The traditional contrast of views on the role of phonology in reading has setup a theoretical dichotomy. Historically reading proceeded either: (a) through a process of assembled phonology or (b) through orthographic codes. In (a) phonology precedes lexical access; it is assembled. In (b) phonology is obtained after lexical access; it is addressed. An attempt to integrate these two processes led to the development of the *dual-route* theory of reading (Coltheart, 1978; but see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2000 for a more recent discussion) —Coltheart's dual route model dominated research into visual word recognition for several decades since its inception. The importance of this model comes from the fact that it attempts to integrate the answers to the question, "How does visual word recognition occur?" by including both a direct lexical access route based on orthography and a phonologically assembled route, thus combining them into one model. The combination of both routes to the lexicon incorporates a compromise in an effort to harmonize the historically contrasting views mentioned on the processes of word recognition.

Since Coltheart's dual route "compromise" made phonology acceptable in visual word recognition, models afterward gave greater or lesser roles to phonological involvement. Under the *weak* phonological model, it was assumed that phonological processing occurred when necessary (e.g., reading a nonword). This was known as the *visual encoding hypothesis* and assumed that for skilled readers visual access was more efficient than phonological assembly; involving retrieval of the whole-word phonological structure from the lexicon rather than assembling the phonological structure. Alternatively, a *strong phonological hypothesis*, assumes phonology is mandatory and automatic in all cases (Frost, 1997; Lukatela & Turvey, 1994; Lukatela, Eaton, Lee, Carello, & Turvey, 2002). In between both extrema exist several hypotheses that have structured the debate concerning the degree to which the phonological route acts independently of the lexical route including the *delayed-phonological* (DP) hypothesis and *verification* hypothesis (see Van Orden, Pennington, and Stone, 1990 for a discussion). The DP hypothesis posits that for skilled readers the output of the phonological route influences visual recognition only after the lexical route has concluded. In this case, phonology has little influence for the skilled reader as it occurs after lexical access. Alternatively, the verification hypothesis predicts that phonology is not delayed but rather upon assembly, a verification process compares the stored lexical representation with the assembled phonological structure (Van Orden, 1987).

The debate, which began as a question of whether phonology was involved at all developed into questions such as how, when and to what degree is phonology involved. With this in mind, the goal of the following answer is to concisely outline the debate concerning the role that phonology has taken in visual word recognition from the early years to the present. To do this I will provide experimental and theoretical evidence to contrast the views above, making a clear statement of where and what phonology is today. Finally, I will conclude that the future hypotheses of phonology are strong ones and future experimentation should aim to explore the depth of phonological representation, answering questions regarding the nature of the phonological information used in visual word recognition.

A Concise History

The early beginnings of the phonology debate begin with Gough (1972)[1] who illustrated that word identification proceeds from spelling to sound to meaning. This view assumed that the transformation from spelling to phonology involved mapping one representation onto the next. Gough argued that developmentally this view was most appropriate and most economical, as the early reader would only need to apply orthographic information to their early (i.e., temporally speaking) recognition system. Then, the young reader would learn to map the appropriate orthographic structure to their already stored phonological representations; representations learned through speech and listening.

At the time, the alternative hypothesis was that of the *direct access* (Becker, 1976; Paap, Newsome, McDonald, & Schvaneveldt, 1982) hypothesis or *lexical look-up* (LLP) hypothesis (Coltheart, 1976). The assumptions here were that visual sensory information provided a starting point for lexical access which terminated in a verification process. Lexical access proceeded as an automatic process that involved generating a visual sensory representation, which was later compared against a prototypical,

[1] It is recognized that this debate begins further back in time. However, Gough (1972) provides a detailed, early, account of the role of phonology in visual word recognition.

stored visual representation. The advantages here is that a skilled reader could quickly compare the spelling representation with a representation that was stored in the lexicon and, using the LLP, retrieve the phonological representation.

Together, both hypotheses led to the development of the *dual-route hypothesis* mentioned above. Which to flesh out a bit: In this model there are two possible procedures for converting print to speech. One procedure is a direct route to the lexicon and the other is a rule-based mapping from printed letter to sound. Thus, the dual route model assigns the direct-lexical route to words that are of high frequency as well as words that are irregular and/or inconsistent (i.e., Pint). In this case, words are accessed by mapping the orthographic pattern of letters to the input lexicon and then retrieving the pronunciation of this entry from the phonological output lexicon. Alternatively, the non-lexical route is necessary for the pronunciation of non-words and low frequency words because it is assumed that these words either have no lexical entry or a weakly activated one. To accomplish this, the non-lexical route makes use of rules that specify relationships between letters and sound known as grapheme to phoneme correspondence (GPC) rules[2]. Note that words that are irregular are so because they violate the grapheme to phoneme conversion rules and words that are inconsistent have more than way to be pronounced. Finally, words that are consistent or have a regular pronunciation pattern are accessed by both routes.

While Coltheart's model accounted for much of the data (circa late 1970's and early 1980's), the role of phonology was limited. A series of experiments run by Humphreys and colleagues (cf. Humphreys, Evett, and Taylor, 1982) suggested a broader for role for phonology. Their findings indicated that phonology was automatically accessed in word recognition. Subjects were presented with 4 prime-target conditions: identity (e.g., made-MADE), homophonic (e.g., maid-MADE), graphemic control (e.g., mark-MADE) and an unrelated condition (e.g., ship-MADE). The findings showed significant homophonic priming relative to the graphemic control. Further, no significant difference was

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[2]Paap, Noel and Johansen (1992) state that there are all or none rules for mapping graphemes to phonemes. They point out that these rules are of all the same strength and are never in conflict with one another. For example, the grapheme /I/ always corresponds to the phoneme /I/. Thus, words that conform to these rules constitute all of the regular words and words that fail these assumptions must then be named correctly by accessing their addressed phonology.

discovered between the unrelated and graphemic control conditions. A second experiment made use of the regularity assumptions of the model; that irregular words are activated by the direct access route whereas regular words can be accessed by either lexical or non-lexical routes. It was found that the effect of homophonic priming was equal for both irregular and regular word conditions. Humphreys et al. interpreted the evidence as indicating that targets gained automatic access to phonology by way of the lexical route. This conclusion was further supported when a third experiment involving a pseudohomophone (smorl-SMALL) condition provided no significant increase in identification accuracy over the graphemic control condition while a significant difference was still found between the identity and grapheme conditions. Had the pseudohomophone condition been significant it would have suggested an early role for phonology. To Humphreys et al. these data suggested that phonological or non-lexical involvement was constrained relative to the role of the lexical access route; phonology's place was at the end of the line.

Evidence that phonology was a mandatory source of information for reading was reported by Van Orden (1987) in the context of the verification hypothesis. Within the verification model, lexical entries are activated by phonological representations and are then subjected to a verification test (spelling check). Van Orden (1987; see also Lukatela and Turvey, 1994a) hypothesized that spelling information is generated by this phonological code and acts as a basis of a "clean up" process. That is, phonological representations associated with a lexical entry are verified against a spelling (orthographic) representation. More precisely, lexical representations of the most active lexical entry are retrieved from memory and are compared with the representation of the stimulus word. When the matching process is complete, all representations that are not consistent with the stimulus's orthography are suppressed; otherwise, the process repeats itself using the next most active entry.

Phonology was shown to have an early role in word recognition using a semantic categorization paradigm. Van Orden's experiments questioned whether subjects would misclassify homophones more often than their orthographically similar control words. Van Orden observed a large homophony effect; finding a higher false-positive rate to the homophones (i.e., "a flower: <u>rows</u>?") than to their controls. In

Experiment 3, it was hypothesized that the percentage of false-positive responses to stimulus foils (e.g., ROWS) should be lowest when the corresponding sound-alike foils (e.g., ROSE) are of high frequency. The rational is simple, readers have a more complete knowledge of the spelling of high frequency words. Van Orden found that false positive error rates to foils decreased as the frequency of sound-alike exemplars increased. This is specific evidence for the role of prelexical phonology in word identification. If the false-positive results had been low for high frequency stimuli it would have suggested that a direct lexical role is used. However, because the false-positive results were high for stimuli (ROWS) whose homophonic neighbors (/roz/) were high frequency, the results indicated that prelexical phonological information (/roz/) was used to make a comparison against the orthographic representation prior to word identification. In sum, Van Orden's results supported the notions that phonology is early, mandatory and plays a constraining role in lexical access.

Van Orden's findings were further supported by a series of experiments run by Lukatela and colleagues. Lukatela and Turvey (1994a) also proposed that the phonological code is rapidly accessed; arguing for a strong role of phonology. Concerned about the results of Humphreys, Evett and Taylor (1982), Lukatela and Turvey (1994a and b) ran a series of experiments. Using a simple lexical decision task involving an associative homophonic priming procedure (e.g., TOAD-frog), Lukatela et. al. presented subjects with six condition in the format PRIME-target; three associated primes and three control primes using a 50-msec stimulus onset asynchrony (SOA). Lukatela et al. found priming of the word frog by a homophone of TOAD, specifically TOWED, was identical to the facilitation by TOAD itself. Experiment 8, found similar success for the pseudohomophone TODE as the orthographic control TORD failed to prime frog. As identified above, the word TOAD is of high frequency and irregular. BY Coltheart's model it would be assumed that TOAD is accessed in the lexicon by the direct lexical route while the word TOWED or non-word TODE would follow the non-lexical route. The fact TOAD and TOWED primed equally well and the orthographic control failed to prime at such a brief SOA of 50 msec suggested that phonological mediation must be automatic. These finding implied that (a) lexical access was phonologically mediated and (b) there was no visual access independent of phonological access.

The conclusions of Lukatela and Turvey in support of Van Orden were that phonology is an early and primary code for lexical access. This established role of phonology motivated a series of studies investigating the manner in which phonology is represented; first how it is represented and later the nature of the phonemic representation. The fact that phonology was earning a stronger role in reading along with a series of papers investigating the structure of representation forced reconsideration about the role of phonology in the dual route model. Previously, dual route models have contained a strictly feed forward structure and predicted behavior using discrete and explicit rules. Whereas, these route models had accounted for regularity effects, they failed to address consistency as described by Van Orden (1987). Alternatively, Van Orden, Pennington, and Stone (1990) proposed the use of covariant learning to account for both consistency and regularity behavior in reading. At issue is that spelling patterns can have more than one phonological representation and phonological representations can have more than one spelling pattern. With covariant learning procedures, it was possible to capture the cumulative statistical regularities of the consistency between input and output (i.e., many spelling to one phonological representation and many phonological to one spelling representation) (Stone and Van Orden, 1994).

Accordingly, Stone, Van Orden and others postulated a new set of hypotheses to study the strong model of phonology. It is evident from their work that a more current view of phonology is necessary such as nonlinear phonology. Van Orden and Goldlinger (1994) proposed a model of *resonance* that is concerned with whole-word nonlinear phonology; whole-word model because printed words are more readily perceived as words than a collection of letters. To understand this, imagine two separate layers of a simple neural network. A *node* is a functional set of connections that act as a single unit within a particular layer. The top layer will be labeled the phonological node and the bottom layer, the visual node. As a word is presented to the visual node it feeds-forward a pattern (bottom-up activation) through the connections to the phonological node; thereby activating multiple phonological representations. The phonological node then feeds-back the pattern to the visual node (top-down activation). When the phonological pattern matches the visual pattern, top-down activation conserves the bottom-up activation and the activation of the network settle into a *resonance*. Nonlinear phonology is played out as the assembly of phonology does not need to be generated all at once by one system. Rather within a single system multiple sub-systems can be connected to capture orthographic to phonological effects at both segmental and sub-segmental representation. Each pushing information in a feed-forward/feed-back manner through the system until a resonance is reached. Once the resonance of the entire word recognition system attains its global attractor, lexical access is completed (Lukatela & Turvey, 2000).

As has been recently shown by Lukatela, Eaton, Lee, and Turvey (2001) the assembled phonological structure for a letter string includes a phonetic feature based description. Lukatela et al. (2001) found that nonword primes (e.g., zea) that differed from their targets (e.g., sea) by a single gesture (initial voicing of the onset) led to faster reaction times than a nonword prime that differed by more than a single gesture. Such phonetic units do not exist in a 1:1 correspondence with discrete orthographic segments and require a nonlinear-based phonology incorporated in the model above. Providing that phonological information is readily available to the reader, perhaps mandatory, and may mediate visual word recognition, the evidence above suggests a system whose input representation is strongly linked to spoken language. If the reading system is tightly coupled to the speech production system, it may be the case that both share a phonological representation. Such a hypothesis has been shown to be true as Lukatela, Eaton, and Turvey (under review) have shown that the underlying phonology represents the physical dynamics of the stored word. In three experiments, it was shown that the lexical decision task to visual presented stimuli is sensitive to vowel length effects (determined by voiced or devoiced final consonants; pleat vs. plead) and this effect was confirmed when a fourth experiment involved naming. In all 4 experiments, long vowels were effectively slower in reaction time latency than the short voweled items. Thus, the mapping may entail a letter to phonemic segment or at a more fine grain level, letter to phonemic feature representation. The current theory of phonology suggests that the reading system at the very least makes use of prelexical phonology where mapping of orthography to phonology is a primary function of the system.

One of the important features of this gestural, or at the very least non-linear, framework is that it allows for different timing relationships in the phonology of word assembly during the recognition processes. As Lukatela and colleagues have shown, our understanding of phonology in reading now requires a theory that incorporates gestural information. It may be the case that phonological units are best defined by articulatory actions or movements, which occur over time. Previous theories of phonological representation, like those requiring GPC rules, are linear in nature and do not incorporate information that can be predicted by context. Therefore, current research needs to continue to explore the nature of the underlying phonological representation.

Summary and Future Prospects

Above, I have shown how the role of phonology in visual word recognition has changed over the last thirty years. Phonology's role was initially considered important as young readers learned to map spelling patterns onto phonological representations. However, for the skilled reader phonology was seen as necessary only when reading demands required it. Yet, persistent interest and experimental evidence has led us back to Gough initial hypothesis that orthography is mapped onto the underlying phonology representation shared by speech.

The future of phonology debate will involve exploration of the underlying phonological representation. One question concerns the specificity of the underlying representations (i.e., Are they truly gestural in nature or phonemic-phonetic representations?). A second question surrounds the extent to which lexical and articulatory processes share the same representation or lexicon. Above, I have pointed out evidence of shared phonological information between lexical and naming procedures. To what extent is this information shared? That is, are these lexicons the same? Perhaps one manner of answering this question involves "teaching" the speech lexicon novel information and studying the impact on visual word recognition. I have provided evidence that a word's phonological representation is of a much finer grain size then previously thought and future research will continue to argue phonology's role as early and mandatory in a theory of word recognition.