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Normal and Abnormal Reading: Phonology and Dyslexia

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Abstract

Background: In this article we review some experimental, modeling, and neuropsychological findings on normal and abnormal reading. We mainly focus on single word reading as a mature area in scientific studies of reading.

Purpose: The aim of the current review study was to show the importance of theories and models that have taken into account the cognitive, specifically phonological, processes in reading. Looking at factors playing roles in reading can be helpful in tackling literacy problems.

Method: Interdisciplinary studies on reading have focused on the role of phonology as revealed by psychological experiments, lesion studies, connectionist modeling. Some words can be recognized and produced easier than others, as shown by the differences between acquired and developmental dyslexia and between surface and deep (phonological) dyslexia.

Findings: The dual-route model of reading assumes two routes for single word reading: a lexical route for reading exception words, such as *have* or *pint* in which no direct correspondences exist between print and sound, and a sub-lexical route for reading regular words such as *save* and *mint* and non-words such as *nust*. Consequently, impairment to each one of these routes leads to a specific kind of dyslexia, discussed latter. The connectionist model of word consists just one process but can successfully read regular and irregular words as well as non-words.

Results: Phonological dyslexia is caused by an impairment, either acquired or developmental, leading to difficulties in reading non-words. Another form of dyslexia is known as surface dyslexia which is caused by impairment, again acquired or developmental, leading to difficulties in reading exception words.

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Implications: These studies even go beyond the phonological awareness. The effect of training has also been shown by connectionist modeling, where the effect of intervention in phonological representation declines sharply once training to read has begun.

Originality/Value: Taken together, recent studies have shown the importance of phonology in reading, despite ongoing debates about the true nature of the phonological deficit in poor reading.

Keywords: Reading, Phonology, Dyslexia, Connectionism.

Introduction

Despite progress in educational and informational domains, many developed countries are not satisfied with their students' reading competency level. For example, the students in United States have scored lower than those in other countries, such as Canada, Australia, and Finland, known to be a crisis in American education (e.g., Finn, 2009). Knowing that more than 90 million adults read at "basic" or "below basic" levels (The National Assessment of Adult Literacy, 2003, in Seidenberg, 2013), studying factors playing roles in normal and abnormal reading can be helpful for tackling the problem (e.g., Seidenberg, 2013).

In this paper we mainly focus on single word reading because it is a mature area of in reading studies. In this regards, many studies on both spoken and written linguistic processes have shown that some words can be recognized and produced easier than others. For example, words with regular spelling-sound correspondence, such as *mint*, are processed easier than irregulars, such as *pint* (e.g., Marshall and Newcombe 1973; Seidenberg and Tanenhaus, 1979; Waters and Seidenberg 1985).

As will be discussed below, studies on abnormal reading (e.g., Castles and Coltheart 1993) have shown that a group of patients, with so called surface dyslexia, have problem in reading irregular words, while another group, with so called phonological dyslexia, have problem in reading non-words and even regular words. This double dissociation has also been shown in inflectional morphology of regular and irregular past tense form (described below). In this article some findings are reviewed where psycholinguistic, connectionist, and neuropsychological methods have been used in the area of reading and inflectional morphology. The aim is to show the importance of theories and models that have taken into account the linguistic, specifically phonological, processes in the study of normal and impaired word perception and production.

Dual-route and connectionist models

There are two predominant theories for reading single (isolated) words. The first one is dual-route theory, which assume that two routes exist for single word

reading: a lexical route for reading exception words, such as *have* or *pint* in which no direct correspondences exist between print and sound, and a sub-lexical (or rule-based) route for reading regular words such as *save* and *mint* and non-words such as *nust*. Consequently, impairment to each one of these routes leads to a specific kind of dyslexia, discussed latter. On the other hand, connectionist models of word recognition (e.g. Seidenberg and McClelland 1989; Plaut et al 1996) use one process to read regular and irregular words as well as non-words. These models include a semantic layer as a secondary component involved indirectly in producing phonology (they used the term phonology in the specific sense referring to phoneme representation, not in the broader, linguistic, sense). The optional way of producing, or in other word activating, phonology is directly from orthography (Figure 1).

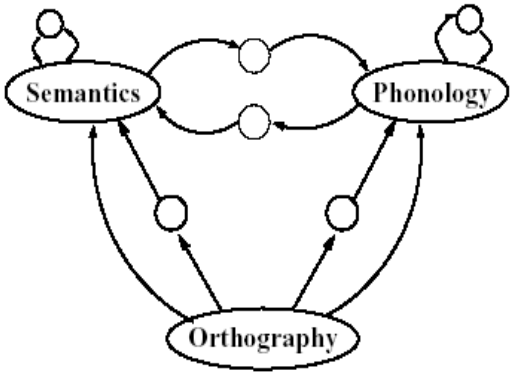

Figure1 .Connectionist model of Seidenberg and McClelland (1989) re-implemented in Harm and Seidenberg (2001).

As can be seen in the Figure 1, these models are dual-route too in a sense, but they use a single process instead of two. There is no locality in representation of lexicon, i.e. both words and non-words are represented and read in the same way. These kinds of models consist of layers containing some neuron-like nodes for representation of units such as graphemes, phonemes, and semantic features. Therefore, information is distributed among the connection weights. Because of this distributed representation, words and non-words are handled in the same way and knowledge about each word partially depends on that of other words. The most obvious effect is the number of rimes each word has, known as rime neighbourhood size (RNS). The consistency of grapheme-phoneme correspondence is a factor in representation of the words. The input layer, orthography or graphemes, is associated to output layer, phonology or phonemes, using learning algorithms such as error back propagation. Also, a complementary pathway from orthography to semantics, i.e. meaning and context, and from semantics to phonology included in some of this models. Both pathways employ a similar process to learn the mappings and operate in parallel. The pathways contribute

differentially depend on the groups of words being exposed to the model. So there is a division of labour between these two pathways which is learned through a developmental process making these models to act like a dual-route model. However, in such models, there is a continuum rather than a distinct division between these pathways.

The reason that Seidenberg and McClelland's (1989) model showed a poor performance on non-word reading (like a phonological dyslexic), as shown by Besner et al (1990), was that their model had a weak phonological representation which was overcome by an external constraint on phonological order (Plaut et al 1996). Later, Harm and Seidenberg (1999), based on previous connectionist models (e.g. Seidenberg and McClelland 1989) and linguistics findings, developed a model of the reading development and impairment by employing a better phonological representation. They included a phonological system in their model to learn the sound structure before learning to read. They showed how learning the orthography-phonology mapping affects phonological representations (described further in a latter section), and thereby how the representations of phonological segmentation result interacts with learning reading. The phonology module uses a recurrent network to associate phonemes together to make basins of attraction which make a flexible representation and a fill-in mechanism to restore missing phonemes in a part of speech. Phonological dyslexia (see below) was modeled by lesioning the phonological module (Figure 2).

Likewise, in the area of inflectional morphology of verbs, Ullman and colleagues (1997) reported a patient study where patients with fluent aphasia and Alzheimer's disease could produce past tense forms of regular verbs (e.g., talked) better than those of irregular verbs (e.g., went). On the other hand, patients with non-fluent aphasia could produce past tense forms of irregulars better than regulars. Some theories (e.g. Pinker 1991, 1999) propose a rule-based process for regular past tense verbs and an associative process for irregular ones. Accordingly, connectionist theories (e.g. Rumelhart and McClellend 1986) propose a single system composed of phonological and semantic knowledge for reading these two types of verbs. For explaining selective impairment of a specific type of verbs, the former theories argue that one of the two processes has been impaired selectively. Likewise, the later theories argue that a phonological impairment is the basis of poorer performance in regular verbs, since, as they argue, regulars have greater phonological complexity than irregulars (described in a following section).

Evidence from Dyslexia

Dyslexia, which is either caused by brain damage or by abnormal development of reading such as less exposure to specific phonological or orthographic patterns, is defined as the failure to show age-appropriate reading skills among children (5-7 percent) despite their normal intelligence, education, and social background (e.g., Stanovich 1986; Ramus 2003). Developmental dyslexia is not specific to English-

speaking children, as shown by Ziegler and colleagues (2003), based on a study on German-speaking children. In languages with consistent orthography such as Finnish, developmental dyslexics can be diagnosed by speed of reading instead of accuracy (for a recent review of this issue and other factors, see Goswami, 2003).

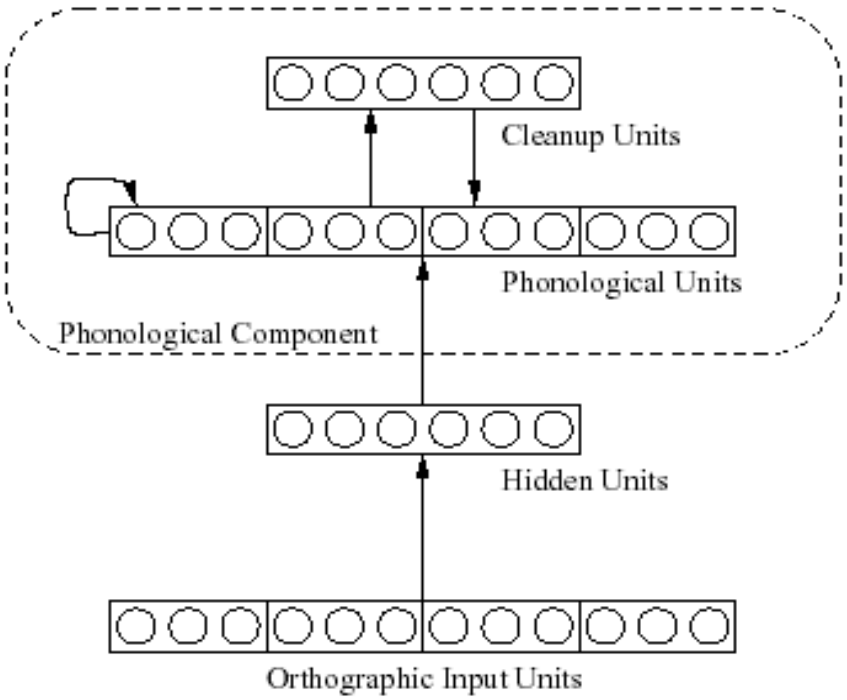

Figure2. Connectionist model of Harm and Seidenberg (1999).

Phonological dyslexia is caused by an impairment, either acquired or developmental, leading to difficulties in reading non-words (e.g., Castles and Coltheart, 1993; Manis et al 1996). Another form of dyslexia is known as surface dyslexia which is caused by impairment, again acquired or developmental, leading to difficulties in reading exception words (irregular words, such as *pint*, which have irregular spelling to sound correspondence). These dissociations have been taken as evidence for dual-route theories (e.g., Castles and Coltheart 1993). As discussed above, dual-route theories assume that two independent pathways are used to produce sound from print. One uses lexical knowledge and the other uses grapheme-phoneme conversion (GPC) rules (Figure 3). In this approach, surface dyslexia is thought to emerge as impairment in the lexical route and phonological dyslexia is caused by impairment in the sublexical or rule-based route which uses GPC rules (Coltheart et el 1993). Whereas phonological dyslexia which is caused by phonological deficits is the most common type of dyslexia, surface dyslexia is

caused by an impairment in orthography to phonology mapping and involves a general developmental delay (e.g., Manis et al 1996; Sperling et and al 2003).

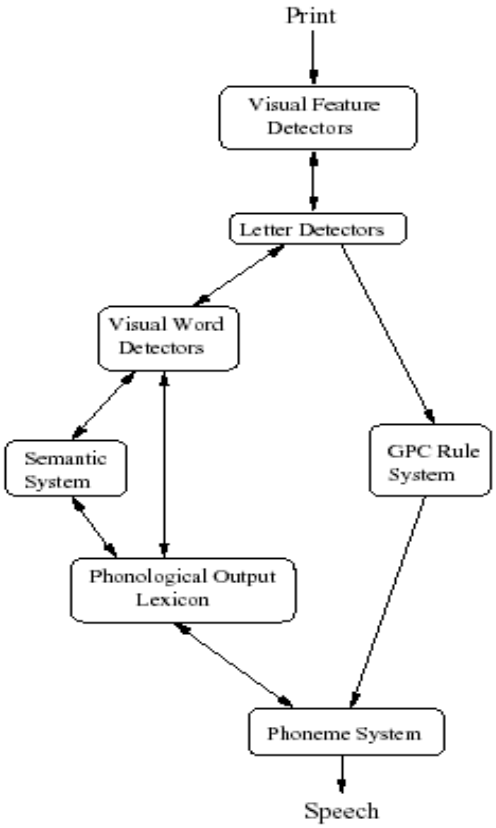

Figure3. Dual-route model (Coltheart et. al. 1993).

Neural Basis of Dyslexia

Reading is a recent but far-reaching add-on to the "mental toolkit of humanity" (Hannagan, Thomas et al., 2015). Though, it is not clear how quickly natural selection shaped a dedicated, special brain resourcesfor reading (Dehaene, 2009). A dysfunctional connection between left fronto-temporal language regions might involve dyslexia, explaining the degraded phonological representations in dyslexic children, but an intact, less-accessible phonological representations in dyslexic adults (Boets, 2014).

According to Ramus (2003), research using neuropsychological methods has led to a couple of groups of theories about abnormal word reading. First group indicates that there is a specific deficit which involves a cognitive deficit specific to phonological representation of speech sound. From a neuropsychological point of

view, it is caused by dysfunction or developmental deficits in the cerebral areas involved in phonology and reading. Second group suggests that there is a general sensorimotor deficit: According to this view dyslexia is caused by impairment to the sensorimotor pathways in the auditory cortex which is made of special type of neurons called magnocellular. Anatomical and physiological studies suggest that some dyslexics have abnormal cortical magnocellular development (e.g., Jenner et al 1992). But some studies could not replicate these findings (e.g. Hayduk et al 1996). Studies have shown that only a sub-group of dyslexic individuals have some kind of magnocellular impairment (e.g. Borsting et al 1996; Talcott et al. 2000). It seems that magnocellular deficit links to orthographic, and not phonological, processing (Talcott et at 2000; Sperling et al 2003; but see Omtzigt et al 2002). Magnocelluar neural processing relates to the ability to read exception words such as *have* or *pint* which, unlike regular word, require orthographic processing and ignoring phonology. Researchers have shown that orthographic processing in dyslexia relates to the coherent motion perception which magnocellular processing is a part of it (Witton et al 1998). Recently, researchers refer to an inability in temporal processing that requires information which changes rapidly with time (e.g., Rey et al 2002; Hautus et al 2003). In recent studies, the magnocellular theory has extended the argument of sensorimotor neural deficits to vision and attention, and generally to motion perception including cerebrum area (Ramus 2003). The problem with this approach is that there are some dyslexics without auditory and visual impairment and some auditory and visual impairment without dyslexia, so magnocellular theory can not account for all forms of dyslexia (Sperling et al 2003). This is also true in the case of mangnocellular and motor control. Therefore, there isn't a total overlap between domains.

More Phonological Findings

A qualitative research on reader's accounts suggested that vivid reading experiences involves an auditory phenomenology, and even non-reading contexts (Alderson-Day et al., 2017). Despite ongoing debates about the true nature of the phonological deficit in dyslexia, phonological processes are still known as the main causes (Kraus, 2012). The inner speech involvement is inferred from the fact that when read, phonologically longer stimuli are read slower than shorter stimuli of the same orthographic length (Abramson and Goldinger, 1997).

Many studies support an impairment in phonological processes including spelling-sound correspondence is the predominant cause of abnormal reading (e.g. Wagner and Torgesen 1987; Siegel and Ryan 1988; Share 1995). These findings have led to the phonological deficit theories which assume that the primary cause of reading impairments is phonological processing. It is obvious that normal children, and even adults, have problem in discriminating some precise phonological pattern differences. Bird and colleagues (2003) have argued that these problems are more severe in dyslexia and other language deficits and in fact are the exaggerated form

of phonological discrimination problems in normal. For example, they showed that aphasic patients had a greater problem in discriminating pairs of words with unvoiced than voiced final alveolars. The errors of normal group, on other hand, were failures to detected differences in pairs of words containing the extra phoneme with consistent voicing (Figure 4).

Bird and colleagues (2003), by reanalyzing Ullman et al's (1997) data of regular and irregular past-tense form, showed that, in general, the regular past tense in English is phonologically more complex than irregular. For example, regardless of the nature of transformation, *blinked* (the past tense of regular verb *blink*) is more complex to pronounce than *thought* (the past tense of irregular verb *think*). Here the /bliŋkt/ is CCVCCC that is easier to recognize or produce than *thought* which consists of CVC. At least here irregular words have smaller number of phonemes.

For explaining the performance of patients who had problem in regular than irregulars, they argued that it is a deficit in phonological, or at least in addition to morphological, processing. They also proposed that the consistency of voicing between a final alveolar stop and its preceding phoneme is the difficult part present in regular past tense verbs.

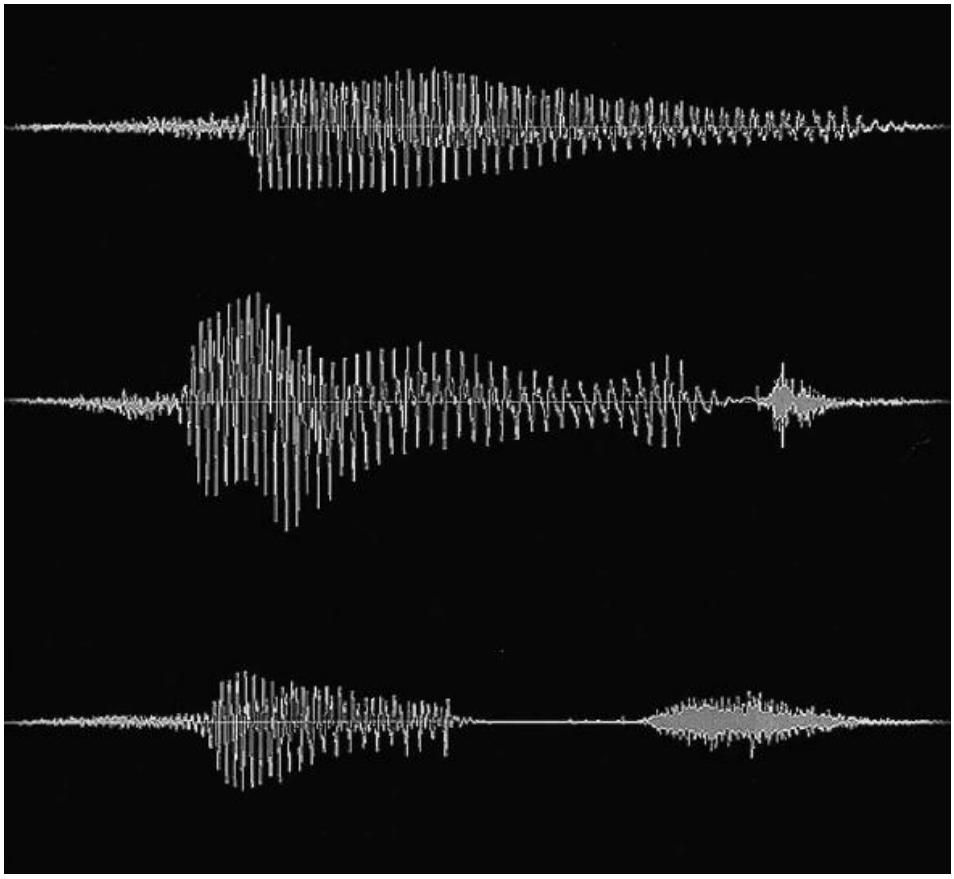

Figure4. Spectrograms of the spoken words "he", "heed", and "heat" showing the shorter vowel, as well as about 14 ms period between the offset of voicing and the final stop, in "heat" (Bird et al 2003).

The Effects of Phonological Training on Dyslexia

Many studies have shown that intervention in phonological awareness and decoding techniques can dramatically help dyslexic individuals (Tallal et al 1996; Merzenich et al 1996; McCandliss and Noble 2003). Neuropsychological research has shown that phonological training causes neural changes in the brain of dyslexics (Habib et al 1999; Habib and Demonet 2000; Simons et al 2002; Temple et al 2003). McCandliss and Noble (2003) showed a reduced recruitment of left presylvian region in phonological challenging tasks. They demonstrated that phonological training intervention can make functional reorganization in the brain area involved in phonological processing. Other studies investigated the benefits of intervention in improving the reading abilities in developmental dyslexia (Merzenich et al 1996; McCandliss and Noble 2003). The results of phonological

training reveal the nature of developmental dyslexia as being different from acquired one, in which structural changes is obvious in the damaged brain. It also shows a direct effect of intensive phonological training methods such as those used in video games containing tasks like speech and non-speech discrimination and phoneme manipulation in syllables and words (e.g., Friel-Patti et al 2001; Hook et al 2001).

The effect of training has also been shown by connectionist modeling. Harm et al (2003) showed that the effect of intervention in phonological representation declines sharply once training to read has begun. They showed that in their model, after 10000 word presentation (epochs), it is too late to overcome the effect of learning with a weak phonological representation. They also showed that interventions in print-sound correspondence improve non-word reading, either early or late in developmental course. This work gave evidence for the appropriateness of different training interventions which are hard to conduct experimentally on children, as they require school and parent permission and involve many factors to be controlled. Other studies have shown that starting to learn reading enhances the phonological skills as a result of exposure to grapheme-phoneme mapping (e.g. Wagner et al, 1994) which illustrates the interaction between phonological skills and literacy. This bidirectional effect has been shown by the impact phonological training has on reading (e.g. Bradley and Bryant 1983; Schneider et al, 2000). This further illustrated by Harm and Seidenberg's (1999) connectionist model in which changes in phonology module allowed changes in orthography-phonology mapping. However, it is not clear how phonological representation and orthography-phonology mapping relate to each other to make a componential representation.

Conclusion

Taken together, recent studies have shown the importance of phonology in many domains of language processing and reading (Kraus, 2012; Alderson-Day et al., 2017), despite ongoing debates about the true nature of the phonological deficit in poor reading. These studies even go beyond the classic notion of phonology such as formant transition and phonological awareness (Liberman et al 1974a, 1974b). Instead, these studies use the dynamic nature of componential segmentation of phonological representation, and its interaction with orthography in reading.

In traditional connectionist models (e.g. Seidenberg and McClelland, 1989; Plaut et al, 1996) the term phonology is simply used to refer to phonemes, but recently some attempts have been started (Harm and Seidenberg 1999; Harm et al 2003; Bird et al 2003) to use it in a more linguistic context to refer to a self-contained mechanism in which some constraints are derived from a dynamic phonemes representation that impose a special impact on phoneme structure such as final voicing, described in the issue on past tense form. It also has influence on, and is getting influence from, other layers such as orthography, morphology, syntax, and

semantics. These are evidence for supporting a complex model which processes regular and irregular words using a single interactive process based on semantic and phonological knowledge which can be illustrated by connectionist modeling to be understood in an imageable way.

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