1068

Toward a Strong Phonological Theory of Visual Word Recognition: True Issues and False Trails

Ram Frost
Hebrew University

A strong phonological theory of reading is proposed and discussed. The first claim of this article is that current debates on word recognition are often based on different axioms regarding the cognitive structures of the mental lexicon rather than conflicting empirical evidence. These axioms lead to different interpretations of the same data. It is argued that once the implicit axioms of competing theories in visual word recognition are explicated, a strong phonological model presents a viable and coherent approach. The assumptions underlying a strong phonological theory of reading are outlined, and 4 theoretical questions are examined: Is phonological recoding a mandatory phase of print processing? Is phonology necessary for lexical access? Is phonology necessary for accessing meaning? How can phonology be derived from orthographic structure? These issues are integrated into a general theory that is constrained by all of the findings.

The process of recognizing printed words has been studied for many years and has been a very active field of scientific inquiry. It has provided researchers not only with novel and ingenious experimental techniques but also with rich and comprehensive sets of data that describe almost every aspect of reading. Yet, despite the abundance of accumulated data, the major controversies that have dominated the field for so many years seem to be as lively as ever. This presents a disheartening state of affairs. Experiments are being run each year by the hundreds, yet their results fail to convince the unconvinced. Moreover, most of the theories that were offered years ago by the pioneers of this field of research are being challenged today just as they were in the past. One such theoretical issue is the role of phonology in visual word recognition. From the early classical articles by researchers such as Rubenstein and Forster (e.g., Forster & Chambers, 1973; Fredriksen & Kroll, 1976; Rubenstein, Lewis, & Rubenstein, 1971) to the more recent connectionist works on reading (e.g., Seidenberg & McClelland, 1989; Van Orden, Pennington, & Stone, 1990), this issue has consistently remained on the agenda. Nevertheless, it seems that the last 25 years of investigation have provided researchers with enough data to enable them to re-examine at least the basic tenets of the

various competing theories. Such a meta-analysis can serve the purpose of redefining the current controversies, thereby clarifying what are still empirical questions to be pursued and what are not.

In a historical perspective, cognitive issues have often been cast into dichotomous alternatives, which have resulted in a pendulum-like swing from one view to the opposite one. Such has been the fate of the propositional versus dual-coding debate, the parallel versus serial processing controversy, and the network versus feature-set semantic memory issue. In the field of word recognition, the current swing of the pendulum seems to have settled for the last 15 years on the dual-route theory. Indeed, the last review of phonological recoding and reading published in *Psychological Bulletin* (McCusker, Hillinger, & Bias, 1981) concluded that dual-access models seem to account best for the large array of findings reported so far. In present context, *dual-route theory* does not refer specifically to the "flow-chart" properties of classical lexical access models. Rather, it refers to the basic assumptions about the relative importance of ortho-graphic versus phonological processing of printed words, regardless of whether these processes are presented in terms of lexical access, cascaded models, or a connectionist framework. Dual-route models (e.g., Coltheart, 1980; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart & Rastle, 1994; Paap & Noel, 1991) have traditionally argued for two distinct and independent modes of processing printed words: one that relies on their visual-orthographic properties and one that recovers their phonological structure. One major claim of dual-access models involves the superiority of visual-orthographic processing that bypasses the computation of phonology. Although this superiority could be limited mainly to frequent words, it is seen as a universal property of the cognitive system, independent of the different characteristics of different writing systems (e.g., Baluch & Besner, 1991). Given the current prominence of dual-access theory, the present article should be considered an attempt to swing the pendulum back toward the recognition of the central and primary role of phonological processing in word recognition. In

line with this general goal, in this article I contend that a strong phonological model, which views phonological processing as the default procedure of the cognitive system, can accommodate most findings in visual word perception and that the converging evidence from a wide range of experimental methods fits this model quite well. If the advantage of a phonological model over its current competitors does not seem sufficiently convincing for reasons of parsimony, utility, and inclusiveness, the minimal goal of the present discussion is to argue that a strong phonological model is at least viable and coherent as the alternative view.

Theory Axioms Versus Empirical Questions

A close examination of the various positions on the role of phonology in reading reveals that they are not necessarily based on conflicting empirical evidence but mostly on different axioms about the cognitive structures of the mental lexicon and the dynamic processes operating on these structures. These axioms are often implicit and not specified a priori as the basis for constructing a specific theory of reading. Thus, they are mostly hidden tenets implicitly assumed by the researcher. More important, arguments based on these tenets often cannot be resolved on the basis of direct empirical evidence. Rather, they involve a general stand on how a theory of reading should be constructed and what phenomena should constrain it as well as an overall assessment of the parsimony and explanatory adequacy of any particular theory. Evidence supporting these basic assumptions often comes from indirect and circumstantial empirical results.

In the first part of this article, I thus outline the working axioms of the strong phonological model of reading. In the second part, the empirical evidence that supports or contests the model is analyzed in light of these implicit axioms. The aim of this analysis is merely to tie the possible stands on reading to the hidden assumptions from which they necessarily follow.

Working Axioms and Working Definitions

The Linguistic Axiom

The first choice point encountered in formulating a theory of reading is whether to regard the domain of visual word perception as belonging primarily to the language domain or to the domain of visual perception. *Primarily* is of crucial importance here because the processing of printed words (linguistic units) obviously involves the visual-perceptual system at some early stages (see Henderson, 1987; and Massaro & Cohen, 1994, for discussions). The issue is, however, whether a theory of reading should be primarily linguistic or primarily visual. Should a theory of processing printed words be more closely related to a theory of processing pictures or pattern recognition, for example, or should it be more closely related, say, to a theory of speech processing? Because both visual and linguistic components are involved in visual word perception, choosing between the visual and the linguistic axioms on purely empirical grounds is not an easy task. In fact, one might argue that there is practically an opposite directionality of cause and effect here: The empirical evidence is assessed differently if the linguistic axiom

is adopted rather than the visual, instead of the empirical evidence necessarily suggesting which axiom is to be adopted.

In this article, I contend that visual word processing should be regarded primarily as a linguistic ability, thus belonging to the faculty of language. Therefore, any debate in this area should be discussed first in terms of what characterizes natural human languages. This imposes important constraints on the explanations that may be offered to account for various phenomena. Those who would like to see a theory of reading as primarily visual and nonlinguistic in nature would therefore belong to a different school of thought (see, e.g., Massaro & Cohen, 1994).

Although the choice of one set of axioms might seem to be as justified as the choice of another, there can be arguments for evaluating the basic tenets of a model or a theory. These arguments may concern the utility of the theory, its possible contribution to the understanding of possible phenomena, its ability to generate a rich variety of experiments and empirical data, and, most important, its capacity to embrace a complex variety of positive findings rather than seeking ways of explaining them away as idiosyncratic strategy hypotheses. When these characteristics are assessed, the visual theory of reading does not seem to be very promising. First, there is ample evidence that reading skills are highly correlated with other linguistic abilities, such as phonological and morphological awareness, rather than with simple visual performance (e.g., Goswami & Bryant, 1990; I. Y. Liberman, Shankweiler, Liberman, Fowler, & Fisher, 1977). Similarly, neuropsychological studies have repeatedly shown a clear relationship between reading disorders and other language disorders (e.g., Coltheart, 1980). Note that if printed words are considered a subset of all analogical stimuli rather than entities of language, their ordered mapping into linguistic units becomes theoretically irrelevant or of secondary importance. Consequently, a visual model would search for correlations between graphic patterns and participants' responses, disregarding the correlation between orthographic units and phonological forms. Thus, such a model would be unable to account for not only the above correlation between reading and other linguistic skills but also most of the effects found in word-recognition studies with healthy participants. For example, the effects of homophony (e.g., Rubenstein, Lewis, at al., 1971), regularity (e.g., Seidenberg, Waters, Barnes, & Tannenhaus, 1984), consistency (e.g., Glushko, 1979), or syllabic structure (e.g., Spoehr, 1978), which constitute a significant portion of the empirical findings on word perception, are of secondary relevance to a pure visual–analogical theory of reading. This is because they involve primarily correlational regularities between stimulus components and phonological or morphophonological units. Such effects would be accounted for by assuming experiment-specific strategies over and over again while considering the variance due to phonological or morphological factors as residual or error variance. In fact, purely visual models of word perception are able to account for very few interesting phenomena within a single unified set of axioms. Consequently, they have very limited explanatory power. They might perhaps accommodate the word frequency effect (e.g., Scarborough, Cortese, & Scarborough, 1977) but only in terms of simple frequency of letter sequences, and they could account for the word superiority effect (Reicher, 1969) but only as a subset of the object superiority effect (e.g., Weisstein & Harris, 1974). Thus, choosing the

visual axiom as a primary axiom in word perception would necessarily result in an impoverished theory, lacking explanatory or descriptive adequacy.

It is important to clarify the meaning of *visual* here. This term has been used interchangeably in the reading literature to mean both analogical and nonphonological processing. Note that the above criticism of the visual axiom involves only its analogical character. To avoid confusion, some researchers use the term *orthographic* instead of visual. This distinction is crucial because it represents a different choice of axiom. Whereas visual encoding, as discussed above, refers to the analogical aspects of the stimulus, orthographic encoding refers to its letter sequence, which is a linguistic structure. Therefore, those who propose, for example, orthographic, nonphonological encoding of printed stimuli accept the linguistic axiom. In fact, most proponents of dual-access models accept the linguistic axioms and constrain the discussions of the prominence of visual access in word recognition to the encoding of abstract orthographic units. Thus, it should be emphasized that within the linguistic framework, the common usage of visual denotes the orthographic rather than the analogical interpretation. Because the visual–analog model does not appear to present a viable unified approach to reading, the following discussions are held within the linguistic framework. Thus, all axioms presented in the following sections are in fact subaxioms of the linguistic view of reading. Before proceeding with a description of these subaxioms and in light of the above clarification, the two major constructs, phonology and orthography, should be explicated to establish a common ground for further discussion.

What Phonology Is and What It Is Not

An important characteristic of human language is phonetic production and perception. Human natural languages are phonetic in nature and communicate meanings by sequences of linguistic categories. How to characterize these categories is a matter of controversy in phonological theory. Linear autosegmental phonology (e.g., Clements, 1985) assumes that a word's phonological form involves a sequence of abstract phonemic units like consonants and vowels, which themselves dominate hierarchically organized discrete and atemporal feature values. In contrast, nonlinear phonology (e.g., Goldsmith, 1976, 1990) argues that the primitives of phonological structures are not discrete features because they depend on the context of articulation. For example, Browman and Goldstein (1986) suggested that the phonological primitives are articulatory gestures having specific temporal properties. Note, however, that the phonological structures postulated in reading theory are basically orthogonal to this debate. In general, the literature on reading describes phonology traditionally, regarding phonemes as classical categories that can be defined, identified, and perceived and that serve as the building blocks of spoken words. According to this view, phonology makes it possible to construct an extremely large set of words from a few dozen linguistic units (phonemes), thus allowing the communication of a vast array of meanings. Phonology is therefore a creative system that exploits combinatorial principles for generative purposes. Every human language has its own pool of phonetic units and a set of phonotactic rules describing their permissible combinations into words. However, most phonemic units are shared by all natural languages. The ability to perceive and produce the abstract phonological entities for comprehending and conveying meaning is the basis of human linguistic ability, and the transformation of the acoustic signal into a phonetic representation is often considered to be governed by a phonetic module that is biologically determined (e.g., A. M. Liberman & Mattingly, 1985; A. M. Liberman & Whalen, 1989).

To know a natural language means to know (among other things) a system of sound-meaning correspondences (Chomsky & Halle, 1968). As Chomsky and Halle pointed out, the phonological rules of a language connect the phonetic surface structures to underlying lexical representations that are abstracted from these phonetic features. The underlying lexical and phonological representations are abstract as compared with the surface phonetic representations but are both given in terms of phonetic features. Lexical representations are therefore abstract in a very clear sense; they relate to the surface spoken signal through a medium of rules of phonological transformations that apply to the signal (Chomsky & Halle, 1968).

Any sentence in a language has syntactic and semantic features. But in the course of understanding language, the syntactic and semantic analyses are contingent on a mapping onto the basic constituents of language, the words, which are represented in a phonologically abstract form in the lexicon. Indeed, the main linguistic constraints on what constitutes a word in a language are phonological; each language has phonotactic rules that constrain the possible units that represent semantic concepts. Thus, the recovery of any linguistic message necessarily entails accessing these phonological units, which are the vehicles that carry syntactic and semantic information and comprise the core of human lexical representations. The linguistic axiom merely asserts that models that account for isolated word perception should be coherent with a more general linguistic theory, and the same basic structures and processes that characterize human general linguistic functions are involved in processing printed words.

Although in the process of speech production the phonological structure of the spoken word is transformed into speech gestures that create sound, it is important to re-emphasize that phonology in itself is *not* sound. This is an important distinction because the term *phonological recoding*, which is meant to describe one possible way of processing printed words, should not be understood as "sounding out" these words or even realizing their surface phonetic properties. On the contrary, the phonological structure of a word is the structural description of the abstract linguistic categories that form that word. Therefore, phonological recoding means recovering this abstract structural description, not transforming it into speech gestures or covertly "playing out" the sounds these gestures could create. This confusion appears in the reading literature in studies aiming to show that phonological recoding does not occur by demonstrating that participants are not sounding out the words in their head in the form of covert speech (e.g., Barron & Baron, 1977; Kleiman, 1975; Levy, 1975; but see Besner, 1987, for a critical review). Although a simplistic articulatory view of phonological recoding is no longer popular, many studies still regard phonological recoding as a process that necessarily results in a detailed phonetic or acoustic representation rather than an abstract phonolog-

ical one. Phonological recoding represents, however, the opposite direction, from surface forms to deep abstract structures. The implications of the above distinction are elaborated in the discussion of the relevant empirical data.

What Orthography Is and What It Is Not

Orthographic systems, whether alphabetic, syllabic, or logographic, were invented a few thousand years ago with the aim of communicating units of spoken language in graphic form. The manner in which orthographies represent their spoken language depends on the characteristics of each language. Writing systems can be distinguished by the size of the linguistic units that the orthographic units transcribe: phonemes in English, syllables (moras), in Japanese *Kana*, or morphosyllables in Chinese characters. Most orthographic systems represent syllabic or subsyllabic linguistic units; that is, they are phonographic in nature. In logographic orthographies (e.g., Chinese, Japanese *Kanji*, Korean *Hanza*), however, the graphemic structure represents meaningful morphemes, not sublinguistic phonological units. But note that even in Chinese, 90% of the characters are phonetic compounds (although not necessarily consistent) and only 10% are semantic determiners whose purpose is to differentiate between the many homophones existing in that language (De-Francis, 1989).

A different transcription strategy was adopted in Japanese and Korean. Both Japanese *Kanji* and Korean *Hanza* imported the Chinese logographs but altered or distorted their phonological components. This is because the logographic symbols were meant to represent meaningful morphemes with a pronunciation differing from the original one, given the different spoken language into which they were imported. However, in both Japanese and Korean, phonographic notations were added as well for the purpose of facilitating reading. In Japanese texts, most *Kanji* words are printed along with a phonetic transcription next to them (*Okurigana*), which provides the reader with the necessary cues for pronouncing the logographs. In Korean, only 20% of printed words are written in the logographic *Hanza*, whereas the other 80% are written in a phonologically shallow script, the *Hangul*. But note that *Hanza* and *Hangul* characters are mixed inconsistently within a given text to facilitate reading, and it is not possible to write exclusively in the logographic *Hanza* (see Simpson & Kang, 1994, for a detailed description).

Thus, although writing systems are admittedly not phonographic to the same extent, they all contain at least some cues concerning the phonological structure of the printed words. The main implication of this characteristic is that writing systems were not designed (and in fact could not have been designed) to transcribe units of meaning directly without some reference to their phonological form. This is because languages are productive by nature, new words are constantly being invented, and meanings evolve with time. The only orthographic system that can in principle deal with language productivity is a spelling system that transcribes subword linguistic units, thereby specifying a priori a set of rules for representing novel words (Mattingly, 1992).

Orthographic systems can therefore be contrasted with pictographic systems. Pictures and many signs (e.g., a picture of a dog, an arrow sign, etc.) represent meaning directly and are characterized by nonarbitrary relations between graphic sign and transcribed meaning. The visual shape of a graphic sign per se conveys its meaning, and often this meaning can be recovered without prior explicit teaching. In contrast, for written words, the relations between graphic signs and meaning are arbitrary. This arbitrariness derives precisely from the fact that the graphic signs convey only phonological units systematically and that the mapping of phonological units into semantic meaning is indeed arbitrary. Van Orden and Goldinger (1994) labeled this state of affairs the *phonological coherence constraint*, arguing that the correlation between orthographic form and semantic features is necessarily low. Thus, the consistency between orthographic and phonological variation is greater than that between spelling and meaning. As a rule, the mapping between orthographic subunits and semantic features is inconsistent and unpredictable (with the possible exception of morphophonemic units, e.g., prefixes and suffixes, or other morphological derivations that are in fact mediated by phonological structures). Consequently, one assumes that at least in alphabetic orthographies, meaning cannot be recovered without explicit instructions that focus on the way the graphic signs represent the surface phonetic units of the spoken language and their matching phonological lexical representations.

In the present context, the above claims concerning human language serve but one purpose, to establish a priori plausibility for the following speech primacy axiom: Spoken language is the base onto which written language is subsequently appended.

The Speech Primacy Axiom

The speech primacy axiom states that the connection between spoken words and semantic meanings is the primary association formed in the process of language acquisition. Only later is an orthographic system developed. Being a secondary system, it is appended parasitically onto the already existing system. Because orthography represents the spoken language, it maps systematically onto phonology rather than meaning. The lexical structure that emerges from the speech primacy axiom thus represents a linear chain of links: Orthography is linked to phonology, which is linked to semantic meaning. Whether this structure changes later on for the skilled reader so that orthography maps directly onto semantic meaning, thus bypassing phonology, is still an open question. This is a major controversy in word perception, and I discuss it at length later on. The speech primacy axiom only asserts who, in principle, should carry the burden of proof in this controversy. Because, in reading acquisition, lexical structure initially connects orthography to phonology and not to meaning, the burden of proof lies on those who argue that a structural change emerges later on with skilled performance and that there is direct access from orthography to meaning, thus bypassing phonological structure. Direct evidence of such a structural change should be provided.

The Lexical Axiom

Any description of the dynamic operations involved in visual word recognition can be evaluated only in relation to the hypothesized structure of the cognitive system that contains the part of human linguistic knowledge called the *mental lexicon*. Cognitive

processes operate on underlying structures and are never independent of them. However, researchers' opinions differ as to the nature of these underlying structures. Thus, the mental lexicon can be viewed as a system composed of lexical entries that are organized into bins in which words are arranged by frequency of occurrence (e.g., Forster, 1992), an interactive system with localized representations connected through excitatory and inhibitory links (e.g., Jacobs, Grainger, Rey, & Ziegler, in press; McClelland & Rumelhart, 1981; also see Grainger & Jacobs, 1997), or an interactive system with distributed representations (e.g., Seidenberg & McClelland, 1989). It is not within the scope of this article for me to review all possible models that have been suggested to describe the corpus of human linguistic knowledge. However, as I argue later, some claims concerning the role of phonology in reading have been greatly affected by the structural assumptions that were proposed as basic axioms. As is the case with almost any cognitive model, most of the theoretical constructs are metaphorical in nature. It is important to examine the psychological reality of these constructs because with time some model metaphors tend to assume an ontological status and their metaphoric nature is often forgotten or overlooked.

The lexical axiom postulates that the cognitive system contains a corpus of linguistic representations corresponding to the basic units of natural languages—the words. How exactly each of these units is organized in relation to the others is a matter for empirical research. The lexical axiom simply states that people have words in their head and that these words are represented as localized units, whether they are labeled *lexical entries* (e.g., Rubenstein, Lewis, et al., 1971) or *word nodes* (e.g., McClelland & Rumelhart, 1981). Thus, the lexical axiom contrasts with models that regard words as nonlocalized distributed representations (e.g., Seidenberg, 1987; Seidenberg & McClelland, 1989). Some of these models have proposed that the human linguistic system can do without a lexicon by demonstrating that a set of interconnected primitive representational units can account for the basic phenomena that are characteristic of reading abilities: correct pronunciation and word–nonword decisions. Other models have advocated subsymbolic nonrepresentational units (e.g., Van Orden & Goldinger, 1994; Van Orden at al., 1990). Criticism of these models is not the point of the present article (but see Forster, 1994; and Stone & Van Orden, 1994). Obviously the endorsement of the lexical axiom as a working hypothesis reflects a view that models that assume localized word representations do a better job in accounting for human linguistic abilities than those models that do not (see Besner, Twilley, McCann, & Seergobin, 1990; Besner, in press; and Forster, 1994, for discussions). But as I argue in the following sections, the lexical axiom—unlike the previous ones—is orthogonal to many (although not all) of the issues discussed in this article. This is because, in general, the architectures of interactive models assuming distributed representations were a priori designed to simulate and account for the major empirical findings that were historically generated using the lexical axiom (e.g., Seidenberg & McClelland, 1989). When the descriptive adequacy of these models was criticized (e.g., Besner et al., 1990), they were often changed into improved versions within the same framework (e.g., Plaut & McClelland, 1993; Plaut, McClelland, Seidenberg, & Patterson, 1996). Thus, the lexical

axiom is assumed, not because of a considerable advantage it has in accounting for existing findings but mainly because it offers a set of terms that can be used consistently for assessing the various theories of visual word recognition (but see Besner, in press).

The Non-Neutrality of the Core Lexical Representation

The conjunction of the lexical and the speech primacy axiom defines a critical assumption concerning the basic structure of the mental lexicon. It suggests that the items listed in it are words; phonological entities representing meaning. Thus, the core of a lexical entry is the abstract form of a phonologically defined unit. Because the constraints on what constitutes a possible word in a language are primarily phonological, not semantic or orthographic, what defines a lexical entry is its phonological form. The list of entries in the lexicon reflects the number of phonological units having meanings, not the array of semantic features. In those languages that have writing systems (a minority of natural human languages), the units of the lexicon have an orthographic form as well. Obviously, skilled readers develop an efficient orthographic system, which could be labeled a visual or orthographic lexicon (e.g., Funnell & Allport, 1987; Monsell, 1987). But this label merely defers the present discussion by one step. My investigation is not concerned with the possible operations within an orthographic system but with a general model of the lexicon that describes the possible end results of these operations, the recovery of phonology and meaning.

The axiom that the human lexical system consists of phonologically defined core nuclei contrasts with another view that posits a *neutrally abstract* lexical representation. According to this view, the lexical units have an underlying core that is not phonological, orthographic, or semantic but is equally abstract in relation to them all. Thus, the phonological form, the orthographic cluster, and the semantic meaning are all satellites of one abstract entity, which can be accessed by any of these representations. The lexical entry is neutrally abstract because it is not closer to one than to the other. It is at the same time an abstraction of the printed form, the phonological structure, and the semantic meaning. The neutrality of the core lexical representation is, in most cases, an implicit axiom. For example, the logogen model (Morton, 1969) assumes an internal structure, which could be activated equally by orthographic, phonological, and semantic information. The neutrality of this lexical unit, therefore, derives from its capacity to accumulate activation additively and indiscriminately from all types of information, regardless of their surface form.

The neutrality of lexical entries is an appealing concept. It views the lexical system as a symmetrical equilateral triangle in which the lexical entry is at the center of the triangle while the phonological, semantic, and orthographic representations are equally distant from this center. Unlike the non-neutral view, such a structure allows all possible connections, paths, transformations, and access routes within the lexicon. This is because all the possible surface structures of a given word map into one abstract representation. However, if the costs and benefits of this structure for a model of reading are considered, the neutral abstractness of the core entry does not come without a considerable cost. One problem with this formulation relates to the

meaning of abstractness in the model. A representation should be defined as abstract with specific reference to the medium being abstracted because abstraction operates on surface forms and, therefore, depends on the idiosyncratic features that undergo abstraction. For example, a phonological representation is considered to be an abstraction of the surface phonetics, whereas an orthographic representation is considered to be an abstraction of the specific visual features of the print. Hence, what makes a phonological form abstract is different from what makes a visual form abstract, and these two differ from the abstraction of semantic features. The concept of an entry that is equally neutral to orthography, phonology, and meaning would thus suggest that one central representation would be at the same time an abstraction of phonetic features, orthographic units, and semantic meaning. Although this seems to be quite convenient for a model, it offers a construct that is basically defined by being undefined.

But even if one could bypass the problematic and fuzzy notion of abstractness by considering the neutral core representation simply as an *address*, the neutrality axiom has another significant cost—namely, its lack of parsimony. The neutrality of lexical entries requires the postulation of an additional theoretical concept in a model of lexical structure. In addition to the phonological, semantic, and orthographic representations, the model assumes yet another representation or address that connects all of them. This ghostlike entity, which cannot be described or defined except by calling it an *abstract interface*, serves no apparent purpose. Its main function in the model is to allow unconstrained operations within the mental lexicon: Anything goes. Thus, a model of lexical structure can do very well without it. Although it is not explicitly stated, the postulation of a neutral core representation is often a hidden but essential building block in theories promoting visual access to meaning. As argued later, without this building block, the logic of direct access to meaning loses some of its appeal.

The Role of Phonology in Visual Word Recognition

Now that the basic axioms and terms have been laid out, the role of phonology in visual word recognition can be examined. To encompass the multiple aspects of this theoretical question, I need to address at least four major issues. The first section of the following discussion examines whether phonological recoding is a mandatory phase of print processing. The second section assesses the role of phonology in lexical access. The third section discusses whether phonology is indeed necessary for accessing meaning, and the final section investigates how phonology can be derived from the orthographic structure. Although these issues represent four different empirical questions, a coherent theory of reading should aim at integrating them into one general model constrained by all the findings. A word of caution is required, however. It is not the aim of the present article to encompass the exceedingly large number of studies that have been generated in the last 2 decades to address these issues. Rather, its goal is to present a typological analysis of research procedures used in visual word perception, along with a critical discussion of their implications and theoretical relevance to the role of phonology in reading.

Is Phonological Recoding a Mandatory Phase of Print Processing?

Depending on the angle from which the pendulum swing is observed, this question could be discussed from opposite perspectives. From the dual-access point of view, phonological processing is expected to be revealed mainly in tasks that explicitly require it. Thus, naming, rhyming judgments, positive pseudohomophone decisions, or matching print to speech or to picture names will all probably result in phonological recoding. In contrast, tasks that do not explicitly involve the phonological properties of the stimulus do not result in phonological coding; even if they do, this coding being relatively slow has no substantial effect on the lexical processes under investigation. Thus, studies generated from the dual-route perspective generally seek a null effect in their experimental results.

From the perspective of a strong phonological model, a phonological representation is a necessary product of processing printed words, even though the explicit pronunciation of their phonological structure is not required. Thus, the strong phonological model would predict that phonological processing will be mandatory, perhaps automatic. Note that arguing for the mandatory nature of a cognitive process is necessarily problematic. First, showing that the process occurs in one task or another does not preclude its absence in some other tasks. Second, a common interpretation of *mandatory* is that the cognitive process is free of strategic control. This, in general, is not easy to establish because a specific strategy can be invoked to account for performance in any task. Thus, it seems that in principle, the case of the strong phonological model cannot be unequivocally substantiated.

Although it may be difficult to provide unequivocal support for the strong phonological model, it may be possible to refute the strong opposing claim of dual-access models. This can be done by demonstrating that phonological recoding is present even in tasks in which it is not required or in which it hinders performance. Such evidence would suggest that the computation of phonology is a default procedure of the cognitive system rather than a secondary one, thus requiring dual-access models to soften their claims regarding the minor role of phonological processes. I therefore discuss several experimental paradigms in which phonological manipulations were not consciously perceived; when they were, phonological recoding was detrimental to participants' performance in the task. The empirical evidence, as I argue later, seems to suggest that the phonological properties of the stimuli nevertheless affected participants' performance. Although each methodology could be criticized in isolation, it is the convergence of empirical evidence that provides the critical mass necessary for assessing the evidence for or against the strong phonological model.

The Backward Masking Paradigm

Perfetti and his colleagues (Berent & Perfetti, 1995; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) argued for the automaticity of phonological recoding using backward mask-

ing.[1] In the backward masking paradigm, a target word is presented for a very short duration (usually 15–30 ms). The target word is followed (i.e., masked) by a pseudoword that appears for 15–60 ms and is then replaced by a simple pattern mask. The pseudoword, which masks the target, can be phonemically similar to the target (e.g., *raik* masking the target *rake*), graphemically similar (*ralk* masking *rake*), or a control mask (*rolt* masking *rake*). The participants' task is to report in writing what they have perceived. Typically, participants perceive only one event, the target word, and do not have any conscious recollection of the nonword mask. Even the target word is not always perceived, given its brief exposure, and is reported in full in only some of the trials (the probability of detecting the target changes with exposure duration and can therefore be set to a specific range by the experimenter). In spite of the fact that the nonword masks are not consciously perceived, they could in principle exert some influence on the detection of the target. This is because the short exposures characteristic of the masking paradigm allow the on-line processing of the nonword masks to merge with the incomplete processing of the word targets. Perfetti and his colleagues consistently found that nonwords that were phonemically similar to the targets they masked produced better identification rates than graphemically similar controls (Berent & Perfetti, 1995; Perfetti & Bell, 1991; Perfetti et al., 1988; see Perfetti, Zhang, & Berent, 1992, for a review). This outcome suggests that the phonological information extracted from the masks contributed to the reinstatement of the phonological properties of the targets. Evidence for phonological recoding using backward masking was similarly demonstrated in deeper orthographies such as Hebrew (Gronau & Frost, 1997) and even the logographic Chinese (Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996).

The strength of the backward masking paradigm in testing whether phonological recoding is mandatory thus lies in its use of brief exposures. Brief exposures (along with pattern masking) allow the investigator to pick up highly transient effects that may otherwise dissipate during the interval between the presentation of target and the masking nonword. More important, the masking procedure reduces the possibility that the observed facilitation is the product of some conscious, retrospective appreciation of the relationship between the mask and the target. One problem with regular phonological priming procedures is that the phonological manipulation (e.g., introducing pseudohomophones into the list) may be consciously perceived by the participants and thereby influence their strategic responses to the targets. The masking of the target by the immediate presentation of the nonword mask has the advantage that the participants' responses are less likely to be influenced by strategic processes based on conscious awareness.

However, a relevant study that questions the automaticity of phonological recoding, as revealed by the backward masking paradigm, was recently presented by Verstaen, Humphreys, Olson, and d'Ydewalle (1995). This study demonstrated that phonemic effects in backward masking may disappear if the stimulus list is composed exclusively of homophones. This outcome clearly suggests that even covert processes may not be immune to some strategic control and that the backward masking paradigm could produce nonphonological processing. Thus, a strong phonological model that assumes that a process of phono-

logical computation is automatically launched in all possible experimental circumstances is at odds with these results. The strong phonological model would therefore have to retract its claims of automaticity. Because the complete absence of strategic effects in an experimental task may prove impossible to demonstrate and no task is completely immune to strategic control, the question of interest should therefore focus on the default operations in word recognition. Demonstrating that some specific stimuli induce nonphonological processing does not contravene the hypothesis that phonological recoding is an autonomous process that is the default rather than the exception. Note that most arguments against a strong phonological model of reading are based on the claim that phonological recoding can occur but only when the demand characteristics of the task explicitly require it. Results from the backward masking paradigm suggest that this claim is incorrect: Phonological recoding occurs under experimental conditions that do not involve both overt strategic phonological computation and participants' awareness.

The Stroop Paradigm

In this experimental paradigm, participants are presented with pseudohomophone nonwords, such as *grean*, in a color-naming task. Interference due to incongruency between the color name and the nonword's phonological representation, or facilitation in the reversed congruent condition, is taken as evidence for mandatory phonological recoding. Two typical studies are reported here.

Dennis and Newstead (1981) have shown that the phonemic similarity of a nonword to a color name incongruent with the printed color (i.e., *grean* printed in red) slowed participants' responses significantly. This outcome suggests that the phonological properties of the orthographic stimulus were recoded and affected participants' performance. However, when the nonwords were phonemically similar to the color names with which the word were actually printed (i.e., *grean* printed in green), no facilitation was observed relatively to controlled nonwords that were phonemically dissimilar. Because facilitation effects of this kind can be shown with words, this result is not compatible with the predictions of a strong phonological model. Dennis and Newstead argued that prelexical phonological recoding is automatic but relatively slow because it exerts its influence only in incongruent conditions. This suggestion, however, is inconsistent with many findings using backward masking that suggest that prelexical phonological computation is very fast, exerting its influence on the initial phases of print processing (e.g., Berent & Perfetti, 1995). Thus, it seems that the pattern of facilitation and inhibition in the Dennis and Newstead study does not provide clear-cut conclusions concerning the automaticity of phonological recoding. This pattern could be related, however, to the general asymmetry between facilitation and inhibition effects in the Stroop task (for a detailed discussion, see MacLeod, 1991).

---

[1] In the present section, I do not advocate a strong version of automaticity in phonological recoding. What characterizes automatic as opposed to nonautomatic or attentional processes has been a focus of extensive discussion in the cognitive literature (see, e.g., Shiffrin, 1988, for a review). I refer only to the mandatory aspect of automaticity.

Recently, Tzelgov, Henik, Sneg, and Baruch (1996) presented evidence for Stroop effects with cross-script homophones. Hebrew-English bilingual participants were required to name in both languages the color of nonwords printed in either Hebrew or English. Nonwords printed in one language were in fact color names in the other language. For example, when the nonwords were printed in English letters, their phonological translation was a color name in Hebrew, and vice versa. Tzelgov et al. found strong Stroop interference with these cross-script homophones. That is, if the English letter string represented a color name in Hebrew that was different from the color to be named, a Stroop interference was found. Because participants were unfamiliar with the printed forms of the stimuli representing color names in the other language, the interference caused by their phonological transcription strongly reinforced the conclusion that prelexical computation of phonology is a mandatory process.

One possible criticism of the Stroop task for examining the mandatory aspect of phonological recoding is that it involves naming. The initial criterion presented previously was that the experimental task to be used would not require explicit pronunciation, which necessarily promotes the computation of phonology. Indeed, mandatory phonological recoding using pseudohomophones has not yet been shown in the Stroop paradigm without using vocal responses. But note that although the paradigm involves naming, it is the color of the printed word that must be named, not the printed word itself. Thus, not only is phonological recoding unnecessary for successful performance in the Stroop paradigm, but it is also disadvantageous because it produces a phonological representation that contrasts with the one to be pronounced. Claiming that pronunciation of the color itself promotes phonological recoding of the print, whether or not the printed word has to be pronounced, would paradoxically reinforce the phonological recoding hypothesis, not weaken it. It would mean that for any form of speech, whether it involves the pronunciation of printed words or the mere expression of thoughts, the cognitive system automatically switches into computing phonology from print.

The Speech Detection Paradigm

Evidence for phonological recoding in a task that does not explicitly require a phonological output can be found in a series of studies conducted by Frost and his colleagues (Frost, 1991; Frost & Kampf, 1993; Frost, Repp, & Katz, 1988). All of these studies used a speech detection task (for a detailed review, see Frost & Kampf, 1993) and reported an auditory illusion when masked speech and matching print were presented simultaneously. The paradigm consisted of presenting participants with speech-plus-noise and noise-only trials; their task was to detect the masked speech in a signal detection paradigm. The auditory stimuli were always accompanied by print that either matched or did not match the masked speech. The noise used in this experiment was amplitude modulated (i.e., the spoken word was masked by noise with the same amplitude envelope). Thus, when a printed word matched the spoken word, it also matched the amplitude envelope of the noise generated from it. All of the above studies showed that participants automatically detected a correspondence between noise amplitude envelopes and printed

stimuli when they matched. The detection of this correspondence made the amplitude-modulated noise sound more speechlike, causing a strong response bias to detect speech in the noise even when it was not present. Thus, the simultaneous presentation of print in parallel with the speech resulted in a detailed phonetic representation, even when the experimental task did not require it. In fact, in the speech detection task, the printed material was detrimental to each participant's performance; they were well informed about this ahead of time. Nevertheless, the effect of matching print was very reliable and appeared for every participant tested. This outcome provides additional support for rapid and mandatory phonetic recoding in silent reading.

The Letter-Search Task

In the letter-search task, participants are required to identify a prespecified target letter in a briefly presented masked letter string. For example, participants are presented with the letter string *brane* and are required to decide whether the letter *i* appears in the string. In principle, this task is graphemic in nature because it calls for the scanning of the orthographic structure for the purpose of detecting the visual features of the target letter. In a recent study, however, Ziegler and Jacobs (1995) have shown that participants' performance depended on the presence of the target letter in words that sounded like the pseudohomophones but were never presented in the visual array. For example, participants made more false alarms in detecting *i* in *brane* relative to *brate* because *i* appears in the word *brain*, which is homophonic with the visually presented *brane*. This seems to suggest that the phonological structure of the pseudohomophonic target *brane* invoked the lexical entry and the orthographic form of the homophonic word *brain*, thus falsely producing the searched-after letter. The existence of a pseudohomophone disadvantage in a supposedly graphemic task provides additional support for the claim that a phonological representation is generated from the printed word at an early stage, thus providing an early source of constraints in visual word recognition (see also Ziegler, Van Orden, & Jacobs, 1997).

In summary, there are several experimental paradigms that have directly tested whether phonological recoding is a mandatory process in word perception. A review of these studies cannot provide unequivocal support for the strong claim that phonological recoding occurs mandatorily, independently of any strategic control. Nevertheless, results from these paradigms consistently tend to suggest that phonological representations are computed following the presentation of printed words, as a rule not as the exception, even in tasks that do not require an explicit phonological output or where phonological recoding hinders performance. This does not fit with the classical view of phonological processes in dual-access theory. Admittedly, the initial premises of each of the above paradigms can be individually questioned. Arguments have been provided against the effectiveness of binocular masking, which was used by Perfetti and his colleagues, in interrupting processing without conscious awareness or in support of specific strategic effects in the Stroop paradigm. These arguments, however, cannot in the long run compromise the conclusion that phonology plays a primary role in visual word perception. If all tasks involve some strategic control and phonological processing occurs even when it is not

clear how phonological structure is relevant to the task, then phonological recoding is indeed a default procedure of the system. To be sure, the conclusion that a phonological representation emerges following the appearance of printed information does not necessarily mean that it serves any functional purpose. Such a phonological representation could be nothing but an epiphenomenon, a residual that remains after the cognitive system has processed the orthographic information. However, this last line of defense would be costly for the explanatory power of any theory of reading. If a phonological code serves no purpose, why would it be consistently generated by the cognitive system?

Is Phonology Necessary for Lexical Access?

Lexical access, perhaps the oldest term in the word recognition literature, was introduced as a theoretical construct in the first search model proposed by Rubenstein, Lewis, et al. (1971). In general, search models have implicitly adopted the lexical axiom, assuming that words are organized in memory as a list of items that is serially searched during word recognition (e.g., Forster & Chambers, 1973; Rubenstein, Garfield, & Millikan, 1971; also see Forster, 1992). According to these models, lexical access involves a period of time in which the encoded visual stimulus makes the initial contact with the stored lexical information, that is, the lexical entry.

A necessary distinction between access representation and lexical representation should be made at this point. Lexical information is maximally rich. Not only does it involve the word's phonological and phonetic structures, orthographic form, and semantic and syntactic features, but each of these representations is also fully specified. Therefore, the initial contact with the lexicon is assumed to occur through an interface access representation (whether phonological or orthographic) that is relatively impoverished or underspecified. The purpose of this access representation is merely to address the relevant lexical information as unequivocally as possible (for a discussion, see Forster, 1992). This does not preclude the subsequent retrieval of fully specified information and its matching the minimal input that led to the lexical access for the purpose of distinguishing between similar words or between words and nonwords with similar phonological structures. The existence of an underspecified access representation, which matches the detailed lexical representations only in part, allows for a very fast search, which is characteristic of visual word recognition. The relative impoverishment of the access representation is therefore the basis for most search models.[2] In the following, this requirement is labeled the *minimality constraint on lexical access.*

The minimality constraint is also postulated by interactive models, if only implicitly. In contrast to classical search models, interactive models regard lexical organization as a subset of associative memory in which words are interconnected nodes within a network (e.g., McClelland & Rumelhart, 1981; Morton, 1969). Originally, these models also adopted the lexical axiom, assuming that lexical access would occur whenever the activation of a word node reaches its threshold. This threshold can be reached, however, with a minimal amount of accumulated information that matches a specific node. As interactive models focus on differences in activation between nodes to describe the recognition process, a lexical node can be activated if it is sufficiently compatible with the input and overcomes the competing activation of its neighbors. Although this is another kind of minimality than the one assumed in search models, it nevertheless emphasizes that underspecified representations could allow for an efficient recognition process.

The minimality constraint is therefore a basic tenet for examining the role of phonology in lexical access. This is because a researcher's investigation should focus on the minimal amount of information needed to locate or activate a lexical item. In search models, the question to be asked therefore involves the form of the impoverished access representation: Is it phonologic or orthographic? In interactive models, the question to be asked is, Is the node that reaches threshold phonologic or orthographic?

Lexical Access and the Lexical Decision Task

The major source of evidence on the code for lexical access comes from the lexical decision task. Thus, the experimental question discussed in this section is, Are lexical decisions based on a phonological or an orthographic representation? Even though the lexical decision task has been the major tool of investigation in word recognition research, the interpretation of decision latencies as reflecting specific lexical processes is by no means straightforward. Lexical decisions latencies have several possible components. Whereas some researchers have argued that the decisions reflect the processing time necessary for lexical access as well as a decision phase (e.g., Forster & Chambers, 1973; and Rubenstein, Lewis, et al., 1971), others have suggested that they may also reflect a fast judgment of familiarity and are often conveyed before lexical access has occurred (e.g., Balota & Chumbley, 1984). Thus, with different experimental conditions, it is not always easy to determine whether the obtained effects are primarily due to one component or another (see Grainger & Jacobs, 1996, for a detailed analysis). Nevertheless, as far as the role of phonological or orthographic information in lexical access is concerned, the working hypothesis is that lexical decisions are indeed contingent on contact with an access representation. It should be emphasized that the lexical axiom underlies this common description of the lexical decision task. Participants' responses are considered to be contingent on a choice or discrimination between representations of discrete lexical units or on detection of their relative level of activation. Consequently, there is a need to examine the possible sources of information on which these decisions are based.

Most studies have approached this theoretical issue by manipulating phonological complexity and monitoring its effect (or the lack of it) on lexical decision. Phonological complexity has been defined in terms of the ease in computing a phonological representation from the print, given the transparent or opaque mapping of spelling patterns into phonology. This transparency could be due to the conformity to grapheme-to-phoneme correspondence rules of a given letter cluster within a given orthography (i.e., regularity), to the uniqueness of the pronunciation of

---

[2] A notable exception is the verification model offered by Paap and his colleagues (e.g., Paap et al., 1992).

a given orthographic cluster in a given language (i.e., consistency), or to the unequivocal mapping rules of graphemes onto phonemes characteristic of a specific writing system (orthographic depth). The logic of this approach is that if lexical decisions are affected by phonological manipulation, then they are probably based on a phonological code; if not, they are probably based on visual representations. As it is often the case in the visual word recognition literature, the results are far from being unequivocal. Nevertheless, it appears that the major controversies are encountered in conjunction with deep orthographies like English, which are characterized by semiopaque relations between spelling and phonology (see Frost, 1992; and Katz & Frost, 1992, for a review). In contrast, a lexical decision in shallower orthographies, in which letters represent phonemes straightforwardly, seem to provide more consistent results (see Carello, Turvey, & Lukatela, 1992, for a review).

Shallow orthographies. There is consistent evidence that lexical decisions in shallow orthographies are based on a prelexically computed phonological code. This evidence arises mainly from studies in Serbo-Croatian. In Serbia and Croatia, both the Roman and the Cyrillic alphabets are taught to all elementary school children and are used interchangeably by the skilled reader. Most characters in the two alphabets are unique to one alphabet or the other, but there are some characters that occur in both. Of those, some receive the same phonemic interpretation, regardless of alphabet (common letters), but others receive a different interpretation in each alphabet (ambiguous letters). Only letter strings composed exclusively of common letters can be pronounced in the same manner in both alphabets. In contrast, strings that contain ambiguous but not unique letters are phonologically bivalent. They can be pronounced in one way if the characters are considered Roman letters and in a distinctly different way if they are considered Cyrillic letters.

The phonological ambiguity arising from the parallel use of the two alphabetic scripts has been exploited in a number of studies to examine the code for lexical access in Serbo-Croatian. For example, Lukatela, Popadic, Ognjenovic, and Turvey (1980) found that lexical decisions for phonologically bivalent words were slower than lexical decisions for phonologically unequivocal words. The effect of phonological ambiguity was not confined to words. Phonologically bivalent letter strings were found to slow participants' responses (although to a lesser extent), even if the two possible readings of the letter strings represented two nonwords (see also Lukatela, Savic, Gligorjevic, Ognjenovic, & Turvey, 1978). Similar results were found by Feldman and Turvey (1983), who compared phonologically bivalent and phonologically unequivocal forms of the same lexical items. Equally interesting, words that were composed exclusively of common letters that were phonologically unequivocal did not produce slower lexical decisions than their unique alphabetic controls (Feldman & Turvey, 1983). Other studies in Serbo-Croatian showed that the magnitude of the difference in decision latencies for bivalent and unequivocal forms of a word varied with the number of ambiguous letters in the bivalent form (Feldman & Turvey, 1983; Feldman, Kostic, Lukatela, & Turvey, 1983). In general, these results suggest quite convincingly that readers of Serbo-Croatian process print use a phonologically analytic strategy that precedes lexical access. Consequently, as a rule, performance is hindered by phonological ambiguity (see

Feldman, 1987; and Turvey, Feldman, & Lukatela, 1984, for a review).

Deep orthographies. Whereas results for Serbo-Croatian are fairly consistent, an opposite pattern emerges for deep orthographies like English or Hebrew. The opaque relations between letters and phonemes in these orthographies create difficulties in assembling phonological representations from print by using discrete grapheme-to-phoneme conversion rules. The experimental procedure for investigating the code for lexical access in English or Hebrew was very similar to the one used in Serbo-Croatian. In general, the phonological complexity of the printed stimuli was manipulated, aiming to examine whether it had any effect on lexical decision. Phonological complexity was usually defined for real words in terms of their conformity to grapheme-to-phoneme correspondence rules that are characteristic of the orthography (Venezky, 1970) and for nonwords in terms of pronounceability. Typically, these experiments included irregular or inconsistent words, unpronounceable nonwords, pseudohomophones, and so forth. The argumentation underlaying this experimental approach seems fairly straightforward: If complexity in computing a prelexical phonological representation does not affect lexical decision latencies, decisions are probably not based on a phonological code.

Although the results in English are somewhat mixed, many studies failed to produce significant effects of phonological complexity on lexical decisions (e.g., Baron, 1973; Coltheart, Davelaar, Jonasson, & Besner, 1977; Fredriksen & Kroll, 1976; Seidenberg et al., 1984). This seems to challenge the strong phonological model. Fredriksen and Kroll's classical study examined the effect of array length, syllabic structure, and frequency on lexical decision and naming. Their results showed that in contrast to naming, lexical decision latencies were not affected by array length or syllabic structure. This outcome led the researchers to conclude that phonological recoding is not a prerequisite for lexical retrieval. Although other studies found similar results (e.g., Baron, 1973; Forster & Chambers, 1973), Fredriksen and Kroll's study is presented here as a typical case because it suffers from a basic weakness in its design, which is common to many studies. This weakness is, in fact, unavoidable from the dual-route perspective: The a priori aim of the experiments was not to reject the null hypothesis, and their theoretical conclusions were based on the lack of statistical significance of the obtained phonological effects. The inability to reject the null hypothesis, however, by no means implies the rejection of the alternative hypothesis. Although this point was raised in several articles (e.g., McCusker et al., 1981; see Van Orden et al., 1992, for a discussion), this methodological strategy is still popular, mainly because alternative strategies have not been forthcoming. In spite of the problematic aspects of these studies, however, their results cannot be entirely dismissed on statistical grounds. If phonological manipulations repeatedly fail to result in significant effects on lexical decisions, this should be a cause for concern for theories advocating mandatory phonological recoding.

The Minimality Constraint and Phonological Complexity

The studies that attempt to demonstrate that lexical decisions are not affected by phonological complexity, however, also suf-

fer from a basic theoretical misconception. The expectation that phonological complexity should affect lexical access hinges on the implicit supposition that this complexity is preserved in the access representation. This assumption, however, contradicts the basic tenet of the impoverished code for lexical access. As previously discussed, the computed interface representation that allows access to a lexical unit should satisfy the minimality constraint on lexical access and should, therefore, be underspecified. Thus, lexical access per se (vs. naming) is expected to bypass phonological complexity, not preserve it.

Consider, for example, the English word *pint*. It is called irregular because most English words ending with *int* are pronounced like *mint*. Several studies have shown that lexical decisions (at least for frequent words) are not affected by lack of regularity, whereas naming is (e.g., Jared, McRae, & Seidenberg, 1990; Jared & Seidenberg, 1991; Seidenberg & McClelland, 1989; Seidenberg at al., 1984). The regularity effect in lexical decision is a well-established phenomenon, and its common interpretation supports visual access in word recognition (e.g., Paap, McDonald, Schvaneveldt, & Noel, 1987; Patterson & Coltheart, 1987). The argumentation in support of orthographic recoding is simple: If the access code is phonological rather than orthographic, lexical decisions for irregular words should take longer because these words are characterized by opaque relations between graphemes and phonemes.

This line of argumentation, however, hinges on one basic assumption, namely, that the phonological code that underlies lexical access is detailed, not impoverished. A fully detailed code would necessarily require the irregularity of spelling patterns to be resolved, and their corresponding phonemes to be fully recovered, prior to lexical access. What makes *pint* irregular is that the letter *i* can be transcribed as the vowel /aI/ or /I/. In contrast, the conversion of *p, n,* and *t* into their respective phonemes does not involve any substantial ambiguity. Thus, a prelexical assembly of phonology could easily produce an underspecified phonological representation consisting of a consonant (C) and vowel (V) CVCC segment, such as /pent/, in which the middle vowel is not clearly defined, ranging from /e/ to /I/ (for a similar argument for morphological representation, see Marslen-Wilson, Komisarjevsky Tyler, Waksler, & Older, 1994). If my theory of lexical access relinquishes its demand for a detailed phonological representation for lexical access, the classical interpretation of the regularity effect in lexical decision is not as convincing. Once the ambiguity of the vowel segment in *pint* does not need to be resolved at the access stage, no regularity effects in lexical decisions should emerge.

This state of affairs is characteristic of any deep orthography in which some of the links between graphemes and phonemes are opaque. For example, the dissociation between finding an underspecified lexical entry and the subsequent recovery of complete phonological information is supported by numerous studies in Hebrew (e.g., Frost & Bentin, 1992a, 1992b). In Hebrew—as in other Semitic languages—all verbs and the vast majority of nouns and adjectives are composed of roots that are usually formed of three (sometimes four) consonants. The three-consonant roots are embedded in pre-existing morphophonological word patterns to form specific words. Due to the productivity of Hebrew morphology, Hebrew orthography was designed to convey primarily the root information to the reader. Hence,

the letters in Hebrew represent mainly consonants, whereas the vowels can be denoted by diacritical marks (points and dashes) presented beneath (or sometimes above) the letters. The diacritical marks, however, are omitted from most texts and are found only in poetry, children's literature, and religious books. Although some of the vowels can also be conveyed by letters, these letters are not regularly used and are considered optional. Because the same root may be combined with different word patterns, frequently the vowel sequence is the only difference between several words. Therefore, when the vowel marks are omitted, the same string of letters sometimes denotes up to seven or eight different words, which share an identical orthographic structure but have different phonological forms.

Studies in Hebrew provide strong evidence of the difference between lexical access and access to detailed phonological information. Bentin, Bargai, and Katz (1984) demonstrated that lexical decisions for phonologically ambiguous letter strings were as fast as for phonologically unequivocal words whereas the naming of ambiguous words was slower than the naming of unambiguous ones. These results suggest that lexical decisions (vs. naming) are based on the recognition of the ambiguous consonantal cluster and do not require a detailed phonological analysis of the printed word. Similarly, Bentin and Frost (1987) showed that lexical decisions for unpointed ambiguous words are faster than lexical decisions for either of the disambiguated pointed alternatives. This outcome, again, suggests that lexical decisions in unpointed Hebrew are based on the early recognition of the consonantal structure shared by the phonological alternatives and that finding a lexical entry does not necessarily entail the recovery of complete phonological information. Recently, Gronau and Frost (1997), using backward masking, demonstrated that the phonological representation computed from print in Hebrew is indeed impoverished and underspecified.

The conclusion to be drawn here is that studies showing that lexical decisions are not affected by spelling-to-sound regularity, or by other forms of phonological complexity, do not rule out prelexical phonological recoding for lexical access. They show at best that the phonological code used for lexical access is not detailed. This, however, is exactly what the minimality constraint is all about. Despite the risks entailed in drawing parallels from historical controversies, this issue bears an interesting similarity to a previous debate on the role of articulation in phonological recoding. Arguments put forward some 20 years ago against the central role of phonological recoding in reading were based on the implicit axioms that phonological processing necessarily involves articulatory planning and that phonological codes are articulatory in nature. Consequently, the finding that articulation does not interact with reading was taken as evidence for the irrelevance of phonological recoding in the processing of print (e.g., Kleiman, 1975; Levy, 1975). Similarly, current arguments against the central role of phonology in reading are based on the implicit axiom that phonological recoding for lexical access is maximally detailed. Thus, the finding that phonological complexity does not affect reading is taken as evidence that phonological recoding is irrelevant to the task. The point of drawing the historical parallel is not to prove the above arguments wrong but to illustrate the role of implicit assumptions in determining experimental paradigms and affecting the possible conclusions that can be drawn from them. The assump-

tion that phonological representations computed for lexical access are necessarily detailed is by no mean self-evident, and its advocates therefore bear the burden of proof.

The importance of constantly reassessing initial axioms and assumptions while interpreting empirical data can be exemplified in yet another issue regarding the effect of phonological complexity on lexical decision. Phonological complexity can be also be defined in terms of consistency rather than word regularity. Consistency involves uniqueness in pronouncing an orthographic body. Thus, if two words are spelled similarly but pronounced differently (e.g., *moth* and *both*), the letter cluster *oth* is considered inconsistent (Glushko, 1979; Patterson & Coltheart, 1987). According to this analysis, words can be regular but inconsistent, and this inconsistency introduces yet another form of phonological complexity in print.

The effect of inconsistency on lexical decision was examined by monitoring its interaction with some other phonological manipulations. For example, inconsistent words were mixed with pseudohomophones in stimulus lists. The logic behind this manipulation was that the combination of inconsistent words with a high ratio of pseudohomophones would be the most detrimental to lexical decision if phonological recoding indeed occurs (see also Pugh, Rexer, & Katz, 1994, for a similar manipulation and extended discussion). Some studies, however, found that word consistency did not interact with the ratio of pseudohomophones in the list (e.g., Andrews, 1982). Consequently, the weak or null effects of consistency were interpreted as contradicting phonological recoding in the lexical decision task.

These studies, however, did not control for *feedback consistency,* that is, whether there is more than one way to spell a pronunciation (see Stone, Vanhoy, & Van Orden, 1997, for a discussion). When feedback consistency is taken into account, the "lost" impact of consistency seems to return in the lexical decision task (Stone et al., 1997). The classical definition of *consistency* as reflecting a one-way ambiguity between spelling and phonology came from the axiom of bottom-up processing in visual word recognition. Because this view claims that stimulus processing proceeds from input to response, the opposite form of ambiguity (between phonology and spelling) probably seemed irrelevant. Only models that assumed a constant interaction between bottom-up and top-down processing could consider feedback consistency as a relevant manipulation in the present sort of task. The conclusion to be drawn here is not that bottom-up models are necessarily inferior to resonance models but that the basic axioms of models largely determine the range of experimental manipulations and the consequent interpretation of the data. More important, this issue exemplifies the weakness of theoretical conclusions based on null effects. If a theory predicts that phonological manipulations will not affect performance, the inability to reject the null hypothesis would be considered an experimental success. The issue of exactly why the phonological effects were missing—whether because feedback consistency was ignored or an impoverished phonological representation was sufficient for lexical decision—will probably not be pursued.

The minimality constraint and access codes. Once it is accepted that the access code should not be phonologically detailed, the question still remains, Is it orthographic or phonological? This question, however, is by no means a simple one. Stud-

ies in Hebrew can easily reveal the complexity of this theoretical problem. One possible account of the lexical decision results in unpointed Hebrew is that they are based on an orthographic cluster that is phonologically ambiguous. According to this account, the access code is orthographic. However, because this orthographic structure also represents a set of phonemes (i.e., consonants), such consonantal entity could serve, in principle, as a phonological access code, just as the orthographic representation would. According to this view, mandatory prelexical computation of phonology is launched following the presentation of printed words, resulting in impoverished phonological representations. Although these representations contain mainly consonantal information they can nevertheless serve as access representations. By a similar argument, both the orthographic cluster *pint* and the underspecified phonological representation /pent/ in English could serve as an access code for the word *pint.*

Admittedly, whether the access code is purely orthographic or phonological but impoverished is not easy to establish with a single experiment. This state of affairs should not come as a surprise. It is a direct result of the basic nature of orthographic systems: They are intimately connected to the phonological units on which they were meant to map. However, even if one experiment cannot distinguish between an orthographic and phonologically impoverished access code, the phonological model seems to gain significant support from all the other related findings that were previously discussed. As stated in the introduction, in this article, I independently discuss four issues that are in fact highly interdependent and constitute a chain of links. The mandatory aspect of prelexical phonological recoding discussed previously is an essential link in this chain. For if a process of phonological computation is launched as a rule following a printed word, the product of this computation procedure should play a role in the recognition process and lexical access. In shallow orthographies, access would be based on a relatively detailed phonological representation; whereas in deep orthographies, it would be based on a relatively impoverished one. This conclusion is further supported by findings regarding the speed of phonological computation, which are discussed in the following sections.

Possible challenges to the strong phonological model. In most cases, studies that challenge the strong phonological model use two sets of stimuli in an attempt to show that the phonological properties of the stimuli affect lexical decisions in one set but not in the other. The classical study of Davelaar, Coltheart, Besner, and Jonasson (1978) provides a good example. This study examined the effect that including pseudohomophones in the stimulus list has on lexical decisions to pairs of homophonic words. Davelaar et al. found that decisions that homophones, such as *groan* and *grown,* are both words were not faster than decisions on nonhomophonic controls, such as *earn* and *grown,* when pseudohomophone pairs, such as *brane* and *brain,* were included. A homophone-pair advantage appeared only when the pseudohomophones were removed. A similar strategic control of phonological recoding in lexical decision was also reported by Pugh et al. (1994).

In another task, using tachistoscopic recognition masking, Hawkins, Reicher, Rogers, and Peterson (1976) examined the probability of correctly detecting a printed word in a forced-choice paradigm. They demonstrated that participants made

more errors when the two alternatives were phonetically identical (e.g., *scent* and *cent*) than when they were not (e.g., *sold* and *cold*). However, this evidence for phonological recoding in lexical access was produced only when the stimulus list contained a low proportion of homophones. When a high proportion of homophones was included, detection rates for homophones and controls were identical. Hawkins et al. therefore concluded that lexical decision can be carried out without the use of phonology.

The strong phonological model needs to address this pattern of results because if the representations used for lexical access are necessarily underspecified, then phonological complexity would be bypassed in all experimental conditions as a default. Thus, the inclusion of a large ratio of pseudohomophones in the stimulus list should have no effect on participants' performance. For example, in contrast to the above studies, Stone and Van Orden's (1994) study provides evidence that suppression of phonological recoding for lexical access is indeed impossible (see also Ferrand & Grainger, 1996). Moreover, recently Pexman, Lupker, Jared, Toplak, and Roubiah (1996) reported an extensive series of experiments showing that the results of both Davelaar et al. (1978) and Pugh et al. (1994) cannot be replicated. However, dismissing all studies showing flexible coding on the grounds that they reflect incidental Type I errors is obviously not convincing. Numerous studies show that effects of phonological complexity (e.g., homophony, regularity, consistency) on lexical decisions depend on specific experimental manipulations (e.g., Waters & Seidenberg, 1985). Moreover, a large number of studies report phonological effects on lexical decision with certain lists of stimuli, whereas no effect appears with other sets of stimuli. If the computation of an underspecified representation is the default procedure for lexical decision, why is the representation detailed in some cases and impoverished in others?

The strong phonological model can address this question by assuming that the phonological representations that are computed in various experimental conditions could differ in their level of specification. According to this view, the computational process could result in an increasingly (or decreasingly) specified representation for the purpose of lexical access. This solution, however, needs to be extensively elaborated. For the model to be falsifiable, it needs to provide a priori criteria that would predict exactly when lexical access requires only an impoverished minimal representation and when richer phonological representations are computed. This research direction should be a primary goal of the model.

Is Phonology Necessary for Access to Meaning?

Whether phonology is necessary for accessing meaning is probably the most controversial issue in the reading literature. Although it has been the focus of heated debates, there is surprisingly little empirical evidence that speaks directly (and convincingly) to this issue. Previously, I distinguished between an underspecified prelexical code necessary for lexical access and the complete lexical representation that emerges following lexical access. Similarly, there should be a dissociation between access to the lexicon and access to meaning. These terms are not synonymous and refer to very different phases of processing print.

Semantic representations are one of many forms of stored lexical information. Therefore, whereas lexical access involves merely finding an interface impoverished representation that points to a specific lexical entry, access to meaning involves the later consequences of this initial contact. Many studies have thus confounded the role of phonology in meaning activation with its role in supporting lexical decisions. This could be a false trail if lexical decision merely reflects lexical access time, as in the case that this task might not actually shed any light on the subsequent accessing of meaning.

The theoretical distinction between lexical access and meaning activation can be further explicated by considering the term *direct access*. The reading literature has traditionally used this term to describe a process of encoding the printed information orthographically without recovering the phonological information that the orthographic structure represents. However, whether lexical search is based on orthographic or phonological information has nothing to do with the recovery of meaning. If indeed the mental lexicon has been accessed directly, the monitored lexical decision latencies should tell something about the speed of matching the encoded orthographic information with an internal representation (presumably orthographic as well). But once a lexical entry has been detected and lexical decisions have been made, there are many possible models that can account for the consequent activation of semantic and phonological information. Thus, direct access to the lexicon may not necessarily imply direct access to meaning. This is because access to the lexicon may very well be orthographically direct, yet the subsequent activation of meaning could still be indirect, that is, mediated by phonology. Experimental evidence in support of direct access from orthography to meaning would thus have to show that a given orthographic structure has conveyed an appropriate semantic meaning without first conveying the underlying phonological entity it represents.

Once it is accepted that lexical access per se (and therefore the lexical decision task) cannot speak unequivocally to the issue of meaning activation, the empirical evidence that actually indicates direct access to meaning becomes scarce and, as I argue later, inconclusive. In the following section, I attempt to examine this evidence and further discuss the different theories on the role of phonology in meaning comprehension in terms of their underlying axioms, plausibility and parsimony.

Empirical Evidence

The semantic decision task. Van Orden and his colleagues (Van Orden, 1987; Van Orden, Johnston, & Halle, 1988) used the semantic decision task to bypass the inherent complexities of lexical decisions described above. In the semantic decision task, participants are given a semantic category, such as *flower*, and they have to decide whether a given word is a member of this semantic category. In contrast to lexical decisions or naming, decisions concerning semantic categories necessarily involve meaning activation.

Van Orden (1987) demonstrated that participants produced large false positive error rates when they responded to stimulus foils that were homophonic to category exemplars. For example, participants categorized *rows* as a flower more often than a spelling control foil such as *robs*. The homophony effect was

found even under brief exposure conditions, suggesting that phonological recoding occurred at an early stage of word recognition, thereby mediating meaning activation. Van Orden et al. (1988) further examined this hypothesis using nonword homophone foils rather than words. In this study, participants were presented with nonwords like *sute* or *surt* and were required to decide whether they represented articles of clothing. False positive errors to *sute* were found to be larger than those to the orthographic control *surt*. The inclusion of nonwords reinforced the initial conclusions of Van Orden, that phonological representations mediate meaning activation. Moreover, because nonwords are not represented lexically, their effect on semantic categorization must be prelexical. As both homophones and pseudohomophones were found to produce virtually identical error rates, Van Orden et al. concluded that stimulus familiarity does not play a role in this process.

The results of Van Orden and his colleagues, however, are not unanimously accepted. Jared and Seidenberg (1991) examined the homophony effect in the semantic categorization task while controlling for word frequency and the size of the semantic category. Their results suggested that the large homophony effect found by Van Orden (1987) was greatly reduced when the semantic categories were broad. Moreover, with broad categories, the effect was restricted to low-frequency words. Jared and Seidenberg argued that the Van Orden's findings were obtained because participants rapidly generated a small number of common exemplars when they were presented with a narrow category (e.g., *rain* preceded by "part of a horse harness"). It is the matching of the pseudohomophone with the generated low-frequency exemplars that caused the false positive errors, not an overall strategy of phonological recoding. The finding that with broad semantic categories, high-frequency words did not produce false positive errors led Jared and Seidenberg to suggest that phonologically mediated activation of meaning does not occur with such words (see also Seidenberg, 1992, for a discussion).

Van Orden (1987) addressed Jared and Seidenberg's (1991) findings by focusing on the competition between dominant and subordinate meanings of homophones (see Van Orden, Atchison, & Podgornik, 1998, for a detailed discussion). Yet another criticism of Van Orden's studies was raised by Coltheart, Patterson, and Leahy (1994), who analyzed the distribution of errors for the various stimuli Van Orden used in his experiments. Coltheart et al. found that most of the false positive errors made by participants were due to homophonic foils that interchanged the vowel pattern *ee* and *ea* (e.g., judging that *meet* belongs to the category of foods). Very few errors were made for homophones that included a change of consonant, like *rows* and *rose*. Coltheart et al. thus suggested that because the interchanging of *ee* and *ea* patterns is a common spelling error in English, it is possible that some of the homophony effect found by Van Orden was due to the trivial inability of some participants to detect the erroneous spelling. This suggestion, however, does not explain the source of this inability, nor does it account for the pattern of errors that are reliably found with homophone foils.

These criticism, however, are all methodological; a more important question is Can the semantic categorization task reveal how meaning is accessed? Although the task probably monitors

meaning activation better than other cognitive tasks such as lexical decision, it does not unequivocally address the issue of direct or mediated access to meaning. Direct access to meaning, as advocated by the classical dual-route model (e.g., Coltheart, 1980), proposes a set of assumptions. First, both visual and phonological recoding are assumed to occur in parallel. More important, however, is the second assumption concerning their relative speed of activation. Dual-route theory posits that visual encoding is faster and consequently its meaning might be accessed from an orthographic representation before a phonological representation has been computed. Proponents of this theory would therefore embrace Van Orden's (1987) result without reservations. Their argument would be straightforward: When participants are presented with *rows*, the semantic meaning of *rows* is visually accessed, suggesting a "no" response to the semantic category of flowers. However, because semantic categorization is not a superficial task, the slower phonological route has ample time to access the meaning of *rose* before the participant responds. Now the cognitive system is faced with two conflicting responses: The visual route initially says "no"; the phonological route subsequently says "yes." This would result in larger false positive errors and slower latencies to *rows* than to *robs*.

What Van Orden's (1987) studies clearly falsify is the old single-route visual model (e.g., Baron, 1973). His results contradict the hypothesis that phonological recoding does not occur following the presentation of the printed stimulus. This hypothesis, however, is not what the dual-route theory proposes. Once it is accepted that phonological recoding is a process that is launched as a rule following print presentation, the theories of direct and mediated access to meaning would both have exactly the same predictions concerning the effect of homophonic foils on semantic categorization, although for entirely different reasons. Whereas Van Orden suggested that his false positive responses occurred because the meaning of *rose* was accessed following *rows* or even *roze*, dual-route theory suggests that these responses occurred because the meaning of *rows*, which was activated earlier by direct access, conflicted with the meaning of *rose*, which was activated later by phonological access. The only conclusion to be drawn from this stalemate is that the semantic categorization task cannot distinguish between these two theories. This is because this task taps relatively late, postlexical processes, and it is not easy to control the exact source of participants' responses.

Fast priming. Some of the problems in the semantic categorization task were remedied by studies using a fast priming paradigm. In a typical study, Lesch and Pollatsek (1993) examined priming with words that were visually similar to or homophones of a word related to the prime (e.g., priming *tree* with *bench* or with *beach*, which is homophonic to *beech*). The stimulus onset asynchronics (SOAs) between prime and targets were 50 or 200 ms, and primes were followed by a pattern mask. Lesch and Pollatsek found that the homophonic prime *beach* facilitated the naming of *tree* at the short SOA of 50 ms but not at the longer SOA of 200 ms. They concluded that meaning is accessed through the automatic activation of a phonological code. A similar strategy was used by Lukatela and Turvey (1994a), who extended Lesch and Pollatsek's study by comparing priming of semantic associates, homophonic words,

and pseudohomophones. Lukatela and Turvey found that at a short SOA of 50 ms, target words like *frog* were named faster following *toad, towed,* or *tode* than following orthographic controls such as *told* or *tord.* The priming effects of semantic associates, homophonic words, and pseudohomophones were identical. The advantage of semantic associates and homophonic words over the pseudohomophones appeared only later, at the 250-ms SOA. Lukatela and Turvey concluded that phonological constraints on access to meaning precede orthographic constraints.

The results from studies that used priming at short SOAs are quite damaging to the visual theory of accessing meaning. This is because, unlike the semantic categorization task, these results contrast the effects of phonological similarity and orthographic similarity over various time courses, showing that phonological similarity plays a more important role in the initial phase of word recognition. Thus, these studies clearly show that access to meaning through a phonological code is very fast. Proponents of the visual approach to reading could argue that these studies used the naming task and, therefore, artificially engaged the phonological system. Moreover, they could still claim that although it is possible that the meaning of a word can be rapidly accessed by a pseudohomophone, there is still no unequivocal proof that it is not accessed faster through the orthographic structure in normal reading. A similar possibility of contrasting interpretations of the same findings can be seen in a recent study by Klopfer (1996) who used the Stroop paradigm. In this study, Klopfer showed that the amount of interference in naming incongruent color words was correlated with the extent of color similarity. Thus, greater interference was found when the color to be named and the printed color name were similar (e.g., yellow–orange vs. yellow–blue). Klopfer concluded that word reading and color-naming processes interact at a conceptual level. Thus, this result could be interpreted to suggest that the printed color word depicted the conceptual meaning of the word directly, and this interacted with the perceived color to cause the Stroop interference. However, it is not easy to establish whether it was the orthographic or the phonological structure of the word that provided access to the word's conceptual representation. Moreover, even if there were experimental evidence that it was indeed the word's phonology that gave access to meaning, it could still be claimed that this was due to the use of the naming task, which promotes the use of the word's phonological rather than orthographic structure. Thus, it seems that new tasks are required to explore this issue further.

Plausibility Arguments

Although the empirical evidence cannot provide clear-cut answers to the present debate, it is nevertheless possible to consider the underlying axioms of each position using plausibility arguments. The various accounts of retrieving a printed word's phonology and meaning necessarily depend on one's structural assumptions concerning the internal organization of linguistic information within the lexicon. It is at this point of my discussion that the axiom of the non-neutrality of the core lexical representation becomes crucial. As stated in the introduction, the postulation of a neutrally abstract core representation is a basic building block of the theory of visual access to meaning. Consider stage

by stage the time course of meaning activation according to the classical dual-route model. If lexical access is visual and direct, an orthographic access code is presumably generated to locate a lexical entry unequivocally. However, for meaning to be directly accessed, it has to be activated without prior recovery of a phonological structure. This could occur only if the core lexical representation is neutral with respect to orthographic, phonological, and semantic information. Such a neutral representation could link the orthographic representation and the semantic information without involving phonology, which is just another satellite of the neutrally abstract core representation. The concept of the neutrality of the core representation can be easily translated into terms used by interactive models. It is reflected in the strength of the connections among the three forms of representation—orthography, phonology, and meaning. In models like Seidenberg and McClelland's (1989), these are represented by the vertices of an equilateral triangle. Neutrality is implicitly assumed by considering all sides of this triangle to have a similar activation status. Thus, in general, each vertex can activate the others with equal strength, and this property permits the independent connections between orthographic and semantic units.

However, if the core representation is non-neutral, it could only be phonologically abstract for all the reasons outlined in the introduction. The speech primacy axiom becomes crucial here because it considers the connection of phonology to meaning the primary connection characterizing human languages. Thus, for most words, orthography would be linked to meaning primarily through phonology. Although a lexical entry could in principle be located through an orthographic code (i.e., direct access), this entry would access a word, which is the phonological entity connected to meaning in the lexicon. This lexical structure, therefore, suggests that in normal reading, meaning is not recovered prior to the word represented by print. Similarly, in resonance theory (Stone & Van Orden, 1994; Van Orden & Goldinger, 1994; Van Orden et al., 1990), the non-neutrality of the core representation is implicitly suggested by explicitly treating this triangle as nonequilateral (although the argument is statistical rather than structural). Because the consistency between orthographic and phonological units is greater than the consistency between spelling and meaning units (the phonological coherence constraint), the resonance between orthographic and phonological units is far stronger than between orthographic and semantic units (Van Orden & Goldinger, 1994).

Thus, it seems that the question of direct access to meaning is contingent on one's specific view of the basic structure of the lexicon. But as previously stated, axioms are not immune to criticism and arguments about their plausibility should be explicitly stated. The lexical structure suggested in this article derives from a simple linguistic argument that cannot easily be contested. The initial link that characterizes natural languages is between words that are phonological structures and the meanings they carry. In the course of acquiring literacy, the newly learned orthographic system adds an additional link that systematically connects a graphemic configuration to these phonological structures. The theory of direct access to meaning claims that this initial link between orthographic and phonological representations is transformed with increasing exposure to printed information. According to this view, as reading skills improve,

a new linkage is formed within the linguistic system, mapping orthographic representations directly onto semantic representations. Thus, what direct access buys for a theory of reading is basically a model of acquired competence. Reading competence is accounted for by postulating a straightforward way to retrieve the semantic message from the print, bypassing the phonological information that the orthographic symbols transcribe. But such a property, as I argue later, may be too costly. Moreover, regardless of the price, it seems that the burden of proof should be shifted to the advocates of direct access.

It is certainly possible to design a lexical system that connects orthographic with semantic lexical representations, thus bypassing or disregarding their phonological structure. However, a theory of direct access from graphic signs to meaning would then need to clarify the qualitative difference between the processing of written words, on the one hand, and pictures or other nonlinguistic symbols, on the other (see, e.g., Potter & Faulconer, 1975).[3] When a reader is presented, for example, with the word *dog* or a picture of a dog, both stimuli are supposed to depict the meaning of *dog* in an essentially similar way if direct access to meaning occurs. This is because both the picture and the printed word are graphic signs and both graphic signs point directly to a meaning. Admittedly, one could argue that in the case of printed words, orthographic representations are connected to meaning whereas, in the case of pictures, pictographic representations elicit meaning comprehension, thereby distinguishing one from the other. This distinction, however, remains empty because it does not provide any explanation of the qualitative differences between these two forms of cognitive processing. It merely circularly reiterates that the former stimulus is a printed word and the latter is a picture, without clarifying in what way they differ.

But note that the argument that direct access to meaning basically treats printed words as pictures is not necessarily a cause for concern to a theory that does not adopt the linguistic axiom. A purely visual–analog theory of reading should not be bothered by it. Indeed, some proponents of direct access to meaning have entertained the idea that some word recognition processes are very similar to the process of recognizing objects and other analogical stimuli (e.g., Jared & Seidenberg, 1991, p. 358). Direct access to meaning should cause serious concern, however, to any linguistic theory of reading. This is because these theories assume the linguistic axiom and consequently regard the orthographic message as consisting primarily of linguistic units. These units transcribe only the word's phonology in some systematic manner and not the word's meaning, which has an entirely opaque association with the printed orthographic form. According to the phonological coherence constraint discussed in the introduction, the only systematic mapping is between graphemes and their phonological transcriptions, whether they are phonemes, syllables, or morphemes, not between graphemes and semantic features. Thus, it seems that the best move for defending direct access to meaning would be to revert to the visual axiom. Once this axiom is postulated, all of the above linguistic arguments become irrelevant. The visual axiom was discussed in length in the Working Axioms and Working Definitions section, and further criticism of it is unnecessary. Postulating it for saving direct access to meaning would probably be a Pyrrhic victory (a too costly victory that is in fact a defeat).

Once again, it is important to emphasize that the plausibility arguments presented above serve merely to provide the general principles of a lexical structure, given the coherence of the various axioms discussed previously. It does not preclude the possibility that for a subset of very familiar words, the orthographic structure indeed conveys meaning directly, almost as analogical stimuli do. Thus, the point to be made here is that phonology plays a primary role in accessing meaning but not necessarily an exclusive one.

How Is Phonology Derived From Print?

A model favoring phonological recoding for lexical access and meaning retrieval needs to provide a detailed description of the dynamical procedures and computational mechanisms that explains exactly how phonology is computed from print. Accounting for the procedures by which phonological information is recovered from visually presented information is the foundation on which all the previous discussions rest. In the present section, I discuss the various models for obtaining a phonological representation. The process by which phonology is derived from print has been investigated mainly with the dual-route model as a theoretical framework. There are two versions of the dual-route model, and they should not be confused. The first one involves two possible routes for generating a phonological code, while the second involves two possible routes for accessing meaning. These issues are almost orthogonal, and it is the former that is discussed here, not the latter.

Assembled Phonology Versus Addressed Phonology

The dual-route model has traditionally offered two possible mechanisms to account for the process of generating a phonological representation from print. The first mechanism involves a computational process that uses a set of conversion rules (or operates through weighted connections in a neural network) that transform letters, letter clusters, or graphemes into phonemes or phonemic clusters. Phonology derived through this mechanism is often labeled *prelexical* or *assembled* phonology (e.g., Baluch & Besner, 1991; Brown & Besner, 1987; Frost, 1994, 1995; Patterson & Coltheart, 1987; Seidenberg, 1992). It is prelexical because it is rule based rather than lexically driven. The alternative to this computation procedure is a process that involves lexical lookup and the retrieval of a phonological representation from lexical storage. Phonology in this case is often labeled *addressed* phonology because it is the orthographic structure of the printed word that addresses the lexicon and the respective phonological representation is retrieved rather than assembled. The dual-route hypothesis thus states that both the lexical and the prelexical routines can operate independently of each other and that the winner of this race is determined by the speed and efficiency of the lexical or the assembly process (Coltheart & Rastle, 1994; Paap, Noel, & Johnasen, 1992; Patterson & Colt-

---

[3] A parallel issue is discussed in the domain of speech perception. One major component of speech perception theories, which adopt the linguistic axiom, involves the need to account for the difference between perceiving speech and perceiving all other auditory stimuli (e.g., A. M. Liberman & Mattingly, 1985; A. M. Liberman & Whalen, 1989).

heart, 1987). The "horse race" metaphor that depicts this state of affairs gives these processes a flavor of independence. This theoretical distinction between lexical and prelexical phonologies has dictated the research methods that have been used to investigate the generation of phonology from print.

The major methodological tenet of models assuming two independent routes to phonology is that lexical phonology has characteristic traces. For example, if phonology is retrieved from the lexicon following lexical access, naming performance should reflect the characteristic traits of lexical search. According to this view, naming latencies should be highly correlated with lexical decision latencies (e.g., Forster & Chambers, 1973; Fredriksen & Kroll, 1976; Katz & Feldman, 1983; West & Stanovich, 1982), significant frequency effects should emerge in naming (e.g., Frost, 1994; Frost, Katz, & Bentin, 1987), and semantic context should facilitate naming performance (e.g., Baluch & Besner, 1991; Frost et al., 1987; Tabossi & Laghi, 1992; see Lupker, 1984; and Neely, 1991, for reviews). However, as in studies monitoring phonological effects in lexical decision, which were previously discussed, this methodological procedure suffers from a serious statistical bias. Phonology can only be proven to be lexical, not prelexical. Thus, if significant frequency or semantic priming effects are indeed obtained, phonology is considered to be lexical. If, however, these effects fail to reach significance, conclusions supporting prelexical processing are drawn. This presents a problematic situation in which the theoretical distinction is systematically confounded with the power of the statistical analysis.

Lexical or Assembled Phonology

What is the default process? There is ample evidence that readers can use both assembled and lexical phonology in the naming task. The real issue, once again, is the *default* of the cognitive system. This has been the focus of heated debates because it bears on an old and fundamental controversy in the literature on reading: the speed and efficiency of visual-orthographic encoding in visual word recognition (for discussions, see Frost, 1995; and Katz & Frost, 1992). This issue is well reflected in the terminology of the dual-route model: direct access versus mediated access. One of the most important metaphors in the literature on reading is direct route or direct access. Green and Shallice (1976) were probably the first to use this metaphor, but it became an influential theoretical construct following Coltheart's (1980) analysis of deep dyslexia. The original distinction involved the issue of whether meaning access is mediated by a phonological representation or derived directly from the print. However, similar terminologies and metaphors were used for distinguishing between visual access, with its consequent retrieval of lexical phonology, and the indirect process of prelexical computation of a phonological representation.

Direct access implies a mechanism that achieves priority over an alternative access route, presumably because it is more straightforward and economic and does not waste cognitive resources. The metaphor therefore reflects an underlying assumption about the naturalness of visual access as opposed to phonological computation. Thus, the visual encoding hypothesis assumes that regardless of the type of orthography, it is usually more efficient to visually access the lexicon and retrieve the

complete phonological structure of the printed word from it rather than to assemble this structure using prelexical conversion rules. The visual encoding hypothesis seems to posit that once the lexicon is directly accessed, the process of retrieving the phonological information from it does not involve significant cognitive effort. Although this supposition is not explicitly stated, it is based on regarding the access procedure as the costly phase of word recognition, whereas postlexical information is assumed to emerge after this phase is successfully completed (e.g., Baluch & Besner, 1991; Besner & Smith, 1992; Seidenberg, 1985; Tabossi & Laghi, 1992).

The visual encoding hypothesis is challenged, however, by studies conducted in shallow orthographies. The extensive use of prelexical phonology in naming has been demonstrated in many studies in Serbo-Croatian (e.g., Feldman & Turvey, 1983; Frost et al., 1987; Katz & Feldman, 1981, 1983; Turvey et al., 1984; see Carello et al., 1992, for a review). More recently, Frost (1994) demonstrated that readers of unpointed Hebrew were willing to delay naming and wait for the vowel (pointed) information to appear, even if the words were phonologically unambiguous and could be read in only one way. These results suggest that even readers of the deep Hebrew orthography strategically prefer prelexical phonological assembly over the retrieval of phonological information from the lexicon following visual access. Similar conclusions were reported by Simpson and Kang (1994), who compared reading in the shallow Korean *Hangul* with reading in the deeper Korean *Hanza*. Simpson and Kang found that phonological assembly was favored by Korean readers when the stimuli were printed in the shallow *Hangul* orthography.

The results from Japanese, who also use both shallow (*Kana*) and logographic scripts, provide additional insight. Feldman and Turvey (1980) contrasted naming latencies of words printed in *Kanji* and printed in *Kana*. They demonstrated that words that are usually printed in the Japanese deep logographic *Kanji* (e.g., color names) were named faster when printed in the shallower syllabic *Kana* than in their familiar *Kanji* form. These results seem to suggest that naming in an orthography that lends itself to phonological assembly is necessarily faster than in a deep orthography, which promotes visual encoding and visual access. Besner and Hildebrandt (1987), however, argued that familiarity plays a significant role in reading Japanese *Kana*. They showed that words regularly printed in *Kana* were named faster than *Kanji* words printed in *Kana*. Similar results were reported by Buchanan and Besner (1993). The differences in naming latencies of visually familiar and unfamiliar words were taken by these researchers as evidence for the use of the assembled and addressed routines in naming in a relatively shallow orthography: fast naming using an addressed code, slow naming using an assembled code. This conclusion, however, derives from the axiom of fast visual access rather than supporting this axiom. The computation of phonology in the assembly process is not necessarily a fixed routine that does not improve with increased reading competence. The faster naming latencies for familiar rather than nonfamiliar Japanese words could have emerged from improved efficiency in assembling the words' phonological structures rather than from reverting to the lexical routine. Thus, to accommodate the results from Japanese, researchers need to

develop a model of acquired competence in assembling phonology. This issue is elaborated in detail in *Skilled Reading*.

Although some studies reported that processing in shallow orthographies was more flexible than originally envisioned (e.g., Baluch & Besner, 1991; Besner & Hildebrandt, 1987; Tabossi & Laghi, 1992; but see Frost, 1994, for a methodological criticism of the Baluch & Besner, 1991, study), the fairly consistent findings showing the use of prelexical phonological computation in shallow orthographies undermine the basic tenet of the visual encoding hypothesis as well as the theoretical justification of the direct access metaphor. Deep and shallow orthographies differ mainly in the extent to which they represent the surface phonology of their language. This characteristic, however, has no bearing on the assumed advantage of visual access over phonological assembly. Note that the direct links between whole-word orthographic clusters and whole-word phonological clusters are assumed to bypass the need for phonological computation, thereby providing the cognitive system with a presumably effortless way for generating phonology for all orthographies, deep or shallow. Why is it, then, that readers of shallow orthographies consistently provide contradictory evidence?

Are the processes indeed independent? It is not only the advantage of addressed over assembled phonology that is challenged by cross-orthography research but also the independence of the two processes. The conceptual distinction between addressed and assembled phonology, as advocated by the dual-route model, refers to two independent routes for generating a phonological representation from print. Thus, the implicit assumption underlying studies supporting the dual-route hypothesis is that the derived phonology of a specific word in a specific experiment is either assembled or addressed. As such, the task of the experimenter is to explore the possible factors predicting the advantage of one route over the other. For example, it has been suggested that the advantage of addressed over assembled phonology depends on the depth of the orthography or on word frequency. Addressed phonology was found to be the faster route in deep orthographies and in naming high-frequency words (e.g., Baluch & Besner, 1991; Seidenberg, 1985), whereas assembled phonology was found to be more prevalent in shallow orthographies and in naming low-frequency words (e.g., Frost, 1994; Frost et al., 1987; Katz & Feldman, 1983; Lukatela & Turvey, 1990; Simpson & Kang, 1994). For example, Katz and Feldman contrasted naming and lexical decisions in Serbo-Croatian and English. In this study, they examined the effects of semantic priming on naming and found that semantic priming facilitated naming in English but not in Serbo-Croatian. This outcome seemed to demonstrate lexical involvement in naming in deep orthographies but not in shallow orthographies. Similar conclusions were later reported by Frost et al., who extended their research into a multilingual comparison. Frost et al. again showed clear lexical involvement in deep orthographies like Hebrew or English but no involvement in shallow orthographies like Serbo-Croatian. All of these studies seem to reinforce the original dual-route conception about independent access routines to the lexicon.

This conception, however, has recently been challenged by studies showing that both lexical knowledge and prelexical computations always affect the naming task. For example, although the direct association between graphemes and phonemes in shallow orthographies is expected to promote the use of assembled rather than lexical phonology, many studies have shown clear and consistent lexical involvement in pronunciation in the shallow Serbo-Croatian (e.g., Lukatela, Feldman, Turvey, Carello, & Katz, 1989), Spanish (Sebastian-Galles, 1991), Persian (Baluch & Besner, 1991), Italian (Tabossi & Laghi, 1992), and pointed Hebrew (Frost, 1994). Similarly, the opaque relations between spelling patterns and phonology in deep orthographies are expected to promote mainly the use of the lexical route in naming. Nevertheless, prelexical assembly of phonology has been demonstrated in deep orthographies like English (e.g., Perfetti et al., 1988) or unpointed Hebrew (Frost, 1995). If both assembled and addressed phonology are present in naming, the experimental strategy of searching for lexical traces in this task seems futile, if not misleading. It biases the experimenter toward a lexical verdict while disregarding the prelexical components in the task (e.g., Baluch & Besner, 1991; Sebastian-Galles, 1991; see Carello, Turvey, & Lukatela, 1994, for a discussion of this point). What should be the topic of investigation is the *relative* use of prelexical and lexical phonology in naming.

Prelexical and Lexical Phonology: The Grain-Size Distinction

To examine the relative use of prelexical and lexical phonology in naming, one should characterize prelexical and the lexical processing differently. What distinguishes the process of assembling phonology from the process of addressing it from the lexicon is the grain size of the computed phonological unit. The rational for the grain-size distinction lies in the different procedures by which a phonological representation is generated from print according to the dual-route model. The prelexical assembly of phonology means the application of a set of transformations that connect minimal orthographic and phonological units (letters and phonemes in the case of alphabetic orthographies like English, letters and syllables in the case of syllabic orthographies like Japanese, and graphemes and morphemes in the case of morphosyllabic orthographies like Chinese). In contrast, addressed phonology involves a direct mapping of whole-word orthographic units onto whole-word phonological units. The complete phonological structure of the printed word is thus addressed by its orthographic form and retrieved as a whole from the mental lexicon. Thus, in contrast to assembled phonology, addressed phonology does not involve any computation at the subword unit level but is derived from straightforward connections between the printed and the spoken representations of a word. The methodological implication for the grain-size distinction is a considerable shift in experimental procedures. Rather than searching for lexical traces in naming performance, experiments would focus on whether a phonological representation was retrieved as a single unit or assembled piecemeal. This can be achieved by rating the level of phonological ambiguity of various subword units and examining whether phonologically inconsistent units within single words have a cumulative effect on naming performance (see Frost, 1995, for a discussion).

The grain-size distinction offers an experimental framework for examining the co-occurrence of prelexical and lexical processes in naming. It examines the size of the computed phonological units and thereby allows for the use of a continuous rather

than a dichotomous measure of phonological computation. For example, using this framework, Frost (1995) has provided clear evidence that both prelexical assembly and lexical shaping occur and operate in parallel to generate a detailed phonological representation. In this study, the effects of missing vowels on naming latencies in unpointed Hebrew was examined. Naming latencies were found to be monotonically related to the number of vowels missing in the print. This outcome suggests that phonology was not retrieved from the mental lexicon as a holistic lexical unit but was initially computed by applying letter-to-phoneme conversion rules. The more vowels missing in the print, the slower the computation process. However, the results also showed that lexical involvement, as reflected by the frequency effect, monotonically increased with the number of missing vowels. Thus, with any stimulus, high or low frequency, with many missing vowels or none, both prelexical assembly and lexical involvement were present.

A Computational View of Naming

In contrast to the classical visual hypothesis, which stems from the dual-route model, the phonological model of reading suggests that the default operation of the cognitive system in word recognition is the prelexical assembly of phonology. The basic claim of the phonological model, which derives from the speech primacy axiom, states that all writing systems are phonological in nature and their primary aim is to convey phonological structures, that is, words, regardless of the graphemic structure adopted by each system (see DeFrancis, 1989; and Mattingly, 1992, for a discussion). The computation of phonological structures from print is thus a primary function of the system, and it is necessarily launched following the visual presentation. According to this account, the assembly of a prelexical phonological representation from print is a mandatory process. The easier it is to generate a prelexical representation, the faster and more efficient the assembly is. The phonological hypothesis also needs to account, however, for naming in deep orthographies in which the assembly of a complete phonological representation cannot be accomplished without some lexical contribution.

Once it is accepted that the initial phase of phonological recoding involves a fast prelexical computation that produces an impoverished phonological representation, several models can account for the manner in which the impoverished product is shaped into a final form. The main empirical issue, however, is to provide evidence for the mandatory process of prelexical computation. Obviously, the more compelling evidence should come from deeper orthographies like English or Hebrew, in which simple grapheme-to-phoneme conversions cannot produce a complete phonological representation. Hebrew and English are good examples because they contain different forms of ambiguity. In unpointed Hebrew, the mapping of letters onto phonemes is fairly consistent and phonological ambiguity results from missing phonemic information in print. In English, however, the letters represent all of the word's phonemes but not always consistently.

Using a backward masking paradigm, Berent and Perfetti (1995) have shown that the phonological representation of English CVC words is computed in two processing cycles with different time courses. The consonants are computed first in a

prelexical process that is fast and automatic. This first phase provides the reader with nothing but a phonological skeleton of consonantal information. In a subsequent cycle, the vowels, which are the main source of phonological ambiguity, are computed using lexical information. This cycle is slower and involves attention-demanding processing. Berent and Perfetti have also shown that the time course of vowel computation depends on vowel complexity. Note how these results converge with the minimality constraint for lexical access. Although these studies had not been designed to address this issue, they clearly provide support for it. This is because they demonstrate that the processing system indeed produces a minimal phonological representation as a primary output.

Additional empirical support for a computational process in English has recently been provided by Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty (1995). Treiman et al. mapped the spelling-to-sound relations of all CVC words in an English dictionary and assigned a pronunciation consistency score to the CV or VC subword units. A regression analysis of naming latencies revealed that the consistency of VC subword units contributed significantly to the prediction of performance in word pronunciation. These results suggest that at least for monosyllabic English words, phonology is assembled rather than addressed as a unit from the lexicon.

Thus, a computational model that accounts for naming in all orthographies should regard the initial phase of phonological computation as a process of converting letters or letter clusters into phonemes or syllables (unambiguous letters first) by using prelexical conversion rules. As described in the section *Is Phonological Recoding a Mandatory Phase of Print Processing?*, this computation procedure is mandatory and may occur in cycles, with consonantal information coming first (Berent & Perfetti, 1995). In deep orthographies, however, this initial phase cannot result in a complete and accurate phonological code and can provide the reader with only an underspecified phonological representation. Unlike lexical decision, which can sometimes be based on this partial information, naming requires detailed phonology. Therefore, the impoverished representation is shaped (whether serially or in parallel) through top-down lexical knowledge to yield a final correct pronunciation. In Hebrew, top-down shaping inserts the missing vowel information; in English, it provides the correct pronunciation of irregular spelling patterns. In almost all orthographies, lexical shaping provides other indispensable phonetic features such as stress assignment (e.g., Carello et al., 1994; Colombo & Tabossi, 1992). This model thus assumes the lexical axiom and regards the contribution of localized word representations as a necessary building block. In this respect, it is closer to the dual-route cascaded model proposed by Coltheart et al. (1993) and Coltheart and Rastle (1994) than to the single-route parallel distributed processing models of reading aloud (e.g., Seidenberg & McClelland, 1989). However, in contrast to the dual-route conception, it assumes a necessary stage of prelexical computation for each pronunciation.

The major conclusion to be drawn here is that the idea that the lexical and prelexical routes operate independently could very well be an illusion. Depending on the researcher's standpoint, either the lexical or the prelexical operating systems can be perceived but not their interaction. The experimental method-

ology used in many of the relevant studies has consisted of monitoring the significance of lexical trace effects, yielding a dichotomous decision: Significant lexical effects were interpreted to suggest that phonology is lexical, while nonsignificant effects were interpreted to suggest that it is prelexical. Consequently, the perceived independence of the two routes to phonology could have resulted from the methodological structure of the experiments, not necessarily from their outcome. Thus, researchers have yet another example of how the experimental methods they use largely determine the possible conclusions that can be drawn from them. According to the computational view of naming, phonology is always assembled and always lexically shaped but not holistically addressed. The lexical route merely alters and supplements what had already been assembled by prelexical computations. This conclusion thus implies that it may be necessary to abandon the independence assumption advocated by the classical dual-route models.

Some Empirical False Trails

Although a discussion of underlying axioms is a necessary step in establishing the general coherence of the strong phonological model, obviously the empirical data accumulated over years of research need to be accommodated by the model as well. Because the traditional rejection of the phonological theory of reading emerged from specific empirical findings and their interpretation, the model needs to provide adequate explanations of them. It would be impossible to encompass all the experimental results that have been interpreted as arguing against a strong phonological theory. Nevertheless, in the present section, I discuss the major findings that are commonly believed to contest the phonological model and argue that they do not necessarily do so. Generally, the visual-nonphonological theory of reading has gained support from experiments showing participants' sensitivity to orthographic manipulations, from the divergence of reading strategies of beginning and skilled readers and from neuropsychological evidence involving reading performance of congenitally deaf or dyslexic patients. Thus, five questions are examined in the present section: First, How does the phonological view accommodate results demonstrating orthographic effects in word recognition? Second, How are the differences between skilled and beginning readers accounted for by a strong phonological model? Third, What can one conclude from studies involving profoundly deaf readers? Fourth, What light can surface, phonological, and deep dyslexia shed on the interdependence of orthography, phonology, and meaning? Finally, What can be inferred from recent neuroimaging techniques about the role of phonology in reading. The aim of the present discussion, however, is not to argue for the advantage of the strong phonological model in explaining the following empirical data. Rather, the goal of this section is merely to argue that the strong phonological model can provide a no less coherent account of the data once its basic axioms are postulated. Therefore, the above five issues are discussed and interpreted on the basis of the fundamental axioms of the phonological view.

Orthographic Knowledge

A strong phonological approach to reading does not preclude orthographic recoding. Readers clearly possess extensive orthographic knowledge, and any theory of reading should incorporate the abundant experimental evidence that suggests that this knowledge affects reading processes. Moreover, almost all languages have various forms of homophony, which introduces semantic ambiguity within the phonological level. This ambiguity is often resolved by the orthographic structure and consequently by visual-orthographic processing. If not for this, readers could not access, for example, the different meanings of homophones like *rows* and *rose* and would be unable to detect spelling errors. Thus, although in this article I contend that access to a phonological representation often precedes meaning retrieval, the word's orthographic structure is clearly indispensable as well. A phonological model of reading must therefore provide a coherent description of the way orthographic information affects word perception and meaning selection.

There are two possible accounts of the role of orthography in reading comprehension. The first involves an *intra*lexical or *post*lexical spelling check. In this view, during or after the access of a phonological entry, a spelling check is carried out to confirm that a correct letter sequence matches the phonemic sequence of the printed word. Orthography would then play a relatively late role in meaning retrieval. A model along these lines was offered by Van Orden and his colleagues (e.g., Van Orden et al., 1988, 1990) to account for the results they obtained in the semantic categorization task and by Turvey and his colleagues who used masked associative priming (see Lukatela & Turvey, 1994a, 1994b, for a detailed discussion). Van Orden et al.'s (1988) model postulates a neutral core lexical representation and describes the cognitive operations within the system as feedback loops from orthographic, to phonological, to lexical (core), and back to orthographic structures. Thus, according to this model, the core lexical representation of *hare* is activated by the printed word *hair* through the phonological representation /haer/. However, a postaccess feedback from *hare* to *hair* provides the reader with the necessary information that there is a semantic mismatch. Like Van Orden et al., Lukatela and Turvey (1994a, 1994b) proposed a model in which the phonological structure of the word is the main link to meaning. Because a given phonological code can result in the activation of more than one semantic representation, the orthographic structure serves as a criterion for the final selection of one lexical candidate but only after the word's phonological structure has been recovered. Lukatela and Turvey (1994a, 1994b) thus suggested that the orthographic input code affects semantic retrieval as a clean-up process that eliminates the noise within the semantic system after phonological access.

A second possible account would consider the role of orthography in reading comprehension as an early phase of the recognition process. In this view, the specific orthographic path by which a phonological entry has been accessed determines (at least to a great extent) the activated semantic meaning. Thus, a complete analysis of lexical processing should not only consider which phonological entry has been finally accessed by the print but also the specific orthographic interface that initiated the access of a word entry in the lexicon. This approach views the processing of *rose* and *rows*, for example, as consisting of two distinct cognitive events. In one, the phonological representation /roz/ is accessed or activated by the orthographic structure *rose*, whereas in the other it is accessed or activated by *rows*.

Thus, what makes these two events semantically distinct is not the final stage of phonological activation but the initial stage of reading that specifies what orthographic interface caused the phonological representation to be accessed. That the system is not entirely foolproof and that confusions can occur is hardly a surprise when such complex systems are considered. This is the source, for example, of the false positive responses to pseudohomophones in the semantic decision task. Even if one assumes that lexical access is based on an orthographic code rather than a phonological one, the basic connection between phonological representations (i.e., words in a language) and their meaning remains unaffected. The acquisition of reading skills merely appends an orthographic interface to the existing lexical system. Thus, it is theoretically possible that lexical search and lexical access are based on orthographic information yet access a phonologically determined lexical entry. Although access to meaning is contingent on finding a phonological entry, it is nevertheless determined by the orthographic structure that led to this specific entry. The phonological model of reading is thus unaffected by evidence of sensitivity to orthographic form (see Monsell, 1987). This is because it regards the orthographic system as interfacing with the core phonological one.

Note that both accounts of how orthography affects semantic comprehension through phonological processing have a strong temporal component. The first account considers its effect following lexical access, the latter at an earlier phase. This temporal construct of the theory results from the adoption of the lexical axiom. Because the axiom assumes word-level lexical representations, the role of orthographic information can be described either before or after lexical access. This form of explanation can be contrasted, for example, with Van Orden and colleagues' (e.g., Van Orden & Goldinger, 1994; Van Orden et al., 1990) more recent resonance framework, which does not presuppose the lexical axiom and regards the same basic process as a resonance among orthographic, phonological, and semantic subsymbolic nonrepresentational units. The temporal construct of the above theory is lost here because the final outcome of processing printed information is seen as resulting from constant on-line feedback from orthographic, phonological, and semantic subunits. Nevertheless, the theory's phonological coherence constraint ensures that phonological units are necessarily involved in meaning activation, and the final conclusion of this model does differ significantly from Van Orden et al.'s (1988) model, which postulates the lexical axiom. This illustrates the claim made when the axioms were outlined, that the lexical axiom can be orthogonal to some issues discussed here, and serves mainly to provide a consistent set of terms for assessing the various theories.

Skilled Reading

The role of phonological recoding in reading acquisition seems to be widely acknowledged. It is the characterization of skilled reading that remains controversial. The major appeal of the dual-route model and the visual-encoding hypothesis stemming from it is that they provide a coherent theoretical description of the apparent efficiency of adult readers in deciphering printed words. Generally stated, the dual-route model defines the acquisition of reading skills as the ability to bypass mecha-

nisms that convert orthographic structures into phonological structures, thereby relying on direct connections to meaning. Thus, the first step of a phonological theory of reading is to provide a description of skilled reading that fits the accumulated experimental data but is nevertheless cast in phonological terms.

The strong phonological model of reading defines the acquisition of reading skills in three independent dimensions: (a) the speed of the assembly process, (b) the size of the computed orthographic units, and (c) the efficiency in accessing the lexicon through impoverished phonological information. These three dimensions, I argue, are sufficient to account for the basic phenomena observed in the visual word perception of skilled readers.

One hidden assumption underlying the metaphor of direct access is that phonological recoding is a relatively slow process. It is not easy to trace the origin or experimental basis of this assumption. It may be derived from the claims that phonological recoding is used mainly by poor readers and that phonological manipulations exert influence only on the processing of low-frequency words. These could, however, be false trails. What is indeed relatively slow is the generation of a detailed and complete phonological representation. This is because it involves not only prelexical assembly but also the addition of lexical information. As for the prelexical assembly process itself, recent data suggest that the initial cycle of phonological computation is very fast. Using the backward masking paradigm, Berent and Perfetti (1995) showed that at least in English, an impoverished phonological representation containing only consonants is computed 20–40 ms from stimulus onset. Simple vowels are computed in the second cycle, 60 ms from stimulus onset. Thus, in approximately 60 ms, a process of prelexical assembly can generate a phonological representation that might be incomplete but still allows unequivocal lexical access, given the minimality constraint discussed previously. It is generally accepted that this speed of processing is far from being slow. The impoverished representation is then shaped into a detailed structure following lexical access. Nevertheless, the initial phase of prelexical assembly can bring the skilled reader quite far in the process of word identification. The strong phonological model of reading views the acquired competence of skilled readers as their ability to complete the initial cycles of assembly in minimal time. Thus, with increased exposure to reading, the beginning reader's efficiency in computing a prelexical phonological representation increases, making it possible to generate a skeletal phonological structure more quickly, thus leading to fast lexical access.

A second dimension involves the size of the computed units. Although in alphabetic orthographies single letters generally represent single phonemes, in many deep orthographies some phonemes are represented by letter clusters. This necessarily introduces additional complexity in the relations between spelling and phonology because the prelexical computation process needs to take the adjacent letters into account to produce the correct phoneme. The skilled reader of English needs to know, for example, that c before e is pronounced /s/, but before o it is pronounced /k/, or that ough could be /o/ or /f/, but it is never the primary phonemic transcription of each letter. The acquisition of reading skills can therefore be characterized as an increased ability to convert larger letter clusters into phonemic clusters, rather than depending on single letter-to-phoneme con-

version. Ultimately, it could be possible, in principle, to convert whole printed words into whole phonological units. This is the origin of the term addressed phonology discussed in *Assembled Phonology Versus Addressed Phonology*. Nevertheless, recent data in Hebrew and English (e.g., Frost, 1995; Treiman et al., 1995) suggest that the optimal conversion unit is not an entire word. Learning to read thus means fine tuning these optimal units, given the specific characteristics of the reader's orthography. The proficient reader learns to parse the printed word into letter units that allow fast conversion into a preliminary phonological representation. In English, these units could represent, for example, a consonant and a subsequent sequence of vowels that are recoded into a syllable; in Hebrew, they could be a triconsonantal cluster; in Chinese, a monosyllabic morpheme; and so forth.

Finally, the third dimension of reading competence involves an acquired efficiency in accessing the lexicon with impoverished phonological information. What makes lexical access fast, in spite of the extreme richness of lexical information, is the ability to access an entry or activate a word node with the accumulation of minimal information, given the minimality constraint. However, the ability to access the lexicon with minimal information is a learned process, involving prolonged exposure to printed words. According to this view, beginning readers are limited to a detailed analysis of the printed word before lexical access is achieved, whereas skilled readers can recognize the same word with a relatively impoverished representation. This difference between beginning and skilled readers necessarily entails a differential sensitivity to manipulations involving phonological complexity. Because beginning readers depend on a detailed phonological representation for lexical access, any manipulation involving phonological complexity would affect their performance in the lexical decision task. In contrast, similar manipulations may have no effect on skilled readers. Thus, experimenters manipulating regularity or consistency in their design should expect these manipulations to affect beginning readers much more than skilled readers. The conclusion that the former phonologically recode and the latter visually access is by no means self-evident and is probably a false trail. Both beginning and skilled readers phonologically recode but differ greatly in the efficiency of this process. More interesting, advocates of visual access have never seemed bothered by the suggestion that reading proficiency entails an overall shift in processing mechanisms, from phonological to visual. One can hardly find a comparable phenomenon where prolonged training of a cognitive skill results, not in a greater efficiency in executing acquired routines but in the sudden adoption of new ones. In this respect, the phonological view is certainly more parsimonious and unified. It regards the process of acquiring reading competence as one continuum in which readers become increasingly more efficient in their phonological decoding skills.

Profoundly Deaf Readers

Congenitally profoundly deaf readers are of special interest to the controversy about the role of phonology in reading because this population was hearing impaired *before* the acquisition of linguistic skills. Because it is assumed that normal phonological skills develop through the ear, efficient reading in

congenitally profoundly deaf children could be seen as supporting the claim that access to meaning and reading comprehension can be achieved directly though visual representations. The argument here seems simple: If phonology is the core nucleus mediating meaning, how can congenitally deaf people read?

Overall, deaf students were consistently found to lag behind normal students in their reading abilities. Thus, on the average, profoundly deaf readers graduating from high school read at the third-grade level (e.g., Conrad, 1979). This finding is not surprising because phonological deficits in the hearing population are almost always associated with reading problems (e.g., Bryant & Bradley, 1985; see Bentin, 1992, for a review). The interesting question, though, concerns the reading mechanisms used by the few profoundly deaf readers who read well. Do they bypass phonological recoding and process printed words as visual entities?

Hanson (1982) presented deaf college students with three types of printed word lists in a short-term recall task: rhyming words, words that are visually similar, and words that are similar in their formational parameters in American sign language. The results clearly showed evidence for phonological recoding, as most interference was found in the rhyming list. More interesting, although most deaf readers are more efficient in sign language than in lipreading, several studies have shown that deaf readers do not use sign coding in reading printed words (e.g., Lichtenstein, 1985; Treiman & Hirsh-Pasek, 1983). Instead, good deaf readers were found to use mechanisms of phonological recoding (Conrad, 1979). These findings are consistently reported in tasks other than short-term recall. For example, Hanson and Fowler (1987) demonstrated a strong rhyming effect in lexical decisions to pairs of words. These results seem to suggest that good readers within the profoundly deaf population not only have access to phonological information but also prefer to use it rather than visual encoding or sign-formative encoding when processing printed words (see Hanson, 1989, for a review).

But how exactly can deaf readers acquire phonological sensitivity? Hanson (1989) suggested it arises from their experience in speaking and lipreading. As the abstract phonological categories of a language are intimately related to the gestures produced by the vocal tracts and oral articulators, phonological sensitivity develops from the motor events that occur during speech production (see A. M. Liberman & Mattingly, 1985, for a discussion). So what can profoundly deaf readers tell researchers about normal reading? Two main conclusions may be drawn at this point. First, the phonological system seems to be so basic to human linguistic abilities that even very partial and fragmented exposure to speech seems to be enough to prime and develop it. Second, if deaf readers who can easily use visual or sign-formative encoding rely mainly on phonological information in reading, a strong case for the role of phonology in normal readers can be made.

Dyslexic Readers

A major support for the dual-route theory stems from observing the various forms of dyslexia. Three types of dyslexia are most relevant to the present debate: surface dyslexia, phonologi-

cal dyslexia, and deep dyslexia (see Patterson, Marshall, & Coltheart, 1985, for a review).

Readers with surface dyslexia appear to read frequent words as if they were novel stimuli. Their reading resembles that of beginning readers; they break words into their syllabic constituents and have special difficulty in reading irregular words correctly. It seems that these readers can rely only on the assembly of phonology without having the ability to address the word's phonological structure from the lexicon (e.g., Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Shallice, Warrington, & McCarthy, 1983). In contrast, individuals with phonological dyslexia can read meaningful familiar words but their reading of novel words or nonwords is severely impaired (e.g., Funnell, 1983; Patterson, 1980). These contrasting forms of reading difficulty provide a double dissociation that supports the theoretical distinction between the visual and the phonological routes to the lexicon (e.g., Coltheart et al., 1993; but see Van Orden, Pennington, & Stone, 1998, for counterarguments). Moreover, the poor reading performance of individuals with surface dyslexia demonstrates the difficulty of reading without the ability to use the direct route. This confirms the basic advantage of visual and direct access in word recognition and reveals the slowness and inefficiency of the assembly route.

This interpretation is indeed consistent with the dual-route theory's basic axiom that the assembled and addressed routines are independent. However, once again, it is not clear whether the data support the basic tenets of the theory or whether the data are interpreted in a specific way given these basic tenets. After all, a strong phonological model of reading would be similarly supported by the properties of surface dyslexia. It would just focus on the grain-size distinction and the process of shaping the impoverished phonological representation computed from print. Thus, according to the strong phonological model, surface dyslexic readers, like normal readers, initially compute a phonological representation from print. However, in contrast to normal readers, they lack the ability to shape this representation using lexical information. This is why familiar words seem novel and why irregular words are read with so many errors. No one denies that without lexical information, reading in deep orthographies is seriously limited. Coltheart et al. (1993) provided convincing arguments for the need of lexical representations for any plausible theory of reading, and this is one reason for adopting the lexical axiom throughout the present article. Nevertheless, the use of the lexical axiom would allow both the dual-route and the phonological model to accommodate the evidence from surface dyslexia. The conclusion to be drawn here is that this form of evidence cannot resolve the differences between dual and single (nondistributed) route theories.

Evidence that is more damaging to the strong phonological model comes from phonological dyslexia. If all readers necessarily engage in the prelexical computation of phonology, how does the model describe the reading of familiar words by phonological dyslexic readers who are seriously limited in their decoding skills? It seems that the phonological model would have to concede that reading can occur through recognizing whole-word units and matching them to whole phonological units. One possible argument of the model would focus on the limited capacity of phonological dyslexic readers to read meaningful words. However, at least the patient described by Funnell (1983)

seemed to deviate from such a description because she was 90% correct, even on words that were infrequent, long, affixed, and abstract. Thus, the phonological model would have to assume that although matching whole-orthographic and whole-phonological units is not a default procedure of the cognitive system, it could in principle be done reasonably well. Whether this constitutes an independent or self-contained routine in normal reading is not clear. Dual-route models not only assume that it does but also claim that it is the most used one in speed reading. The evidence from surface and phonological dyslexia does not provide an unequivocal resolution to this debate.

Another possible argument against the strong phonological model of reading stems from observing deep dyslexic readers. A fairly large proportion of reading errors produced by deep dyslexic readers consists of mispronunciations that have no phonological resemblance to the presented printed words but are semantically associated with them (e.g., rock and stone). This pattern of response seems to suggest that deep dyslexic readers often bypass the word's phonological structure and access meaning directly from print (for a review, see Marshall & Newcombe, 1980). Indeed, the mere finding that some readers systematically produce semantic associates of printed words was taken as evidence supporting the existence of a direct path between orthography and meaning (Coltheart, 1980; Green & Shallice, 1976).

There are two problems with this type of evidence. First, the final output of the reading process is opaque to the cognitive processes that generated it. More specifically, the production of the semantic associate instead of the word itself could be due to an early error in lexical access or to a late error in recovering the cognitive events that led to this access. The common interpretation of the semantic errors of deep dyslexic readers is that the printed word directly activates a semantic node in semantic memory. But because phonological recoding did not occur, the reader produced a semantic neighbor rather than the word itself (Coltheart, 1985). This account, however, cannot exclude a parallel interpretation that focuses on a late output stage. In this view, the printed word is indeed recoded phonologically, and meaning is accessed just as the strong phonological model predicted. However, the patient cannot recover the phonological structure that led to this semantic activation at the output stage; therefore, semantic associations are often produced. This interpretation is supported by recent studies suggesting that acquired dyslexic readers are indeed profoundly limited in tasks involving phonological output that are not necessarily related to reading (Patterson & Marcel, 1992; Patterson & Vargha-Kadem, 1991). Thus, the symptomatic picture of deep dyslexic readers remains the same, even when reading is not involved.

A recent case study presented by Hildebrandt and Sokol (1993) provides strong support for this view, revealing yet another problem with the classical interpretation of deep dyslexia. Hildebrandt and Sokol described an acquired dyslexic individual who showed no evidence of having access to subword phonological units on tasks that are standardly used to assess acquired dyslexia (e.g., word–nonword naming). The individual, however, showed clear spelling regularity effects for low-frequency words in the lexical decision task, suggesting a sublexical phonological analysis in processing printed words. Hildebrandt and Sokol argued that the nature of a task largely determines the interpretation of the reader's responses. In tasks that require

explicit phonological output, dyslexic participants displayed severe limitations in processing phonological information. However, in implicit tasks that did not require phonological output, these participants showed clear evidence that the phonological properties of the printed word had indeed been processed.

Additional support for the role of phonological recoding in the reading of deep dyslexic readers comes from a study monitoring the type of phonological errors they produce (Black & Byng, 1986). Black and Byng reported that reading errors of deep dyslexic participants were constrained by prosodic factors. For example, bisyllabic words stressed on the second syllable were found to be significantly harder to read than comparable words with the stress on the first syllable. In addition, participants made more errors in the part of the letter string that corresponded to the stressed syllable. Black and Byng therefore concluded that prosodic factors constrained the early stages of lexical access of their participants. Thus, even if the output stage interpretation discussed above is not adopted, it seems that some phonological recoding occurs even for deep dyslexic readers.

The final argument from deep dyslexia is a theoretical one. Paradoxically, the strong phonological model sees this neurological disorder as a unique demonstration of the role of phonology in reading. If deep dyslexia indeed reflects the inability to recover the printed word's phonological structure, the symptoms displayed by deep dyslexic readers exemplify how a lexical system that connects orthographic with semantic representations directly would work. The main limitation of such a system is that orthographic units are mapped systematically onto phonological units, not onto semantic representations. The argument of systematicity is a crucial one. A theory of reading would like to argue for a clear psychological difference between the reading of synonyms such as *perhaps* and *maybe*. These synonyms presumably map onto very similar (if not identical) semantic representations; however, they represent two different words. Normal readers, however, do not confuse the readings of these two words, as deep dyslexic readers might, because orthographic symbols map systematically only onto phonological structures.

Note that taking the strong visual encoding hypothesis ad absurdum would mean that normally efficient readers and deep dyslexic readers should process printed words almost identically. As previously discussed, the visual model posits that the meaning of most frequent words is directly accessed from their orthographic structure. This "popular" route, however, is presumably the one mostly used by deep dyslexic readers. Why is it that normal readers do not produce semantic errors as consistently as deep dyslexic readers do? The answer probably lies within the phonological system, which is the nucleus of the mental lexicon. If this system is intact, it serves as the major cognitive intersection to which all lexical paths necessarily connect, preventing these types of errors. Obviously, proponents of the visual-encoding hypothesis could counter the above argument by arguing that deep dyslexic readers cannot be compared with normal readers because many other possible mechanisms might also be involved in the behavior deep dyslexic readers display. Nevertheless, the dual-route's assumption concerning the similar extreme reliance of both proficient readers and deep dyslexic readers on the visual route seems problematic from the dual-route perspective.

Neuroimaging Techniques

In recent years, the role of orthographic versus phonological processing has also been discussed and argued following studies that used neuroimaging techniques like position emission tomography (PET) and functional magnetic resonance imaging (fMRI). In general, research involving neuroimaging focuses on differential neural activation in different areas of the brain that are known to be involved in phonological or visual information processing. Increased or reduced activation in phonologically relevant regions in one task, as compared with another, is taken as evidence for phonological or nonphonological processing in that specific task. Similarly, neural activity in the visual areas is taken as evidence for visual processing. Although these studies do not seem to yield clear-cut conclusions, a summary of my debate cannot be complete without referring to them as well.

In a series of PET studies, Petersen and his colleagues (Petersen, Fox, Snyder, & Raichle, 1990; Petersen, Posner, Mintun, & Raichle, 1989) found that processing spoken words resulted in temporal lobe activation whereas no activation was found in silent reading. This result was taken by some researchers as evidence that phonological processing plays a little role in visual word recognition. However, other researchers using PET (e.g., Price et al., 1994) found increased activation at both temporal lobe and inferior frontal sites (e.g., Wernicke's and Broca's areas) in tasks involving printed word recognition. Recent studies using fMRI have also obtained evidence of involvement of these regions in the reading of real words (e.g., Pugh et al., 1996). Thus, to date, the results of neuroimaging studies have been equivocal with respect to the strong phonological model of reading. Moreover, although the identification of the neuroanatomical systems engaged in language processes is of major importance for cognitive neuroscience, its direct relevance to the present debate remains questionable. This is because, at least at present, there is no clear connection between the cognitive theoretical constructs used in word perception research (i.e., assembled vs. addressed phonology, direct vs. indirect route, etc.) and their respective brain structures (for a detailed discussion, see Van Orden & Paap, in press).

Toward a Strong Phonological Approach to Reading

My aim in this article was to propose a unified approach for investigating visual word recognition while considering the perception of printed words as one of the many faculties of the human linguistic system. Once it is accepted that the linguistic axiom offers a more viable approach to reading than the visual-analogical axiom, the other axioms of the strong phonological model logically follow. Thus, the speech primacy and the non-neutrality axioms both suggest that the core lexical representations of words are phonologically defined. These axioms are theoretically coherent with the linguistic axiom because they derive from the phonological nature of human natural languages. The choice of basic axioms is crucial for assessing the large variety of findings in word recognition. The various issues discussed in the present article suggest that once it is assumed that the core entries of the lexicon are phonological, a considerable amount of evidence that has been interpreted as demonstrating

visual recoding can be re-interpreted as demonstrating phonological recoding.

But although, in general, different axioms could provide different interpretations for the empirical data, the aim of the present article was not to argue for complete subjectivity or scientific nihilism. Rather, there are two main conclusions to be drawn from this state of affairs. First, the axioms underlying my theory and experimental manipulations should be made explicit to allow the empirical data to be evaluated. Second, making my postulated axioms explicit allows them to be discussed in terms of their parsimony, their coherence, their convergence or divergence from other axioms in my theory, their ability to explain positive empirical findings in the field, and their contribution in generating experimental techniques and falsifiable models. Thus, although many of this article's arguments in favor of a phonological view of reading are theoretical rather than experimental, this does not imply that the issues discussed here have no empirical reality. On the contrary, the axioms I assume need to be assessed constantly on the basis of the accumulated empirical data. The point is that only when the axioms are made explicit can they be evaluated in connection with the empirical data that are indeed relevant to them.

The consistent evidence for phonological computation, its role in lexical access when the minimality constraint is taken into account, the manner in which phonology is assembled from print and shaped into a detailed representation, and the basic role of phonological structures in conveying meaning all suggest that the role of phonology is more important than dual-route models have assumed. This could lead to one of two theoretical shifts. One possibility is to retract the basic tenets regarding the role of phonology in reading, which are implicitly assumed by dual-route models. These tenets involve the default operation of the cognitive system in generating a phonological representation, the speed and efficiency of the computation procedure, and the nature of the representations produced. Such a theoretical approach would keep the dual-route view but would reconsider the description of phonological processing within the model. A more dramatic shift would consist of abandoning the dual-route framework and advocating a strong phonological model of word recognition. The discussions presented in this article were aimed at suggesting that this model is a viable alternative to dual-route models: It presents a unified and defensible set of axioms, it is coherent with a linguistic approach to visual word recognition, it can accommodate most positive experimental findings in the field, and it can, therefore, withstand detailed empirical scrutiny.

The final question to be examined concerns the methodology of future experiments using the framework of the strong phonological model. Reviewing the present controversies has shown that the current methods of investigation have often resulted in a stalemate. Thus, what may be required is a shift in experimental paradigms. Dual-route models, which have dominated research in visual word recognition since its early stages, have made a significant contribution to the conceptual determination of possible mechanisms for processing printed words. Often casting these mechanisms in terms of independent paths, these models have implicitly shaped experimental methods of investigation. These methods have consisted, in most cases, of searching for a binary decision: Is phonology assembled or addressed? Is phonology activated or not? Is meaning accessed or not? These

dichotomous choices may have missed a possible truth about the lexical system: Phonology is always partly assembled and always partly lexical, it is always activated but not necessarily fully specified, and it plays a major role in accessing meaning but not an exclusive one. If this state of affairs is correct, it cannot be investigated by all-or-none methods.

To present a robust alternative to dual-route models and consequently prevent a reversed pendulum swing, the strong phonological view needs to provide a detailed model of phonological computation that will specify how exactly impoverished representations interact with lexical information. Empirical investigations should therefore focus on mapping the computations involved in visual word recognition. For example, experiments should aim at continuously measuring the different time courses for generating consonantal versus vowel information, measuring the exact size of computed orthographic and phonological units in various letter clusters by beginning or skilled readers, measuring the relative contribution of each phonologically opaque letter to naming time, predicting the degree of impoverishment of computed representations in different experimental conditions and assessing their role in lexical access, or monitoring the increased specification of phonological and semantic information over time, following print presentation. Thus, instead of setting one's experimental camera at the finish line of the cognitive events, one should aim at filming their on-line, step-by-step development.

References

Andrews, S. (1982). Phonological recoding: Is the regularity effect consistent? *Memory & Cognition, 10,* 565–575.

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

Baluch, B., & Besner, D. (1991). Strategic use of lexical and nonlexical routines in visual word recognition: Evidence from oral reading in Persian. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 644–652.

Baron, J. (1973). Phonemic stage not necessary for reading. *Quarterly Journal of Experimental Psychology, 25,* 241–246.

Barron, R. W., & Baron, J. (1977). How children get meaning from printed words. *Child Development, 48,* 587–594.

Bentin, S. (1992). Phonological awareness, reading, and reading acquisition: A survey and appraisal of current knowledge. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). Amsterdam: North-Holland.

Bentin, S., Bargai, N., & Katz, L. (1984). Orthographic and phonemic coding for lexical access: Evidence from Hebrew. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 353–368.

Bentin, S., & Frost, R. (1987). Processing lexical ambiguity and visual word recognition in a deep orthography. *Memory & Cognition, 15,* 13–23.

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

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

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

Besner, D., & Hildebrandt, N. (1987). Orthographic and phonological codes in the oral reading of Japanese *Kana. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 335–343.

Besner, D., & Smith, M. C. (1992). Basic processes in reading: Is the orthographic depth hypothesis sinking? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 45–66). Amsterdam: North-Holland.

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

Black, M., & Byng, S. (1986). Prosodic constraints on lexical access in reading. *Cognitive Neuropsychology, 3*, 369–409.

Browman, C. P., & Goldstein, L. (1986). Towards an articulatory phonology. *Phonology Yearbook, 3*, 219–252.

Brown, P., & Besner, D. (1987). The assembly of phonology in oral reading: A new model. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 471–490). Hillsdale, NJ: Erlbaum.

Bryant, P., & Bradley, L. (1985). *Children's reading problems.* Oxford, England: Blackwell.

Buchanan, L., & Besner, D. (1993). Reading aloud: Evidence for the use of a whole word nonsemantic pathway. *Canadian Journal of Experimental Psychology, 47*, 133–152.

Carello, C., Turvey, M. T., & Lukatela, G. (1992). Can theories of word recognition remain stubbornly nonphonological? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 211–226). Amsterdam: North-Holland.

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

Chomsky, N., & Halle, M. (1968). *The sound pattern of English.* New York: Harper & Row.

Clements, G. N. (1985). The geometry of phonological features. *Phonology, 2*, 225–252.

Colombo, L., & Tabossi, P. (1992). Strategies and stress assignments: Evidence from a shallow orthography. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 319–340). Amsterdam: North Holland.

Coltheart, M. (1980). Reading phonological recoding and deep dyslexia. In M. Coltheart, K. Patterson, & J. C. Marshal (Eds.), *Deep dyslexia* (pp. 197–226). London: Routledge & K. Paul.

Coltheart, M. (1985). The cognitive neuropsychology of reading. In M. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 3–37). Hillsdale, NJ: Erlbaum.

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

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the mental lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535–555). London: Academic Press.

Coltheart, M., Masterson, J., Byng, S., Prior, M., & Riddoch, J. (1983). Surface dyslexia. *Quarterly Journal of Experimental Psychology, 35A*, 469–495.

Coltheart, V., Patterson, K., & Leahy, J. (1994). When a ROWS is a ROSE: Phonological effects in written word comprehension. *Quarterly Journal of Experimental Psychology, 47*, 915–955.

Coltheart, M., & Rastle, K. (1994). Serial processing and reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1197–1211.

Conrad, R. (1979). *The deaf schoolchild.* London: Harper & Row.

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

DeFrancis, J. (1989). *Visible speech: The diverse oneness of writing systems.* Honolulu: University of Hawaii Press.

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

Feldman, L. B. (1987). Phonological and morphological analysis by skilled readers of Serbo-Croatian. In A. Allport, D. MacKay, W. Prinz, & E. Scheerer (Eds.), *Language perception and production* (pp. 198–209). London: Academic Press.

Feldman, L. B., Kostic, A., Lukatela, G., & Turvey, M. T. (1983). An evaluation of the "basic orthographic syllabic structure" in a phonologically shallow orthography. *Psychological Research, 45*, 55–72.

Feldman, L. B., & Turvey, M. T. (1980). Words written in *Kana* are named faster than the same words written in *Kanji. Language and Speech, 23*, 141–147.

Feldman, L. B., & Turvey, M. T. (1983). Word recognition in Serbo-Croatian is phonologically analytic. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 288–298.

Ferrand, L., & Grainger, J. (1996). List context effects on masked phonological priming in the lexical decision task. *Psychonomic Bulletin & Review, 3*, 515–519.

Forster, K. I. (1992). Memory addressing mechanisms and lexical access. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 211–226). Amsterdam: North-Holland.

Forster, K. I. (1994). Computational modeling and elementary process analysis in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1292–1311.

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

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

Frost, R. (1991). Phonetic recoding of print and its effect on the detection of speech in amplitude modulated noise. *Cognition, 39*, 195–214.

Frost, R. (1992). Orthography and phonology: The psychological reality of orthographic depth. In M. Noonan, P. Downing, & S. Lima (Eds.), *The linguistics of literacy* (pp. 255–274). Amsterdam/Philadelphia: John Benjamins.

Frost, R. (1994). Prelexical and postlexical strategies in reading: Evidence from a deep and a shallow orthography. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 116–129.

Frost, R. (1995). Phonological computation and missing vowels: Mapping lexical involvement in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 398–408.

Frost, R., & Bentin, S. (1992a). Processing phonological and semantic ambiguity: Evidence from semantic priming at different SOAs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 58–68.

Frost, R., & Bentin, S. (1992b). Reading consonants and guessing vowels: Visual word recognition in Hebrew orthography. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 27–44). Amsterdam: North-Holland.

Frost, R., & Kampf, M. (1993). Phonetic recoding of phonologically ambiguous printed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 23–33.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 104–115.

Frost, R., Repp, B. H., & Katz, L. (1988). Can speech perception be influenced by a simultaneous presentation of print? *Journal of Memory and Language, 27*, 741–755.

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

Funnell, E., & Allport, D. A. (1987). Nonlinguistic cognition and word meanings: Neuropsychological exploration of common mechanisms. In D. A. Allport, D. G. Mackay, W. Prinz, & E. Scheerer (Eds.), *Language perception and production: Relationships among listening, speaking, reading, and writing* (pp. 367–400). London: Academic Press.

Goldsmith, J. (1976). An overview of autosegmental phonology. *Linguistic Analysis, 2*, 23–68.

Goldsmith, J. (1990). *Autosegmental and metrical phonology*. Oxford, England: Basil Blackwell.

Goswami, U., & Bryant, P. (1990). *Phonologic skills and learning to read*. East Sussex, England: Erlbaum.

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

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*, 518–565.

Grainger, J., & Jacobs, M. A. (Eds.). (1997). *Localist connectionist approaches to human cognition*. Hillsdale, NJ: Erlbaum.

Green, D. W., & Shallice, T. (1976). Direct visual access in reading for meaning. *Memory & Cognition, 4*, 753–758.

Gronau, N., & Frost, R. (1997). Prelexical phonologic computation in a deep orthography: Evidence from backward masking in Hebrew. *Psychonomic Bulletin & Review, 4*, 107–112.

Hanson, V. L. (1982). Short-term recall by deaf signers of ASL: Implication for order recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 572–583.

Hanson, V. L. (1989). Phonology and reading: Evidence from profoundly deaf readers. In D. Shankweiler & I. Y. Liberman (Eds.), *Phonology and reading disability: Solving the reading puzzle* (IARLD Research Monograph Series, pp. 69–89). Ann Arbor: University of Michigan Press.

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

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

Henderson, L. (1987). Word recognition: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 171–200). Hillsdale, NJ: Erlbaum.

Hildebrandt, N., & Sokol, S. M. (1993). Implicit sublexical phonological processing in an acquired dyslexic patient. *Reading and Writing: An Interdisciplinary Journal, 5*, 43–68.

Jacobs, A. M., Grainger, J., Rey, A., & Ziegler, J. C. (in press). An interactive activation multiple read-out model of orthographic and phonological processes in visual word recognition. In J. Grainger & A. M. Jacobs (Eds.), *Localist connectionist approaches to human cognition*. Hillsdale, NJ: Erlbaum.

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

Jared, D., & Seidenberg, M. S. (1991). Does word identification proceed from spelling to sound to meaning? *Journal of Experimental Psychology: General, 120*, 358–394.

Katz, L., & Feldman, L. B. (1981). Linguistic coding in word recognition. In A. M. Lesgold & C. A. Perfetti (Eds.), *Interactive processes in reading* (pp. 85–105). Hillsdale, NJ: Erlbaum.

Katz, L., & Feldman, L. B. (1983). Relation between pronunciation and recognition of printed words in deep and shallow orthographies. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 157–166.

Katz, L., & Frost, R. (1992). Reading in different orthographies: The orthographic depth hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). Amsterdam: North-Holland.

Kleiman, G. M. (1975). Speech recoding in reading. *Journal of Verbal Learning and Verbal Behaviour, 14*, 323–339.

Klopfer, D. S. (1996). Stroop interference and color–word similarity. *Psychological Science, 7*, 150–157.

Lesch, M. F., & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 285–294.

Levy, B. A. (1975). Vocalization and suppression effects in sentence memory. *Journal of Verbal Learning and Verbal Behavior, 14*, 304–316.

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

Liberman, A. M., & Whalen, D. (1989, January 27). A specialization for speech perception. *Science, 243*, 489–494.

Liberman, I. Y., Shankweiler, D., Liberman, A. M., Fowler, C., & Fisher, F. W. (1977). Phonetic segmentation and recoding in the beginning reader. In A. S. Reber & D. L. Scarborough (Eds.), *Towards a psychology of reading* (pp. 207–226). Hillsdale, NJ: Erlbaum.

Lichtenstein, E. H. (1985). Deaf working memory processes and English skills. In D. S. Martin (Ed.), *Cognition, education, and deafness: Directions for research and instruction* (pp. 157–171). Washington DC: Gallaudet College Press.

Lukatela, G., Feldman, L. B., Turvey, M. T., Carello, C., & Katz, L. (1989). Context effects in bi-alphabetical word perception. *Journal of Memory and Language, 28*, 214–236.

Lukatela, G., Popadic, D., Ognjenovic, P., & Turvey, M. T. (1980). Lexical decision in a phonologically shallow orthography. *Memory & Cognition, 8*, 415–423.

Lukatela, G., Savic, M., Gligorjevic, B., Ognjenovic, P., & Turvey, M. T. (1978). Bialphabetical lexical decision. *Language and Speech, 21*, 142–165.

Lukatela, G., & Turvey, M. T. (1990). Automatic and prelexical computation of phonology in visual word identification. *European Journal of Cognitive Psychology, 2*, 325–343.

Lukatela, G., & Turvey, M. T. (1994a). Visual access is initially phonological. 1: Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 107–128.

Lukatela, G., & Turvey, M. T. (1994b). Visual access is initially phonological. 2: Evidence from associative priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 331–353.

Lupker, J. S. (1984). Semantic priming without association: A second look. *Journal of Verbal Learning and Verbal Behavior, 23*, 709–733.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 193–203.

Marshall, J. C., & Newcombe, F. (1980). The conceptual status of deep dyslexia: An historical perspective. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 1–21). London: Routledge & Kegan Paul.

Marslen-Wilson, W., Komisarjevsky Tyler, L., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3–33.

Massaro, D. W., & Cohen, M. M. (1994). Visual, orthographic, phonological, and lexical influences in reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1107–1129.

Mattingly, I. G. (1992). Linguistic awareness and orthographic form. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 11–26). Amsterdam: North-Holland.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation

model of context effects in letter perception. Part 1: An account of basic findings. *Psychological Review, 88*, 375–407.

McCusker, L. X., Hillinger, M. L., & Bias, R. C. (1981). Phonological recoding and reading. *Psychological Bulletin, 88*, 217–245.

Monsell, S. (1987). Nonvisual orthographic processing and the orthographic input lexicon. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 299–323). Hillsdale, NJ: Erlbaum.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review, 76*, 165–178.

Neely, J. H. (1991). Semantic priming effects in visual word recognition. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Paap, K. R., McDonald, J. E., Schvaneveldt, R. W., & Noel, R. W. (1987). Frequency and pronounceability in visually presented naming and lexical decision. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 221–243). Hillsdale, NJ: Erlbaum.

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

Paap, K. R., Noel, R. W., & Johnasen, L. S. (1992). Dual-route models of print to sound: Red herrings and real horses. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 293–318). Amsterdam: North-Holland.

Patterson, K. E. (1980). Derivational errors. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 286–306). London: Routledge & K. Paul.

Patterson, K., & Coltheart, V. (1987). Phonological processes in reading: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 421–447). Hillsdale, NJ: Erlbaum.

Patterson, K., & Marcel, A. (1992). Phonological ALEXIA or PHONOLOGICAL Alexia? In L. Alegria, D. Holender, J. Junca de Morais, & M. Radeau (Eds.), *Analytic approaches to human cognition* (pp. 259–274). Amsterdam: North-Holland.

Patterson, K., Marshall, J. C., & Coltheart, M. (Eds.). (1985). *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading*. Hillsdale, NJ: Erlbaum.

Patterson, K., & Vargha-Kadem, F. (1991). Neuropsychological observations on the affinity between reading and phonological abilities. *Mind & Language, 6*, 140–145.

Perfetti, C. A., & Bell, L. C. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and masked priming. *Journal of Memory and Language, 30*, 473–485.

Perfetti, C. A., Bell, L. C., & Delaney, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking. *Journal of Memory and Language, 27*, 59–70.

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a universal phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227–248). Amsterdam: North-Holland.

Petersen, S. E., Fox, P. T., Snyder, A. Z., & Raichle, M. E. (1990, August 31). Activation of extrastriate and frontal cortical areas by visual word-like stimuli. *Science, 249*, 1041–1044.

Petersen, S. E., Posner, M. I., Mintun, M., & Raichle, M. E. (1989). Positron emission tomographic studies of the processing of single words. *Journal of Cognitive Neuroscience, 1*, 153–170.

Pexman, P. M., Lupker, S. J., Jared, D., Toplak, M., & Roubiah, A. (1996, November). *Strategically controlling phonology in response to pseudohomophones?* Paper presented at the 37th meeting of the Psychonomic Society, Chicago, IL.

Plaut, D. C., & McClelland, J. L. (1993). Generalization with componential attractors: Words and nonwords reading in an attractor network. In *Proceedings of the 15th annual conference of the Cognitive Science Society* (pp. 824–829). Hillsdale, NJ: Erlbaum.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56–116.

Potter, M. C., & Faulconer, B. A. (1975, February 6). Time to understand pictures and words. *Nature, 253*, 437–438.

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

Pugh, K., Rexer, K., & Katz, L. (1994). Evidence for flexible coding in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 807–825.

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

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology, 81*, 275–280.

Rubenstein, H., Garfield, L., & Millikan, J. (1971). Homographic entries in the lexicon. *Journal of Verbal Learning and Verbal Behaviour, 9*, 487–494.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behaviour, 10*, 645–657.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1–17.

Sebastian-Galles, N. (1991). Reading by analogy in a shallow orthography. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 471–477.

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

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII* (pp. 245–263). Hillsdale, NJ: Erlbaum.

Seidenberg, M. S. (1992). Beyond orthographic depth in reading: Equitable division of labor. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 85–118). Amsterdam: North-Holland.

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

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

Shallice, T., Warrington, E. K., & McCarthy, R. (1983). Reading without semantics. *Quarterly Journal of Experimental Psychology, 35A*, 111–138.

Shiffrin, R. M. (1988). Attention. In R. C. Atkinson, R. J. Herrnstein, G. Lindzay, & R. D. Luce (Eds.), *Steven's handbook of experimental psychology. Vol. 2: Learning and cognition* (pp. 739–811). New York: Wiley.

Simpson, G. B., & Kang, H. (1994). The flexible use of phonological information in word recognition in Korean. *Journal of Memory and Language, 33*, 319–331.

Spoehr, K. T. (1978). Phonological recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 17*, 127–141.

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

Stone, G. O., & Van Orden, G. C. (1994). Building a resonance frame-

work for word recognition using design and system principles. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1248–1268.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in two writing systems: Italian and English. *Memory & Cognition, 20,* 303–313.

Tan, L. H., Hoosain, R., & Peng, D. L. (1995). Role of early presemantic phonological code in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 43–54.

Tan, L. H., Hoosain, R., & Siok, W. W. T. (1996). The activation of phonological codes before access to character meaning in written Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 865–882.

Treiman, R., & Hirsh-Pasek, K. (1983). Silent reading: Insight from congenitally deaf readers. *Cognitive Psychology, 15,* 39–65.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124,* 107–136.

Turvey, M. T., Feldman, L. B., & Lukatela, G. (1984). The Serbo-Croatian orthography constrains the reader to a phonologically analytic strategy. In L. Henderson (Ed.), *Orthographies and reading: Perspectives from cognitive psychology, neuropsychology, and linguistics* (pp. 81–89). Hillsdale, NJ: Erlbaum.

Tzelgov, J., Henik, A., Sneg, R., & Baruch, O. (1996). Unintentional reading via the phonological route: The Stroop effect with cross-script homophones. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 336–339.

Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound, and reading. *Memory & Cognition, 15,* 181–198.

Van Orden, G. C., Atchison, C. S., & Podgornik, M. N. (1998). *When a rows is not a rose: Null effects and the absence of cognitive structure.* Manuscript submitted for publication.

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

Van Orden, G. C., Johnston, J. C., & Halle, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 371–386.

Van Orden, G. C., & Paap, K. R. (in press). Functional neuroimaging fails to discover pieces in the mind in the parts of the brain. *Philosophy of Science.*

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

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1998). *What do double dissociations prove? Modularity yields a degenerating research program.* Manuscript submitted for publication.

Van Orden, G. C., Stone, G. O., Garlington, K. L., Markson, L. R., Pinnt, G. S., Simonfy, C. M., & Brichetto, T. (1992). "Assembled" phonology and reading: A case study in how theoretical perspective shapes empirical investigation. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 85–118). Amsterdam: North-Holland.

Venezky, R. L. (1970). *The structure of English orthography.* The Hague, The Netherlands: Mouton.

Verstaen, A., Humphreys, G. W., Olson, A., & d'Ydewalle, G. (1995). Are phonemic effects in backward masking evidence for automatic prelexical phonemic activation in visual word recognition? *Journal of Memory and Language, 34,* 335–356.

Waters, G. S., & Seidenberg, M. S. (1985). Spelling–sound effects in reading. Time course and decision criteria. *Memory & Cognition, 13,* 557–572.

Weisstein, N., & Harris, C. S. (1974, November 22). Visual detection of line segments: An object superiority effect. *Science, 186,* 752–754.

West, R. F., & Stanovich, K. E. (1982). Source of inhibition in experiments on the effect of sentence context on word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 5,* 385–399.

Ziegler, J. C., & Jacobs, A. M. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language, 34,* 567–593.

Ziegler, J. C., Van Orden, G. C., & Jacobs, A. M. (1997). Phonology can help or hurt the perception of print. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 845–860.