (3), 340-341.

Nixon, S. M. (2002). [Feedback and feedforward consistency of onsets and rimes in English]. Unpublished raw data.

Nixon, S. M. et al. (in preparation). *Validating Internet-based estimates of meaning dominance.*

Norris, D. G. (1994). Shortlist: A connectionist model of continuous speech recognition. *Cognition, 52*, 189-234

Norris, D., McQueen, J. M., & Cutler, A. (2000a). Feedback on feedback: It's feedforward. *Behavioral and Brain Sciences, 23*, 352-370.

Norris, D., McQueen, J. M., & Cutler, A. (2000b). Merging information in speech recognition: Feedback is never necessary. *Behavioral and Brain Sciences, 23*, 299-370.

Pecher, D. (2001). Perception is a two-way junction: Feedback semantics in word recognition. *Psychonomic Bulletin & Review, 8* (3), 545-551.

Peereman, R. & Content, A. (1997). Orthographic and phonological neighborhoods in naming: Not all neighbors are equally influential in orthographic space. *Journal of Memory and Language, 37* (3), 382-410.

Peereman, R., Content, A., & Bonin, P. (1998). Is perception a two-way street? The case of feedback consistency in visual word recognition. *Journal of Memory and Language, 39*, 151-174.

Pexman, P. M., Hino, Y., & Lupker, S. J. (2004). Semantic ambiguity and the process of generating meaning from print. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30* (6), 1252-1270.

Pexman, P. M. & Lupker, S. J. (1999). Ambiguity and visual word recognition: Can feedback explain both homophone and polysemy effects? *Canadian Journal of Experimental Psychology, 53* (4), 323:334.

Pexman, P. M., Lupker, S. J., & Hino, Y. (2002). The impact of feedback semantics in visual word recognition: Number-of-feature effects in lexical decision and naming tasks. *Psychonomic Bulletin and Review, 9* (3), 542-549.

Pexman, P. M., Lupker, S. J., & Jared, D. (2001). Homophone effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27* (1), 139-156.

Pexman, P. M., Lupker, S. J., & Reggin, L. D. (2002). Phonological effects in visual word recognition: Investigating the impact of feedback activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28* (3), 572-584.

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* (1), 56-115.

Protopapas, A. (1999). Connectionist modeling of speech perception. *Psychological Bulletin, 125* (4), 410-436.

Radeau, M., Morais, J., Mousty, P., Saerens, M. & Bertelson, P. (1992). A listener's investigation of printed word processing. *Journal of Experimental Psychology: Human Perception and Performance, 18* (3), 861-871.

Radeau, M., Mousty, P., & Bertelson, P. (1989). The effect of the uniqueness point in spoken word recognition. *Psychological Research, 51*, 123-128.

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Bulletin, 111* (1), 159-182.

Rodd, J. M., Gaskell, M. G., Marslen-Wilson, W. D. (2004). Modeling the effects of semantic ambiguity in word recognition. *Cognitive Science, 28*, 89-104.

Rodd, J., Gaskell, G., & Marslen-Wilson, W. (2002). Making sense of semantic ambiguity: Semantic competition in lexical access. *Journal of Memory and Language, 46*, 245-266.

Rondthaler, E. & Lias, E. J. (Eds.). (1986). *Dictionary of simplified American spelling: An alternative spelling for English*. New York, NY: The American Language Academy.

Rueckl, J. G. (2002). The dynamics of visual word recognition. *Ecological Psychology, 14* (1-2), 5-19.

Rumelhart, D. E. & McClelland, J. L. (1982). An interactive activation model of contact effects in letter perception: II. The contextual enhancement effect and some tests and extension of the model. *Psychological Review, 89* (1), 60-94.

Samuel, A. G. (2001). Some empirical tests of Merge's architecture. *Language and Cognitive Processes, 16* (5/6), 709-714.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). E-Prime (Version 1.1) [Computer software]. Pittsburgh, PA: Psychology Software Tools, Inc.

Sears, C. R., Hino, Y., & Lupker, S. J. (1995). Neighborhood size and neighborhood frequency effects in word recognition. *Journal of Experimental Psychology: Human Perception & Performance, 21* (4), 876-900.

Seidenberg, M. S. & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96* (4), 523-68.

Smith, M. C. & Besner, D. (2001). Modulating semantic feedback in visual word recognition. *Psychonomic Bulletin and Review, 8* (1), 111-117.

Starr, M. S. & Fleming, K. K. (2001). A rose by any other name is not the same: The role of orthographic knowledge in homophone confusion errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27* (3), 744-760.

Stone, G. O., Vanhoy, M., & Van Orden, G. C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory and Language, 36*, 337-359.

Stone, G. O. & Van Orden, G. C. (1994). Building a resonance framework for word recognition using design and system principles. *Journal of Experimental Psychology: Human Perception and Performance, 20* (6), 1248-1268.

Tanenhaus, M. K., Magnuson, J. S., McMurray, B., & Aslin, R. N. (2000). No compelling evidence against feedback in spoken word recognition. *Behavioral and Brain Sciences, 23* (3), 348-349.

Twilley, L. C. & Dixon, P. (2000). Meaning resolution processes for words: A parallel independent model. *Psychonomic Bulletin & Review, 7* (1), 49-82.

Unsworth, S. J. & Pexman, P. M. (2003). The impact of reader skill on phonological processing in visual word recognition. *The Quarterly Journal of Experimental Psychology, 56A* (1), 63-81.

Van Orden, G. C. (2002). Nonlinear dynamics and psycholinguistics. *Ecological Psychology, 14* (1-2), 1-4.

Van Orden, G. C., Bosman, A. M. T., Goldinger, S. D., & Farrar, W. T. (1997). A recurrent network account of reading, spelling, and dyslexia. In G. E. Stelmach & P. A. Vroon (Eds.) & J. W. Donahoe & V. Packard Dorsel (Vol. Eds.), *Advances in Psychology: Vol. 121. Neural-Network Models of Cognition: Biobehavioral Foundations* (pp. 522 - 538). New York, NY: Elsevier.

Van Orden, G. C. & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of primed words. *Journal of Experimental Psychology: Human Perception and Performance, 20* (6), 1269-1291.

Van Orden, G. C., Jansen op de Haar, M. A., & Bosman, A. M. T. (1997). Complex dynamic systems predict dissociations, but they do not reduce to autonomous components. *Cognitive Neuropsychology, 14* (1), 131-165.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97* (4), 488-522.

Ventura, P., Morais, J., Pattamadilok, C., & Kolinsky, R. (2004). The locus of the orthographic consistency effect in auditory word recognition. *Language and Cognitive Processes, 19* (1), 57-95.

Vitevitch, M. S. (2002). The influence of phonological similarity neighborhoods on speech production. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 28* (4), 735-747.

Whaley, C. P. (1978). Word-nonword classification time. *Journal of Verbal Learning and Verbal Behavior, 17*, 143-154.

Zeno, S. M., Ivens, S. H., Millard, R. T., & Ruvvuri, R. (1995). *The Educator's Word Frequency Guide.* New York, NY: Touchstone Applied Science Associates.

Ziegler, J. C. & Ferrand, L. (1998). Orthography shapes the perception of speech: the consistency effect in auditory word recognition. *Psychonomic Bulletin and Review, 5* (4), 683-689.

Ziegler, J. C., Ferrand, L., & Montant, M. (2004). Visual phonology: The effects of orthographic consistency on different auditory word recognition tasks. *Memory and Cognition, 32* (5), 732-741.

Ziegler, J. C., Montant, M., & Jacobs, A. M. (1997). The feedback consistency effect in lexical decision and naming. *Journal of Memory and Language, 37*, 533-554.

Ziegler, J. C., Muneaux, M., & Grainger, J. (2003). Neighborhood effects in auditory word recognition: Phonological competition and orthographic facilitation. *Journal of Memory and Language, 48*, 779-793.

Zorzi, M. (2000). Serial processing in reading aloud: No challenge for a parallel model. *Journal of Experimental Psychology: Human Perception and Performance, 26* (2), 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* (4), 1131-1161.