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Exploring the Cognitive Underpinnings of Word Retrieval Deficits in Dyslexia Using the Tip-of-the-Tongue Paradigm

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DEDICATION

To my family, you are my inspiration.

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Over the past thirty years a consensus has emerged that the word reading difficulties of dyslexic readers stem from deficits in phonological processing. One experimental paradigm that has provided support for this view is the finding that dyslexic readers demonstrate deficits in word retrieval from long term memory on picture naming tasks. Dyslexic readers are able to retrieve fewer words in their receptive vocabularies and are less accurate than normally developing readers. However, the conclusion that dyslexic readers' difficulties in picture naming are the consequence of deficits in phonological processing is inferential. The current study uses the tip-of-the-tongue (TOT) paradigm to provide evidence that dyslexic readers demonstrate a specific deficit in the retrieval of phonological information from long term memory. Participants consisted of 16 dyslexic children and 31 control children, mean age of 115 months. Children were given a picture naming task consisting of 143 target words that varied in length and frequency of use. Results indicate that dyslexic children report more TOT experiences than control children. Moreover, when examined from the perspective of theoretical models of word retrieval, dyslexic children did not differ from control children in the percent of failures at the first step of word retrieval, the retrieval of semantic information. However, dyslexic children reported a significantly higher proportion of failures at the second step in word retrieval, the retrieval of phonological representations. This is one of the first studies to provide direct support that dyslexia is related to a specific deficit in phonological representation.

Introduction

Behavioral Features of Dyslexia

Dyslexia is a specific learning disability in the domain of reading. The first case study of dyslexia was reported in the literature over 100 years ago (Morgan, 1896). Throughout the twentieth century, learning disability theory emerged and developed from observations of children who had significant academic and behavioral difficulties and resembled, in many ways, children with brain injury. However, in contrast to children with brain injury, the learning disabled children did not have a history of serious illnesses or brain trauma (Doris, 1993; Hallahan & Mercer, 2002; Strauss & Lehtinen, 1947). In 1962, Samuel Kirk coined the term learning disability to describe children who demonstrate "a retardation, disorder, or delayed development in one of more of the processes of speech, language, reading, spelling, writing, or arithmetic resulting from a possible cerebral dysfunction and not from mental retardation, sensory deprivation, or cultural or instructional factors" (Kirk, 1962, p.263; Lyon et al., 2001).

One of the cornerstone assumptions of learning disability theory is that each learning disability is caused by dysfunction in a specific cognitive domain (Hallahan & Mercer, 2002; Lyon et al., 2001; Lyon, 1995; Stanovich, 1998). Specific cognitive dysfunction, in turn, manifests as impaired achievement in a particular domain of learning. In the case of reading disabilities, the failure to learn to read effectively is limited to this domain of achievement and is postulated to arise as a result of impairments that impact cognitive functions related to reading specifically. Thus, learning disabilities are distinct from cognitive deficits which impact global functioning. The failure to learn to read resulting from general low cognitive ability or perceptual difficulties such as hearing or vision deficits is not a learning disability. A related assumption is that the locus of the disorder is within the individual. Accordingly, although children may have difficulties learning to read for a variety of reasons, including inadequate educational experiences, lack of motivation, poverty, and emotional and behavioral problems, reading difficulties caused by these factors are not regarded to be learning disabilities. Stemming from learning disability theory are predictions that dyslexia should be both a persistent disorder and should be found in all languages and writing systems. However, the specific behavioral manifestations of dyslexia will vary depending on the characteristics and features of the language.

In English, the characteristic behavioral feature of dyslexia is difficulty reading individual words. Dyslexic readers also have difficulty comprehending written text, but this difficulty is secondary to, and a result of, their difficulty reading individual words (Gough & Tunmer., 1986; Shankweiler et al., 1999; Van Orden, Pennington, & Stone, 1990). Word reading difficulty is not simply the result of a developmental delay in the acquisition of reading skills, but instead represents a specific impairment. The specificity of this deficit has been demonstrated in reading-level matched experimental designs: when dyslexic individuals are matched with younger normal readers on the basis of their reading comprehension levels the dyslexic readers demonstrate weaker word reading skill than the younger normal readers (Perfetti, 1985; Perfetti & Hogaboam, 1975; Rack, Snowling, & Olson, 1992; Siegel & Ryan, 1984; Snowling, 2000; Stanovich, 1982, 1991; van IJzendoorn & Bus, 1994; Vellutino & Scanlon, 1987; Vellutino, Scanlon, Small, &

Tanzman, 1991). The implications of these findings emphasize that although the dyslexic and younger reading-level matched children read with the same level of comprehension, the developmental path that each group has traveled to reach that point is distinct.

Word reading difficulty in dyslexia is most pronounced when decoding pseudowords. Pseudowords are words that obey the orthographic conventions of the written language and are pronounceable but are not real words. Since pseudowords are novel and have not been encountered before, they must be decoded by mapping individual letters or groups of letters onto their corresponding sounds (phonemes). Thus, pseudoword reading is a measure of decoding skill. Because the words are meaningless, pseudoword reading cannot be facilitated by semantic processes in which the orthographic and phonological representation of the word is matched with retrieved semantic information. When dyslexic readers are matched with younger normally developing readers based on their reading comprehension or word reading ability, the dyslexic readers demonstrate a specific deficit in pseudoword reading (Bruck, 1988; Gottardo, Chiappe, Siegel, & Stanovich, 1999; Lyon, Shaywitz, & Shaywitz, 2003; Olson, Forsberg, Wise, & Rack, 1994; Snowling, 1980, 2000; Stanovich, 1988; van IJzendoorn & Bus, 1994; Vellutino, 1979).

Evidence for Persistence and Universality of Dyslexia

Further evidence that word reading difficulty in dyslexia represents a specific deficit, rather than just a developmental delay in mastering reading skills, comes from studies of adults with childhood histories of dyslexia. Dyslexic adults exhibit a wide range of reading skills as adults; however, regardless of their reading comprehension levels, adult dyslexic readers demonstrate persistent word and pseudoword reading difficulties especially when response time is constrained (Birch & Chase, 2004; Bruck, 1990; Felton, Naylor, & Wood, 1990; Hanley, 1997; Hatcher, Snowling, & Griffiths, 2002; Lefly & Pennington, 1991; Miller-Shaul, 2005; Pennginton, Van Orden, Smith, Green, & Haith, 1990; Ramus et al., 2003; Shaywitz et al., 2003).

Dyslexia has been studied most extensively in English, but the assumptions of learning disability theory, that learning disabilities are learning disorders specific to a domain of achievement with a locus within the individual, predict that dyslexia should also be universal. Strong language-specific differences have been found in the speed with which normal children learn to read in different languages or, more specifically, different orthographies. Shallow or transparent orthographies such as Arabic, Dutch, Finnish, German, Greek, pointed (vowelized) Hebrew, Italian, Serbo-Croatian, Spanish, and Turkish have consistent mappings between the written symbols of the language (graphemes) and their corresponding sounds (phonemes). Children learning to read in these languages learn to read familiar words and pseudowords with over 90% accuracy after only one year of schooling (Seymour, Aro, & Erskine, 2003). In contrast, word reading accuracy develops more slowly in deep or opaque orthographies such as French, Portuguese, Danish, and English. English is the deepest orthography of all with the most inconsistent mapping between graphemes and phonemes. And in contrast to children learning to read in shallow orthographies, by the end of first grade children learning to read in English can only read approximately 30% of familiar words and pseudowords (Seymour et al., 2003).

Despite these significant variations in the ease with which children learn to read in different orthographies, dyslexic children have been found in all languages studied (Goulandris, 2003; Ziegler & Goswami, 2005). Children demonstrating pseudoword decoding difficulties, when compared to either chronological-age (CA) or reading-level matched normal readers, have been found in both transparent orthographies such as Arabic (Abu-Rabia, Share, & Mansour, 2003), Dutch (de Jong, 2003; van der Leij, van Daal, & de Jong, 2002), German (Wimmer, 1996), Greek (Pórpodas, 1999), pointed Hebrew (Breznitz, 2004; Share, 2003), Hindi (Gupta, 2004), Korean (Kim & Davis, 2004), Polish (Szczerbiński, 2003), Serbo-Croatian (Lukatela, Carello, Shankweiler, & Liberman, 1995), and Swedish (Olofsson, 2003) as well as opaque orthographies such as Danish (Elbro, 1996, 1998; Elbro, Nielsen, & Petersen, 1994), French (Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000), and unpointed Hebrew (Breznitz, 1997; Share, 2003).

The persistence of deficits in word reading accuracy, however, is not a universal feature of dyslexia. In transparent orthographies, many older dyslexic children and adults demonstrate accurate word and pseudoword reading abilities. The primary features of dyslexia in transparent orthographies are poor reading fluency, poor spelling, and slow and effortful phonological decoding characterized by sequential grapheme-phoneme translation (Goswami, 2000; Goulandris, 2003; Leinonen et al., 2001; Spinelli et al., 2005; Wolff & Lundberg, 2003; Ziegler & Goswami, 2005; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Thus, in transparent orthographies dyslexic readers often demonstrate normal word reading accuracy, in contrast to dyslexic readers in English for whom word reading accuracy is often a primary behavioral marker.

The behavioral manifestations of dyslexia are strongly influenced by the orthography of the language (Frith, 2001; Goulandris, 2003; Ziegler & Goswami, 2005). In transparent orthographies, the amount of variability in word reading accuracy between dyslexic and normal readers is reduced because of the consistency of these languages. In contrast, all readers in English have many opportunities to make errors when reading because of the inconsistency in the mappings between sounds and symbols. Thus, the potential variability in word reading accuracy is high. However, there are strong commonalities across different languages when word reading latency is compared. Dyslexic readers universally demonstrate significant deficits in word and pseudo-word reading latency compared to reading-level matched control readers. Moreover, the effect sizes of the word reading latency deficits are comparable in different orthographies. When dyslexic readers' word reading latency is compared, it is consistently impaired compared to reading-level matched controls in both transparent and deep orthographies (Paulesu et al., 2001; Ziegler et al., 2003). Thus, the universal feature of word and pseudoword reading difficulties across languages is related to word reading latency. Deficits in word reading accuracy are not a universal feature of dyslexia and are influenced by the transparency of the orthography.

In addition, although word and pseudoword reading difficulties are hallmark symptoms and persistent and universal features of dyslexia (Perfetti, 1985; Perfetti & Hogaboam, 1975; Rack et al., 1992; Siegel & Ryan, 1984; Snowling, 2000; Stanovich, 1982, 1991; van IJzendoorn & Bus, 1994; Vellutino & Scanlon, 1987; Vellutino et al., 1991; Ziegler & Goswami, 2005), in practice, reading disabilities are not identified based on these criteria exclusively. In English, reading disabilities may be identified by underachievement in one or more sub-domains of reading achievement including reading comprehension, reading fluency, word reading accuracy, and pseudoword reading. Another factor that contributes to the heterogeneity of samples is the wide range of assessment measures that are used to assess reading achievement. Without careful attention to the specific reading sub-domains that are impaired, groups may be selected that contain individuals with a range of strengths and weakness in specific reading domains. The lack of specificity in the selection criteria may prevent the identification of different subgroups of disabled readers with distinct types of reading problems. A nuanced understanding of the complexity of reading difficulties may be obscured by use of selection criteria based on deficits in multiple sub-domains of reading.

In addition, underachievement is also not defined consistently. Current diagnostic criteria for reading disorders define reading underachievement in relation to IQ (DSM-IV). This discrepancy model of dyslexia identification is based on the conceptualization of dyslexia as “unexpected” poor reading achievement in children of average intelligence (Snowling, 2000; Vellutino, Fletcher, Snowling, & Scanlon, 2004). However, no consistent criteria have been established regarding the degree of discrepancy necessary to identify dyslexic readers and cutoff scores vary considerably.

Moreover, recently there has been a movement towards adopting low reading achievement independent of IQ as a selection criterion for identifying dyslexic readers.

This perspective argues that dyslexia simply represents the lower end of the normal distribution of reading achievement (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; Shaywitz, Escobar, Shaywitz, Flectcher, & Makuch, 1992). Because dyslexic readers demonstrate difficulties in word reading and often have reading comprehension deficits as a consequence of their word reading difficulties, it is likely that many dyslexic readers' reading achievement would fall within the tail of the normal distribution of reading achievement scores. However, there is little consensus in the literature regarding what constitutes low achievement and a wide range of cut-off scores have been used to define low achievement (Lyon et al., 2001).

Finally, reading failure is not always due to reading disabilities. Dyslexia is distinct from reading difficulties related to other factors such as lack of educational experiences, poor instruction, lack of motivation, emotional or attentional disorders, or more general cognitive limitations and developmental delays. Although often treated as such, dyslexia is not synonymous with poor reading. Poor readers are neither simple nor singular: reading failure may be due to multiple factors and any given reader may have difficulties for one or many different reasons. A detailed understanding of the cognitive underpinnings of dyslexia promises to yield more specific models of dyslexia, which in turn will enable researchers to tease apart and clearly define different subtypes of reading disability and reading failure. This in turn will permit not only more accurate diagnosis but also the development of more effective and targeted interventions.

Picture Naming: Text-free Word Retrieval from LTM

One experimental paradigm that explores text-independent deficits associated with dyslexia is picture or confrontational naming. This approach has been used to study the difficulties dyslexic readers experience retrieving words from long-term memory (Katz, 1986; Snowling, van Wagendonk, & Stafford, 1988; Wagner & Torgesen, 1987). In these tasks the individual is “confronted” with a picture and has to retrieve the name of the object depicted. A number of early studies showed that dyslexic readers have more difficulty recalling the names of pictures compared to chronological-age matched normal readers (Denkla & Rudel, 1976; Katz, 1986; Wolf & Goodglass, 1986). These early studies did not compare the dyslexic readers’ picture naming skill with respect to a reading-level matched control group, leaving open the rival interpretation that deficits in naming were simply a consequence of dyslexic readers’ lack of reading exposure and experience.

The earliest studies comparing picture naming skill of dyslexic readers with a reading-level matched control group did not find differences in word retrieval ability (Snowling et al., 1988). In contrast, subsequent studies have found that dyslexic readers demonstrate deficits in picture naming tasks in reading-level matched designs (Nation, Marshall, & Snowling, 2001; Swan & Goswami, 1997; Wolf, 1991; Wolf & Obregón, 1992). These conflicting results can be understood when the task demands in the different studies are compared. Dyslexic readers have less difficulty retrieving short, high frequency words from memory as was assessed in the early study by Snowling et al. (1988). Later studies demonstrated that dyslexic readers are less accurate in word retrieval tasks with longer words, or with short, low frequency, less familiar words (Swan & Goswami, 1997).

Even when dyslexic readers have been found to have well developed vocabularies based on their ability to accurately define words or on recognition tasks where they must choose the correct name for a pictured object, they continue to demonstrate difficulties in word retrieval. It is notable that in Swan and Goswami's (1997) study the dyslexic readers' performance was superior to all of the comparison groups including reading-level and CA matched controls on a word recognition task, indicating that this group of dyslexic children had well developed vocabularies. Despite their good vocabularies, the dyslexic children's free recall of words, especially long, low frequency words, was impaired compared to both reading-age and chronological-age matched groups on the picture naming task.

Similar deficits on picture naming tasks have also been found in adults with childhood histories of dyslexia indicating that the word retrieval deficits of dyslexic readers represent a persistent problem. Adult dyslexic readers are less accurate and consistent than CA or reading-level matched controls on picture naming tasks (Dietrich & Brady, 2001). Although the picture naming paradigm has not been explored in many languages, a number of studies have confirmed the results in English suggesting that this deficit is also a universal feature of dyslexia. In Danish, which is closer to English in terms of the opacity of its orthography, naming deficits have been found in both children and adults (Elbro, 1998; Elbro & Jensen, 2005; Elbro et al., 1994). Retrieval of words from long term memory has also been studied in several transparent languages and similar deficits have been found in vowelized Hebrew (Faust, Dimitrovsky, & Shacht, 2003), German (Goswami, Schneider, & Scheurich, 1999), and Swedish (Wolff & Lundberg, 2003). Thus, dyslexic readers demonstrate text-independent deficits in word retrieval that are both persistent through development and common to different languages.

Cognitive Processes in Picture Naming

To bring the specific cognitive deficits that underpin the difficulties of dyslexic readers on picture naming tasks into sharper focus it is helpful to turn to a different field of research: theories of word retrieval from the field of linguistics provide a lens through which dyslexic readers' difficulties can be better understood. Linguistic theories of word retrieval model empirical findings from three distinct research traditions (Caramazza & Miozzo, 1997; Dell, 1986; Levelt, 1999, 2001; Levelt, Roelofs, & Meyer, 1999). One tradition has focused on building models that account for spontaneously and experimentally induced speech errors. The second tradition has sought to understand the cognitive processes and sequential steps in word retrieval by an examination of word retrieval latencies under different conditions and types of interference. The third tradition has focused on elucidating steps in word retrieval through an analysis of the study of brain injury and the different processes that are disrupted after brain trauma. Several models integrate the findings from these different research traditions and also incorporate computational simulations of word retrieval (Levelt et al., 1999; Roelofs, 1997). The specifics and details of models of word retrieval, including the precise number of steps and types of lexical representations retrieved, continue to be debated; however, most share a common basic architecture in which lexical retrieval occurs in two broad steps (Caramazza & Miozzo, 1997; Dell, 1986; Johnson, Paivio, & Clark, 1996; Levelt, 1999, 2001).

One influential theory that embodies this basic architecture is Levelt's model of lexical retrieval (Levelt, 1999; Levelt et al., 1999). According to Levelt's model, in the first broad step of lexical retrieval a concept is activated. Concept activation triggers retrieval of the semantic representation for the word; this representation is referred to as a lemma. At the same time, activation spreads to other semantically related concepts, and lemmas for these concepts are also retrieved. For example, in response to a picture of a sheep, the semantic concept corresponding to sheep will be activated, as well as other semantic associates, such as 'animal' and 'goat.' The goal of the first step in word retrieval is to determine rapidly and select the appropriate lemma from the speaker's lexicon.

In the second broad step of word retrieval, the phonological information necessary to direct the assembly of the spoken form of the word is retrieved (Levelt, 1999, 2001; Levelt et al., 1999). The phonological representation of the selected word, referred to as a lexeme, specifies the phonological segments of the target word which, in turn, direct assembly of the articulatory gestures necessary for speech. The two steps accomplish distinct functions; in the first step activation spreads through related concepts and culminates in the selection of the most strongly activated concept. The second step involves the retrieval and sequential assembly of the phonological components of the selected lexical concept.

This two-step model identifies two distinct processes in word retrieval and provides a framework for garnering a deeper understanding of the specific processes that are impaired in dyslexia. Unfortunately, picture naming tasks only assess the endpoint of the word retrieval process and consequently do not permit an examination of the individual steps of word retrieval. Studies that have employed this research paradigm report the overall finding that dyslexic readers name fewer pictures than normally developing readers, but this general finding does not provide insight into where specifically in the process of word retrieval a breakdown occurs. Despite the limitations of the picture naming method, a number of studies have reported that, in addition to their overall naming difficulties, dyslexic readers also make characteristic errors on picture naming tasks. An analysis of these errors from the perspective of Levelt's two-step model of word retrieval points to a breakdown in one of the steps of word retrieval.

Firstly, dyslexic readers make semantic errors on picture naming tasks. These errors are characterized by either substitutions of semantically related words or circumlocutions. For example, when presented with a picture of the low frequency word 'sword' the dyslexic reader might respond with the more common word 'knife' that comes from the same broad semantic category (Denkla & Rudel, 1976; Miller & Felton, 2001; Nation et al., 2001; Snowling, 2000; Swan & Goswami, 1997; Wolf, 1997). Similarly, when unable to retrieve a target word, the dyslexic reader's responses may be a circumlocution in which semantic information about the target or a definition is provided. For example, in response to a picture of a 'hammock' a dyslexic reader responded "a net you sleep on" (Constable, Stackhouse, & Wells, 1997). In a more pronounced example of circumlocution, a dyslexic reader having difficulty recalling the word ‘ocean’ responded:

> The water, the water, lots of water, salty water with big fish, it’s a lotion. No, no, that’s not what I mean. Oh, you know, it’s on all the maps, it’s a lotion—ocean, that’s what it is—a sea, no big sea, it’s an ocean, an ocean (Shaywitz, 2003, p.37)!

The common feature of these examples is that the dyslexic reader is able to retrieve semantic information about the target word - a related word is retrieved, a definition is provided, or a round-about description is given with the dyslexic individual providing many descriptive details and features about the target word. The characteristics of these errors suggest that, from the perspective of Levelt’s model of word retrieval, the first step in word retrieval is intact. The target concept is activated and activation spreads to other related concepts. Nevertheless, in each example the individual is either not able or has great difficulty accessing the spoken form of the word suggesting a disruption in the second step of word retrieval.

Secondly, dyslexic readers make more phonological errors on confrontational naming tasks than control readers and a common feature of these errors is that they are phonologically similar to the target word. For example, when the target word was ladybird, a dyslexic reader responded with the phonologically related response ‘baby bird’ (Snowling, 2000). In another example, the dyslexic reader responded with the pseudoword ‘donimoes’ when attempting to retrieve the word ‘dominoes.’ In both of these examples the dyslexic readers' errors contain a similar number of sounds as the target word but the phonemes are rearranged or new phonemes are substituted. Generally, the phonological errors of dyslexic readers are close in length and sound to the target word. For example, for the target word banana, a dyslexic reader is more likely to say, "bandana" than "bat" (Nation et al., 2001; Snowling, 2000; Swan & Goswami, 1997; Wolf, 1997).

The phonological errors that dyslexic readers make are not limited to the picture naming paradigm and can be elicited on word recognition tasks in which the foils are phonologically related words or pseudowords. For example, dyslexic readers make errors in accepting word and pseudoword foils such as 'vegetarian,' 'vetinarian,' and 'vetranarian' for the target word veterinarian (Elbro, 1998; Elbro, Borstrøm, & Petersen, 1998; Fowler & Swainson, 2004). The common feature of the phonological errors is that they are very close to the target word. This suggests that the dyslexic reader is able to retrieve the semantic representation of the target word but the phonological representation is garbled or indistinct.

Levelt's two-step model of word retrieval provides a means of understanding and explaining the underlying processes that are impaired in dyslexia, but most picture naming studies have not tested this interpretation directly. Thus, it has not been established that the phonological errors of dyslexic readers are due to errors restricted to the second step of word retrieval following accurate retrieval of semantic representations. Most studies have simply reported overall naming deficits, frequencies and types of errors, or specific examples of types of errors. The results, thus, are an end-point analysis and do not provide direct insight into the process of word retrieval. The interpretation that phonological representations are at the root of dyslexic readers' confrontational naming difficulties, although suggestive, is based on inference, and this conclusion will be more strongly supported by studies that specifically probe each step of word retrieval directly.

The tip-of-the-tongue (TOT) experience permits just such an exploration by providing a window into the two steps of word retrieval. In a TOT experience, the speaker is able to retrieve the semantic representation or lemma for the target word, and thus is able to report that the word is known but just currently inaccessible or on the "tip-of-the-tongue" (Brown, 1991; Burke, MacKay, Worthley, & Wade, 1991; Levelt, 1999). However, the speaker is unable to access the word's phonological representation or lexeme, and thus is unable to recover the spoken form of the word either overtly or covertly. During the TOT experience, the speaker is able to provide semantic information about the word, such as a description or a definition, and sometimes is able to provide partial phonological information, such as the initial sound or number of syllables in the word (Brown, 1991; Faust et al., 2003; Levelt, 1999). Nevertheless, the phonological information that is accessible is not sufficiently well specified to direct the assembly of the spoken word. The TOT experience exemplifies the distinctness of the two steps in word retrieval and provides a means of exploring these steps of word retrieval independently. An examination of the difficulties of dyslexic readers on picture naming tasks using the TOT paradigm provides a means of establishing more directly that dyslexic readers' picture naming failures are the result of difficulties with phonological representation.

The TOT method differs from standard picture naming methods by going beyond simply reporting success or failure and exploring in detail the experience of the speaker and their word knowledge when word retrieval fails. In this instance, the speaker is asked to make a judgment about whether they feel they know the name of the object but simply cannot recover it at that moment (TOT), or if they feel they simply do not know the name of the object and would likely not recognize the name in a multiple choice task (DK). Faust and coworkers have used the TOT paradigm to examine naming difficulties of third and fourth grade dyslexic children (Faust et al., 2003) and adolescents (Faust & Sharfstein-Friedman, 2003) reading in Hebrew. The study with the younger children included 15 dyslexic children (mean age = 9.11, SD = 0.7) and 15 control children (mean age = 9.13, SD = 0.7) and the authors anticipated that the dyslexic children would be able to name fewer pictures correctly and would report more TOT experiences and DK responses than a comparison group of classmates with reading achievement in the average range. These predictions were mostly borne out. The dyslexic readers named significantly fewer objects (M = 57.2, SD = 9.1) than the control group (M = 70.1, SD = 6.9) and the dyslexic group reported more TOT experiences (M = 30.4, SD = 8.3) than the control group (M = 17.6, SD = 6.1). However, the two groups did not differ significantly in the number of objects they reported they did not know. The authors argued that these findings indicated that dyslexic readers had a specific problem retrieving or representing the phonological codes for familiar words. In addition, they argued that the lack of difference in DK responses between the two groups indicated that, at least at this developmental step, the dyslexic children did not demonstrate a deficit in vocabulary development.

In the TOT paradigm it is possible to probe the nature of reported TOT experiences. Because the TOT experience exemplifies a failure in the second step of word retrieval, access to semantic information about the target word should be unimpaired and readily provided. Thus, although dyslexic readers are expected to report more frequent TOT experiences, they should not differ from unimpaired readers in their ability to access semantic information about the target word. This finding would support the view that the first step in word retrieval is intact in dyslexia and dyslexic readers' difficulty in picture naming is restricted to the second step of word retrieval.

In their groundbreaking study of the TOT experience in dyslexic readers, Faust, Dimitrovsky, and Shacht (2003) anticipated that dyslexic and normally achieving children would not differ in the amount of semantic information provided about words for which they reported a TOT experience, and indeed, they found that both the dyslexic and normally developing children did not differ in the amount or type of semantic information provided. Both groups reported a range of semantic information including descriptions, object functions, and category membership. These results suggest that, when the name of a picture is inaccessible, the TOT methodology provides a means of establishing that dyslexic readers are nevertheless able to access information from the first step of lexical retrieval. The ability to retrieve semantic information during a TOT experience suggests that dyslexic readers do not differ from their normally achieving peers in their ability to encode semantic information and points to the second step of word retrieval, the retrieval of phonological representations, as the locus of dyslexic readers' difficulties on picture naming tasks.

The quality of the phonological representations in the second step of lexical retrieval can be probed by examining the types of errors made during resolution of the TOT experience in a target-word recognition task. The child is asked to resolve the TOT experience by choosing the correct target word in a forced-choice recognition task. Foils that have been used in picture naming (Nation et al., 2001; Swan & Goswami, 1997) and TOT (Faust et al., 2003) experimental paradigms have included phonologically similar words, phonologically similar pseudowords, semantic foils, and perceptually related foils. For example, if the pictured word is 'banana,' in the recognition task the individual would be presented with the choices 'banana,' and the foils 'bandana,' 'banama,' 'pineapple,' and 'boomerang.'

Faust et al. (2003) predicted that normally achieving children would resolve TOT experiences more successfully than dyslexic children by choosing the correct target word in the recognition task. They also anticipated that the group of dyslexic children would be more likely to make phonological errors on the recognition task and incorrectly choose the phonological word and pseudoword foils. These predictions were confirmed. The normally achieving readers correctly chose the target word when presented with a forced-choice recognition task. In contrast, the dyslexic readers were more likely to make errors and choose the phonologically related word or pseudoword foils. The authors interpreted these findings from the perspective of Levelt's two-step model and concluded that the dyslexic readers' phonological representations are less distinct or fully-specified. As a result the dyslexic children were more likely to be confused by phonologically related foils.

However, there were a number of limitations of the first studies exploring TOT experiences in dyslexic readers. Firstly, a major focus of Faust and coworkers' studies using the TOT paradigm with dyslexic children (Faust et al., 2003) and adolescents (Faust & Sharfstein-Friedman, 2003) was spontaneous recovery from the TOT experience and factors that influence this recovery. The authors interposed an intermediary cueing task and examined whether there was a differential effect of providing phonological cues to dyslexic and normal readers. As a result, the base rates of persistent TOT experiences in the comparison group were very low in the recognition task. The mean and standard deviation for the one type of phonological error was zero and the mean number of other types of errors in the recognition task approached zero. The low error rates in the comparison group presents difficulties and raises questions regarding whether the study had adequate sensitivity to accurately measure errors on the recognition task.

Secondly, Faust and coworkers did not examine the TOT paradigm in reference to other experimental contexts employing this methodology. The TOT paradigm has been employed extensively to examine the effects of aging on word retrieval (Brown & Nix, 1996; Burke et al., 1991; Dahlgren, 1998; Heine, Ober, & Shenaut, 1999; James & Burke, 2000; Rastle & Burke, 1996; Vitevich & Sommers, 2003; White & Abrams, 2002) and in comparisons of mono- and bilingual speakers (Gollan & Acenas, 2004; Gollan, Bonanni, & Montoya, 2005; Gollan & Silverberg, 2001). Successful picture naming or word retrieval is denoted GOT as in “got the word” (Gollan et al., 2005; Koriat & Lieblich, 1974). In these studies DK responses are also further characterized depending on whether the individual continues to report that the target word is unfamiliar even when presented with the correct word (postDK) or acknowledges that the word is familiar even though it could not be retrieved (notGOT). When viewed from the perspective of models of word retrieval, both postDK and notGOT responses represent failures of both steps of word retrieval.

When examining TOT experiences, Gollan & Brown (2006) argue that simply reporting raw numbers of TOT may be misleading and cannot be interpreted as characterizing overall deficits in word retrieval because other factors such as experience may influence the likelihood of experiencing a TOT. They recommend examining the frequency of TOT experiences with words of differing difficulty or frequency, and, in addition, emphasize the importance of bringing this experimental paradigm into alignment with word retrieval theory. If both GOT and TOT represent successes in accessing semantic information about the target word, which is the first step of word retrieval, then given that the total number of target words is N, the proportion of failures at step 1 can be calculated as:

$$\frac{N-(TOTs+GOTs)}{N}$$

Word retrieval failures at step 1 represent the proportion of words that are either not in the participant’s lexicon or for which semantic information cannot be accessed (postDKs and notGOTs). Since TOTs specifically represent failure of the second step of word retrieval, the proportion of failures at step two alone is:

$$\frac{TOTs}{(TOTs + GOTs)}$$

Gollan and Brown (2006) also found that calculating the proportion of failures at step one and step two generates statistics related to word retrieval generally. Using their theory based method they found that the proportion of failures at each step was strongly correlated with naming latency. In contrast, they found that raw TOT scores were not correlated with naming latencies with all of the different classes of word difficulties.

Thus, although examination of TOT experiences in dyslexic readers represents a relatively new application of this experimental paradigm, it is essential to examine the TOT paradigm within the broader context of the word retrieval literature to demonstrate more clearly that dyslexic readers do not differ from their normally developing peers in the retrieval of semantic information at step 1, and instead, demonstrate a specific deficit in the second step of word retrieval – the retrieval of phonological representations. The Faust group (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) did not explore Hebrew speaking children's TOT experiences of dyslexic readers in the context of the theoretical models of word retrieval. Additionally, Faust and coworkers (Faust & Dimitrovsky, 1997; Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) reported aggregate data for total numbers of correctly named words, TOT experiences, unfamiliar words (DK), and the proportion of total responses each type of response represented for the two groups of dyslexic and normally developing children. Means and standard deviations for these dependent variables were reported only in the study with younger dyslexic children (Faust et al., 2003). The authors did not provide sufficiently detailed data to enable others to classify the word retrieval failures from a theoretical perspective.

Fourthly, to circumvent statistical difficulties caused by floor effects for TOT experiences, ceiling effects for correct naming of the target words, and violations of assumptions of homogeneity of variance, the authors (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) used nonparametric statistical analyses. Nonparametric analyses have several drawbacks. They only permit comparison of two groups on a single variable and thus do not permit analysis of interactions between multiple independent variables. In addition, when many comparisons are made the probability of type I errors increases. However, most importantly, the basis cited by the authors for using nonparametric statistical analyses, namely to circumvent problems caused violations of assumptions of homogeneity of variance, is not appropriate since nonparametric tests also assume homogeneity of variance and are not appropriate when homoscedasticity is violated (Kasuya, 2001; Zimmerman, 1996). Moreover, the authors ignored specific characteristics of the data, which call into question the types of statistical analyses conducted. Specifically, TOT experiences are examples of count data for relatively rare events. Regression modeling using the Poisson probability distribution is more appropriate for modeling count data for rare events.

Fifthly, in part because of the type of statistical analysis used, the authors (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) did not examine the influence of target word characteristics such as word length and frequency on TOT frequency in dyslexic and normal readers. Previous studies (Nation et al., 2001; Swan & Goswami, 1997; Wolf

& Bowers, 1999)comparing dyslexic children and control children on word retrieval in a picture naming tasks found that dyslexic children demonstrated a more pronounced deficits in word retrieval with low frequency and phonologically complex words. It will be important to examine the influence of stimulus word type on tip-of-the-tongue experiences and within the context of theoretical models of word retrieval.

Sixthly, because the first studies employing the TOT paradigm to examine picture naming deficits in dyslexia were with children learning to read in Hebrew, it is imperative to extend these findings to other languages. Corroboration of these findings will support the hypothesis that deficits in phonological representation are central to and a universal feature of dyslexia.

Finally, Dyslexic readers are able to successfully name many objects. Similarly, dyslexic readers are usually not completely unable to read, and indeed some older dyslexic readers are able to read with considerable accuracy (Bruck, 1992). The persistent feature of accurate dyslexic readers in English and the hallmark feature of dyslexia in transparent orthographies is slow reading fluency. If the text independent word retrieval difficulties of dyslexic readers, as exemplified by their performance on picture naming tasks, represent a fundamental processing deficit, then, even when successful, picture naming should be laborious and slow. Thus, an examination of word retrieval latency provides a complement to the examination of word retrieval through the TOT methodology, and permits an analysis of differences between normally developing and dyslexic readers under conditions when word retrieval is successful. Naming latencies for target words that are named successfully would be expected to be longer for dyslexic readers than normally developing readers reflecting a generalized impairment in phonological representation. In addition, naming latencies would be expected to be most strongly related to retrieval failures at step 2.

The Current Study

The current study used the TOT paradigm to examine dyslexic readers' picture naming difficulties from the perspective of current theories of word retrieval. The goal of the study was to establish more directly that dyslexic readers demonstrate a specific deficit in the second step of word retrieval, namely phonological representation. Rather than simply examine the end state of success or failure in picture naming, the TOT paradigm permits comparison of dyslexic and normally developing readers at both the first step of word retrieval, in which semantic representations are retrieved, as well the second step, in which phonological representations are accessed. A more in-depth analysis of the quality of dyslexic readers' phonological representations was also explored by examining the types of errors dyslexic readers make in a recognition task for target words that cannot be retrieved. Finally, the relationship between failures in each step of word retrieval with word naming latencies when word retrieval is successful was examined. The goal was to establish that difficulties with phonological representation are related to word retrieval latency and access to distinct and well specified phonological representations represents a bottleneck in efficient word retrieval, both when the target word is known but inaccessible, and when picture naming is successful.

Age and characteristics of participants

This study focused on eight- to ten-year-old children with dyslexia. There are several factors influencing the suitability of this age group. Firstly, starting in grades three and four most children transition from “learning to read” to “reading to learn” (Snowling, 2000). Normally developing children will have mastered basic word reading skills and will read fluently. Selecting dyslexic children at this age will ensure that their reading difficulties are persistent, and not simply due to developmental delays mastering word decoding.

Secondly, children may not be evaluated for learning disabilities until they have failed to make academic progress for several years. By the third and fourth grades, it is likely that children with long-standing reading difficulties will have received a formal learning disabilities evaluation. Thus, choosing participants in this age range permitted the identification of a homogenous sample of children meeting the specific deficit criteria outlined in this study without having to conduct extensive screening assessments. Using a strictly defined group of dyslexic readers increased the power of the study and contributed to understanding the specific deficits of a narrowly defined group of poor readers. There are both theoretical and practical implications that emerge from this approach. From a theoretical perspective, it is essential to characterize the specific features of a narrowly defined group, and then determine whether these features generalize to larger groups of poor readers who have been identified by distinct criteria. This will enable researchers to understand more clearly whether there are distinct subtypes and etiologies of reading failure. From a practical perspective, understanding the specific weaknesses of individual children has implications for both diagnosis and treatment.

Thirdly, children in this age range are able to more accurately monitor their memory and make more reliable judgments about whether they are familiar with the name of an object or simply do not know the name (Wellman, 1977). By third grade children are expected to be able to identify more accurately tip-of-the-tongue experiences.

Fourthly, some issues concerning choosing an appropriate control group are less pronounced at this age. Comparisons between dyslexic and normally developing readers often use reading-level matched younger children as the control group. When differences in reading-related subskills and cognitive processing are found between these two groups they are viewed as related to cognitive processes that are likely causally related to dyslexia and less likely simply a consequence of lack of reading experience (Olson et al., 1994; Snowling, 2000; Stanovich, 1988; Stanovich & Siegel, 1994). Even though reading-level matched groups may be regarded as a more appropriate and stringent control, this control group is not without problems (Bowey, Cain, & Ryan, 1992). Developmental differences in cognitive processing may obscure genuine differences when older, more developmentally mature, dyslexic readers are compared to younger, less mature, reading-level matched readers. For example, even though a 9-year-old child with dyslexia may be reading at the same level as a normally developing 7-year-old, the older child may be cognitively more mature and may demonstrate faster reaction speeds and more highly developed metacognitive awareness (Wellman, 1977). In the context of this study, these types of developmental differences might obscure genuine differences in TOT experiences and picture naming latencies if a younger reading-level matched control group is the comparison group.

The most appropriate control group for this study is normally developing readers matched in receptive vocabulary with the dyslexic readers. Measures of receptive vocabulary are ideal because they do not require a verbal response, and thus, are not confounded by dyslexic readers' word retrieval difficulties. In addition, because this study examined text independent deficits in dyslexia, it was less important to match the dyslexic readers and control group on word reading skill or reading comprehension as found in many reading-level matched designs. Moreover, it is likely that the receptive vocabularies of 8-10 year-old normally developing and dyslexic children will be in the same range at this age because the normally developing children are only beginning to "reading to learn" and gain extensive vocabulary through reading experience. Up until this age most vocabulary development is not garnered through reading (Biemiller, 2003; Cunningham, 2005; Hart & Risley, 1995). Therefore, by studying children in this age range it was easier to match dyslexic and control group children of the same developmental step on measures of receptive vocabulary. In contrast, older groups of dyslexic readers likely have less well developed receptive vocabularies than their age-matched peers because of the cumulative effects of differences in exposure to print on vocabulary.

Finally, studies with older and younger adults have found fluent picture naming and TOT experiences are strongly influenced by experience (Gollan & Brown, 2006).

The TOT paradigm is not well researched in children. Until the influence of experience on word retrieval and TOT experiences in children has been more thoroughly examined, it is best to control for possible confounds in vocabulary development and experience by studying children in the 8-10 year-old age range where these factors are less pronounced.

Stimuli

In both TOT and picture naming studies different strategies have been chosen for selecting appropriate target words. Faust and coworkers (Faust & Dimitrovsky, 1997; Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) used 90 target words that were rated as familiar to a sample 13 children one to two years younger than the age group of the children in the study. To elicit more TOT experiences and to avoid ceiling effects, target words were chosen that were not considered to be basic vocabulary words. One study (Gollan & Brown, 2006) examining TOT experiences in adults found that older adults demonstrated a larger proportion of failures at both step one and step two of word retrieval for difficult words than younger adults, whereas there were no differences between the two groups in retrieval of easy words. In the Gollan and Brown study word difficulty was determined by ratings of undergraduate students and the students' difficulty ratings were significantly related to word frequency.

In contrast, recent studies using picture naming methodology to study naming latency (Nation et al., 2001) or naming errors (Nation et al., 2001; Swan & Goswami, 1997; Wolf & Bowers, 1999) have used more varied stimuli and have explored differences in picture naming between dyslexic and normally developing children across different categories of target words by selecting target words varying on dimensions of length and frequency of occurrence. These studies have found that dyslexic readers demonstrate particular difficulties naming long and/or low frequency target words. The current study examined TOT experiences in dyslexic readers using target stimuli that vary in frequency and word length. A total of four different groups of words were studied including words of short length and high frequency, short length and low frequency, long length and high frequency, and long length and low frequency.

Hypotheses:

Hypothesis 1: The first hypothesis consisted of three components. In the first part, dyslexic children were predicted to report more TOT experiences in a picture naming task than their normally developing peers. Furthermore, it was also predicted that the characteristics of the word would be related to TOT experiences; low frequency and phonologically complex words would prompt more TOT's and this would be especially salient for dyslexic children. In the second part, dyslexic children were predicted to retrieve fewer target words successfully (GOTs). Successful word retrieval was predicted to be dependent on the target word frequency and length. Finally, in the third part, no significant group differences in the number of DK responses were predicted and word retrieval failures were predicted to be related only to word frequency and length.

Hypothesis 2: Dyslexic and normally developing children were predicted to diverge on a recognition task. Dyslexic children were predicted to make more phonological errors in a forced-choice recognition task to resolve the TOT experience. Dyslexic children were predicted to choose phonologically related words and pseudowords instead of the correct target word or semantically and perceptually related foils more frequently than their normally developing peers.

Hypothesis 3: When examined from the perspective of theoretical models of word retrieval, dyslexic readers were predicted to differ from normally developing readers only in the second step of word retrieval. The proportion of failures in word retrieval for step 1, the retrieval of semantic information, was predicted not to differ for the two groups of readers. However, dyslexic readers were predicted to demonstrate significantly more failures in word retrieval at step 2, the retrieval of phonological information. Word retrieval latencies are predicted to be most strongly correlated with word retrieval failures at step 2.

Hypothesis 4: Dyslexic readers' increased frequency of TOT experiences were predicted to be related to a generalized deficit in word retrieval; dyslexic readers were predicted to demonstrate longer word retrieval latencies even when picture naming was successful. Longer latencies were predicted to be most pronounced for phonologically complex and less frequently encountered words.

Method

Participants

Children in the dyslexic group were recruited through St. Louis County Special School District. Recruitment was conducted in two phases due to low response rates. In the first phase, approximately 400 children with reading disabilities were identified by Special School District. Recruitment flyers and cover letters describing the study were mailed directly to their families. In the second phase of recruitment, flyers and cover letters were mailed to 418 chairs of Individual Education Plan teams. The chairs were asked to distribute the information about the study directly to the approximately 1800 children with a reading disability in basic reading or to their parents and guardians at annual IEP review conferences. In addition, children with basic reading disability were recruited through the St. Louis Charter School.

A total of 33 children with learning disabilities participated in the study. Sixteen children were retained in the final dyslexic group. These children met the criteria of a diagnosis of Learning Disability in Basic Reading and, at minimum, a 20 point discrepancy between their IQ and word- or pseudoword-reading scores on standardized measures of reading and IQ. The average discrepancy between IQ and word- or pseudoword-reading in the dyslexic group was 30 points (2 standard deviations).

The 17 children with learning disabilities who were eliminated from the analysis were not included for several reasons. Thirteen children were eliminated because their learning disability was not in basic reading or they did not meet the discrepancy criteria for inclusion in the experimental group upon review of records. Parents of three children either could not provide psychoeducational records for review or did not authorize release of records, and one child chose not to complete the study. In the final retained dyslexic group, fourteen children were recruited through Special School District, one child attended St. Louis Charter School, and one child attended a private school in St. Louis County.

Children in the control group were recruited through several public and private schools in St. Louis County and through word-of-mouth by parents of children who had participated in the study. A total of 47 control children participated in the study. Of these children, sixteen were not included in the final sample. Eight children were omitted because they were siblings of other children in the study. The siblings were randomly removed to prevent a possible confound of shared familial environment. Four children were omitted because of missing data or audio files; two children had unspecified learning disabilities and reading difficulties, one child did not meet the inclusion criterion of receptive vocabulary in the average range or above, and one child was removed from the sample because of difficulty attending to and completing the picture naming task. The 31 children retained in the control group represented three public, three parochial, and one private elementary school in St. Louis City and County.

The final sample consisted of 15 girls and 32 boys. There were four girls and 12 boys in dyslexic group and 11 girls and 20 boys in the control group. Forty three out of 47 the children were Caucasian; one child in the dyslexic group was African American while the control group contained one African American, one biracial, and one Asian child. The average age in the total sample was 9.58 years (SD = 0.79). The average age in the dyslexic group was 9.83 years (SD = 0.96) and the average age in the control group was 9.42 years months (SD = 0.65).

Measures

Peabody Picture Vocabulary Test – Third Edition (PPVT-III). The Peabody Picture Vocabulary Test (Dunn & Dunn, 1997) is an individually administered, norm-referenced test of receptive or listening vocabulary for individuals ages 2½ to 90. Each item consists of a picture plate consisting of a set of four black-and-white illustrations.

The examinee chooses the picture that best represents the target word spoken by the examiner. One advantage of the PPVT-III for this study is that no verbal response is required; children can point to the correct picture or refer to it by number. Scores on the PPVT-III correlate highly with measures of verbal intelligence and the test can be regarded as a screening test of intellectual functioning (Williams & Wang, 1997). The correlation between the PPVT-III and Verbal IQ scale of the WISC-III is .91. The PPVT-III can also be viewed as a measure of achievement since it measures vocabulary acquisition. In this study, the PPVT-III provided a means of controlling for vocabulary development between the control and dyslexic groups. Split-half reliability of the PPVT-III for children in the 8-10 year age range is .94 and test-retest reliability is .93. The PPVT-III administration takes approximately 15 minutes and raw scores were converted to age-referenced standard scores with a mean of 100 and standard deviation of 15.

Naming Task. Picture naming stimuli were selected from a set of black-and-white line drawings of 520 common objects available as freeware from the International Picture Naming Project (IPNP; (Szekely et al., 2005; 2003). The IPNP pictures combine stimuli from a number of earlier studies and have been used to develop picture naming and reaction time norms in comparative studies of adults and children and in cross-linguistic studies. The stimuli were chosen to represent four different classes of target words varying on the dimensions of frequency and length. The four types of target words were: short high frequency, short low frequency, long high frequency, and long low frequency. Short target words were 4 phonemes in length or shorter. Long target words were 6 or more phonemes. Low frequency target words had frequency ratings of less than 10 per million and high frequency target words had ratings of greater than 20 per million (Baayen, Piepenbrock, & Gulikers, 1995; Carroll, Davies, & Richman, 1971; Johnson, Moe, & Baumann, 1983; Szekely et al., 2003). When possible, target words were selected that previously had been demonstrated to have a dominant target name in studies with children (Cycowicz, Friedman, Rothstein, & Snodgrass, 1997; Szekely et al., 2005; 2003). A number target words were not available as picture stimuli in the IPNP data base. Pen and ink drawings were made for these target words or picture stimuli were obtained through images available on the internet.

An initial pilot study was conducted using 222 target words. There were 15 participants in the pilot study in the same age range as participants in the study. These children were recruited through parent contacts at local public, private, and parochial elementary schools. From this set of words, 156 stimuli were selected containing 39 of each type of target word. After data collection for the study was completed, several target words were removed from the data set because the picture stimuli were visually confusing and did not elicit a dominant response or the stimulus had a synonymous short name that was a common response. For example, the target word ‘hippopotamus’ was removed from the data set because the response ‘hippo’ was common and reflected retrieval of a short, phonologically simple word compared to a long, phonologically complex word. A total of 12 words were removed from the data set. The final data set contained 39 high frequency short words, 34 high frequency long words, 35 low frequency short words, and 35 low frequency long words.

The stimuli were presented to the children on a lap top computer. When children named the picture correctly, the next stimulus was presented immediately. The presentation of the stimuli was briefly interrupted when the children: responded incorrectly, reported a tip-of-the-tongue experience, or reported that they did not know the name of the stimulus. While the administration was paused, the children were first prompted to provide another response or to provide any information they could about the word they were attempting to retrieve and then presented with the recognition task for that stimulus word. The presentation of the stimuli via the computer was resumed after completion of these tasks.

Response Latency Measurement. Response latency, from the onset of the picture stimulus to the child's response, was measured using a Cedrus SV-1 Smart Voice Key. Children wore a headset fitted with a microphone which was calibrated prior to picture naming and adjusted during the 8 training trials. The presentation software was programmed to indicate when a reaction time measurement was recorded. When reaction time data was recorded a symbol appeared in the upper right hand corner of the computer screen. The examiner recorded whether or not the response was valid. Invalid responses included incorrect names, false starts, "don't know" responses, tip-of-the-tongue responses, pronominal verbalizations such as "that's an armadillo," and background noises.

Recognition Task. The recognition task for a target word was presented during the pause in presentation of the stimuli after an incorrect response, a tip-of-the-tongue experience, or a "don't know" response. The target word and four foils were printed in

48 pt on an 8" x 11.5" card. Two of the foils were phonologically related to the target word: one was a real word and the other was a pseudoword. The third foil was from the same semantic category as the target word; the fourth foil was perceptually related to the target word. The five words were written in random order and were read aloud to the children as the examiner pointed to each word.

Receptive Vocabulary Task. The receptive vocabulary task was developed in the same format of the PPVT-III. This task was administered after completion of the picture naming task for any target words that were incorrectly named or not known. For each target word, a picture plate was created consisting of four black-and-white pictures, one of which was the target word. The children were asked to identify which of the four picture stimuli was the target word spoken by the examiner.

Response Coding. When the child responded with the correct target name the response was coded as "got the word," or *got*. No additional tasks were administered.

Two types of responses were coded as tip-of-the-tongue, *tot*. Firstly, responses were coded as *tot* when children reported a tip-of-the-tongue experience and were able to provide semantic information about the target word. Secondly, responses were coded as *tot* when they met following criteria: children did not explicitly report a tip-of-the-tongue but reported that they were thinking of a word, children were able to provide accurate semantic information about the target word, and they identified the target word or one of the phonological foils as the word they were trying to recall on the recognition task. Even when children did not overtly report a tip-of-the-tongue experience, their body language and vocalizations usually belied their experience. One child was noted to remark “It doesn’t feel like it is on the tip of my tongue, it is more in the back of my throat.”

If, after reporting a tip-of-the-tongue experience, children chose either the semantic or perceptual foils or reported that none of the words in the recognition task was the word they had been attempting to retrieve instead of the target word, the response was coded as *notgot* to indicate that they were having a tip-of-the-tongue experience for a word other than the target.

Two types of responses represented word naming failures. The first type, coded as *notgot*, represented a failure to retrieve a known or familiar word. Responses were coded as *notgot* when the naming response was incorrect but the child was able to correctly identify the correct target word from the choices of target word, and semantic, perceptual, and phonological foils in the recognition task. In addition, responses were also coded as *notgot* if the initial naming response was incorrect and the child was also not able to choose the target word when the recognition task was presented but was able to correctly identify the picture of the target word on the receptive task. In both these instances the target word was familiar, but could not be retrieved (Gollan & Brown, 2006). The second type of word naming failure, coded as “post don’t know” (*pdk*), represented a lack of knowledge about the target word. Responses were coded as *pdk* if they met the following three criteria: firstly, the target name was not know or not named correctly. Secondly, the name could not be identified in the recognition task. And thirdly, when the target name was provided in the receptive task, the child could not match the name to the correct picture stimulus. The frequency of “post don’t know” responses was very low. It is likely that children were able to correctly identify the correct stimulus picture on the receptive task because an association between the name and picture was made during the recognition task. As a result, *notgot* and *pdk* responses were combined into a single variable, *ngpdk*.

Two types of responses were coded as phonological errors in the recognition task to resolve tip-of-the-tongue experiences; *phon*. The recognition task was administered immediately after a tip-of-the-tongue report. A list of words including the target word, a phonologically related word foil, a phonologically related nonword foil, a semantically related foil, and a perceptually related foil was presented and read aloud to the child. Children were asked to choose which, if any, was the word they were attempting to retrieve. Responses were coded as *phon* when children chose either the phonologically related word or the phonologically related nonword.

Rater Coding and Reliability. Children's responses were digitally recorded for later review. Recordings were reviewed by two independent raters who were not aware of the children's reading status. The raters overlapped on 20% of the audio recordings. The raters were trained to reliably categorize incorrect responses as semantically, phonologically, or perceptually related to the target word. In addition, when children failed to retrieve a target name but provided information about the word, the raters coded the information as correct or incorrect semantic or phonological information (Faust et al., 2003; Swan & Goswami, 1997). Semantic information included information such as information about function ("That is something you cook with."), category ("That goes in the kitchen"), personal experience ("I saw that when I went to the museum."), or perceptual features of the object (“It is hard like rock.”). Information about the target word’s consonants, their position, or the target’s word length was categorized as phonological (Brown, 1991). Information that was not related to the target word was coded as incorrect. Inter-rater agreement was calculated as the percent agreement between the two raters (Stemler, 2004). The overall agreement between the two raters was 92% and ranged between 83% and 100% on individual audio files.

Procedure

Children were tested individually in their homes and all children participating in the study received ten dollars independent of completion of the study. The administration was completed in one session usually lasting from between 45 and 90 minutes. After reviewing the consent forms with the parents and assent forms with the children, the children were asked if they were familiar with the expression “it’s on the tip-of-my-tongue,” and if so, could they recall a time when they had experienced a TOT. The examiner provided an example of a time when she had experienced a tip-of-the-tongue and modeled providing semantic information about the object for which she was unable to recall the name. After describing her experience, the examiner again asked children who at first reported being unfamiliar whether they could recall ever experiencing a TOT and all children reported being familiar with the experience.

For each picture stimulus, a fixation point (+) was presented at the center of the screen for 500 ms. After the offset of the fixation point, the picture was presented for up to 20,000 ms at which point the picture was replaced with a second fixation point (·).

Children were instructed to name the pictures as quickly and clearly as possible. The examiner emphasized the importance of responding only with the object name to avoid errors in response latency measurement caused by false starts, hesitations (e.g., "umm") or extraneous information (e.g., "I know what that is … a volcano" or "that's a volcano"). Children's responses were digitally recorded and response latency was measured using headset with microphone attached to an SV-1 reaction time recorder. The presentation software was programmed so that when the SV-1 reaction time recorder measured the response latency a symbol appeared in the upper right hand corner of the screen. The examiner used this information to note whether the response recorded by the SV-1 recorder reflected a correct naming response, a response to an extraneous sound, an incorrect, "don't know," or tip-of-the-tongue response.

At the beginning of the presentation, eight training trials were presented and final adjustments to the SV-1 recorder were made. Several of the targets in the training trials were selected to elicit incorrect, tip-of-the-tongue, or "don't know" responses. These trial items then provided opportunities for children to become familiar with the recognition task. Following the trial examples, the stimuli were presented in blocks of four pictures containing one of each target word type varying in word length and frequency. The presentation of the different types of target words within each block was randomized. The order of stimuli was constant across participants.

Children were reminded to respond as quickly as possible to the picture stimuli. When children provided an incorrect name, reported a tip-of-the-tongue experience, reported that they did not know the name of the stimulus, or if 20,000 ms elapsed without a response, the picture naming task was paused briefly. Children were prompted to provide another response or provide any information they could think of about the word they were attempting to retrieve. If the children persisted in not being able retrieve the correct name of the stimulus, the recognition task for that target word was administered: the children were prompted to choose the name of the stimulus from the target word and four foils, which were presented and read aloud to the children. After choosing one of the words, children were asked if this was the word they had been attempting to retrieve, their response was recorded, and the picture naming task was resumed. Occasionally, children reported that they did not recognize any of the words in the recognition task as the target word or the word they were attempting to retrieve. In this instance, their response was also recorded and the picture naming task was resumed. At the end of the picture naming task, children were given a receptive vocabulary task for any stimuli that had not been correctly identified in both the picture naming task and recognition task. The receptive task determined whether the target word was in the child's lexicon. Children were presented with a picture plate of four pictures and asked to identify the target word spoken by the examiner. Upon completion of this task, the PPVT was administered.

Results

Preliminary Analyses

Potential Covariates. Preliminary analyses of demographic variables indicated that there were no significant differences between the dyslexia and control groups in gender, $\chi^2(1) = .53$, $p > .47$ and age, $t(22.43) = -1.58$, $p = .13$. Children were administered the PPVT-III to control for a possible confound between the groups on vocabulary development. The average PPVT-III receptive vocabulary standard score of children the study was 118 (SD = 14); the average for the dyslexia group was 114 (SD = 16), and the average for the control group was 121 (SD = 13). The difference between the two groups' receptive vocabulary was not significant, $t(47) = 1.47$, $p = .162$, and thus was not used as a covariate in further analyses.

Distributions and Analysis Considerations. The variable *got* represented the number of correctly named stimuli of each word type. However, the number of stimuli for each type of word was not the same, thus the modal *got* value for each type of word stimulus reflected this difference. For high frequency short words the modal value of the *got* variable was 39, for high frequency long words the modal value was 34, for low frequency short words the modal value was 35, and for low frequency long words the modal value was 35. To create a new variable with a common modal value the *got* variable was reflected to create the variable *rgot*. *rgot* was calculated by determining difference between the total number of words of a given frequency and length and the number of words named correctly ($rgot = n_{FxL} - got_{FxL}$). The variable rgot **was a measure** of the total number of words that were not successfully retrieved and was the sum of tip-of-the-tongue experiences, incorrectly named targets, and "don't know" responses.

Each of the variables, *tot*, *rgot*, and *ngpdk*, represents count data and has a distribution with a modal value of 0 and a positively skewed tail (see Figures 1, 2, 3).

The distributions of the dependent variables reflect the fact that, in general, tip-of-the-tongue experiences and incorrect naming or not knowing the name of a stimulus are rare events; the most common outcome is correct naming of the picture stimulus. An examination of the means and standard deviations of the variables reveals that the means and standard deviations of the *tot, rgot*, and *ngpdk* variables for high frequency, short words in the control group were 0. The distributions and descriptive statistics of these variables violate assumptions of homogeneity of variance and normality necessary for Ordinary Least Squares regression or ANOVA. The Poisson probability distribution is the most appropriate to model count data for rare events (Cohen, Cohen, West, & Aiken, 2003; Dunteman, 2005; Fox, 1997, 2002; Gardner, 1995). Poisson regression modeling permits analysis of count data without transformation and does not assume that the error terms or dependent variables are normally distributed.

Poisson regression falls within the family of generalized linear models (GLM) (Dobson, 2002; McCullagh & Nelder, 1989). All GLM consist of three components. The first is the dependent variable, Y_i, which is conditional upon the independent variables and follows the exponential Poisson distribution. The second component is the linear predictor of the independent variables

$$\eta_i = \alpha + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_k X_{ik}$$

The third component is a link function $L(\cdot)$ that transforms the expectation of the dependent variable, $\mu_i \equiv E(Y_i)$, to the linear predictor η_i. The best fit of this data set was the square root link function, where $L(\mu_i) = \sqrt{\mu_i}$.

Main Analysis

Hypothesis I. The first hypothesis contained three components. The first was the prediction that dyslexic children would report more tip-of-the-tongue experiences than control children. It was also expected that the characteristics of the target word would be related to TOT experiences; low frequency and phonologically complex words would elicit more tip-of-the-tongue experiences. Furthermore, the characteristics of the target word were predicted to be particularly salient for dyslexic children. To test this hypothesis a full-factorial Poisson regression analysis was undertaken examining the prediction of tip-of-the-tongue experiences by the independent variables, group (dyslexic or control), word length (short or long), and word frequency (high or low).

The overall fit of the model, including all of the independent variables and interaction terms, was significantly better than the null model, $\chi^2 = 160.73$, $df = 7$, $p < .001$. McFadden's ρ^2 provides a measure of association and is related to R^2 in Ordinary Least Squares regression. McFadden's ρ^2 is a measure of the proportion of the variance accounted for by the model and is computed as:

McFadden's $\rho^2 = 1 -$ (Log-likelihood(model))/(Log-likelihood(null))

$= 1 -$ (Residual Deviance/Null Deviance)

For the prediction model of tip-of-the-tongue experiences, McFadden's $\rho^2 = .72$, indicating that the full-factorial model with predictors group, word length, and word frequency accounts for 72% of the variance in tip-of-the-tongue experiences in the picture naming task.

Examination of the parameter estimates for the Poisson prediction model of tip-of-the-tongue experiences indicated significant main effects for the predictors group, length, and frequency (see Table 1). Dyslexic children (M = 3.26, SD = 3.53) experienced more tip-of-the-tongue experiences than control children (M = 2.06, SD = 2.54), $p < .05$. Tip-of-the-tongue experiences were more likely with long words (M = 2.82, SD = 3.11) than with short words (M = 2.14, SD = 2.79), $p < .001$, and with low frequency words (M = 4.69, SD = 2.71) than with high frequency words (M = .265, SD = .651), $p < .001$. The only significant interaction effect in the model was between word length and word frequency, $p < .05$, indicating that the effect of word length on tip-of-the-tongue experiences was more pronounced with low frequency words than with high frequency words. The predicted interactions between group and word length, group and word frequency, and the three-way interaction between group, word length, and word frequency were not significant. These results partially supported Hypothesis 1.

The second component of Hypothesis 1 was the prediction that dyslexic children would retrieve fewer target words successfully than control children. When framed in terms of the Poisson regression model, a main effect for group was predicted. Word retrieval was also predicted to be dependent on word length and frequency. For this component of Hypothesis 1, the dependent variable for the prediction model was *rgot*, which is the count of successful word retrievals subtracted from the total number of stimuli in that group of word length and frequency. The variable *rgot* can be conceptualized as the count of words that either cannot be named or are named incorrectly. The full-factorial Poisson prediction model of the variable *rgot,* including the independent variables group, word length, and word frequency, indicated that the overall fit was significantly better than the null model, $\chi^2 = 899.29$, $df = 7$, $p < .0001$.

McFadden's ρ^2 was .70, indicating that the full-factorial model with predictors, group, word length, and word frequency accounted for 70% of the variance in words that cannot be named in the picture naming task.

Examination of the parameter estimates for the Poisson prediction model of *rgot* indicated significant main effects for the predictors, length, and frequency (see Table 2). Successful word retrieval was more likely with short words (reflected *rgot* M = 3.43, SD = 4.32) than long words (*rgot* M = 5.03, SD = 5.14), $p < .001$, and more likely with high frequency words (*rgot* M = .78, SD = 1.39) than low frequency words (*rgot* M = 7.68, SD = 4.51), $p < .001$. There was no main effect for group. The hypothesis that dyslexic children would name significantly fewer words was not supported. There was a trend in this direction, but it did not reach significance (*rgot* $M_{dyslexic} = 5.34$, $SD_{dyslexic} = 5.74$ cf. $M_{control} = 3.64$, $SD_{control} = 4.13$). The interaction between length and frequency was significant, indicating that the effect of word length on word retrieval was more pronounced with low frequency words than high frequency words, $p < .01$. Thus, the second component of Hypothesis 1 was partially supported.

The third component of Hypothesis 1 was the prediction that word retrieval failures would only be related to word length and word frequency in a sample of children who did not differ in receptive vocabulary. When framed in terms of the Poisson regression model, word retrieval failures were predicted to be related to word length and word frequency only. The full-factorial Poisson prediction model of the variable *ngpdk* by the independent variables, group, word frequency, and word length indicated that the overall fit of the model of was significantly better than the null model,

$\chi^2 = 334.61$, $df = 7$, $p < .0001$. McFadden's ρ^2 was .49, indicating that the full-factorial model with predictors, group, word length, and word frequency accounted for 49% of the variance in words incorrectly named or not known in the picture naming task.

Examination of the parameter estimates for the Poisson prediction model of *ngpdk* indicated significant main effects for the predictors length and frequency (see Table 3). Word retrieval failures were more likely with long words (M = 1.96, SD = 2.77) than short words (M = 1.28, SD = 2.07), $p < .001$, and more likely with low frequency words (M = 2.98, SD = .647) than high frequency words (M = .255, SD = .647), $p < .001$. Children were more likely not to know or incorrectly name stimuli representing low frequency or long words. There was no main effect for group and none of the interactions were significant. Thus, the third component of Hypothesis 1 was supported.

Hypothesis 2. When children were provided the opportunity to resolve a tip-of-the-tongue experience in a forced-choice recognition task, dyslexic children were predicted to make more phonological errors than control children. Dyslexic children were predicted to choose phonologically related words or nonwords instead of the correct target word on the recognition task. The variable *phon* was the count of phonological errors made in the recognition task to resolve tip-of-the-tongue experiences and represents the sum of phonological word and nonword errors made for each stimulus word category. The variable *phon* had a modal value of 0 and a maximum of 4 and was strongly positively skewed (see Figure 4). The *phon* variable violated assumptions of homogeneity of variance and normality necessary for Ordinary Least Squares regression or ANOVA. Thus, Poisson regression analysis using the square root link function was used to model the prediction of *phon* by the independent variables group, word length, and word frequency.

The overall fit of the model, including all of the independent variables and interaction terms, was significantly better than the null model, $\chi^2 = 11.126$, $df = 7$, $p < .0001$. McFadden's ρ^2 was .36 indicating that the full-factorial model accounted for 36% of the variance in words incorrectly named or not known in the picture naming task. Examination of the parameter estimates for the Poisson prediction model of phonological errors revealed that only word frequency was a significant predictor, $p < .001$ (see Table 4). Thus, children are more likely to choose a phonological foil when attempting to resolve a tip-of-the-tongue for a low frequency target word. Group was not a significant predictor of phonological errors on the recognition task to resolve tip-of-the-tongue experiences. The hypothesis that dyslexic children would be more likely to make phonological errors on the recognition task was not supported.

Hypothesis 3. The third hypothesis predicted that, when word retrieval was examined from the perspective of theoretical models, dyslexic readers would differ from control children only in the retrieval of phonological information, the second step in word retrieval. To test this hypothesis, two new variables were created from the count data and the predictors of word retrieval failures at both step 1 and step 2 were examined.

The variable '*step1*' is a measure of the proportion of failures to retrieve semantic information about the target word. Both successful naming of the target (*got*) and tip-of-the-tongue experiences (*tot*) reflect retrieval of semantic information about the target word. Word retrieval failures at step 1 represent the proportion of words that are either not in the participant's lexicon or for which semantic information cannot be accessed. Thus, failures at step 1 can be computed from the total number of target words by subtracting successful retrievals at step 1, (*tot* + *got*):

$$step1 = \frac{N - (tot + got)}{N}$$

The variable '*step2*' is a measure of the proportion of failures to assemble the phonological representation of the word. Only target words for which semantic information is successfully retrieved contribute to successes or failures at step 2. Both tip-of-the-tongue experiences (*tot*) and successful target naming (*got*) reflect successful retrieval of semantic information (step 1). However, although in a tip-of-the-tongue experience the semantic information for the target word is retrieved, the phonological representation is not and there is a failure at step 2 of word retrieval. The proportion of failures at step 2 is calculated as the ratio of failures at step 2 (*tot*) to successes at step 1 (*tot* + *got*):

$$step2 = \frac{tot}{(tot + got)}$$

Poisson regression requires that the dependent variable assume only integer values, thus the proportion of failures at step 1 and step 2 was converted to percent failures at each step, *pcstep1* and *pcstep2*. The variables *pcstep1* and *pcstep2* can be conceptualized as the rate of failures in word retrieval at step 1 and step 2 per 100 words. The distributions of the *pcstep1* and *pcstep2* variables are positively skewed with a modal value of 0. The most common outcome at each step of word retrieval is success. Poisson regression modeling using the square root link function was used to test the prediction model.

First, a full-factorial Poisson regression analysis was undertaken to examine the prediction of word retrieval failures at step 1 (the retrieval of semantic information) using the independent variables group, word length, and word frequency. The overall fit of the model, including all of the independent variables and interaction terms, was significantly better than the null model, $\chi^2 = 830.16$, $df = 7$, $p < .0001$. McFadden's ρ^2 was .44 indicating that the full-factorial model accounted for 44% of the variance in percentage of failures to retrieve the semantic information for a target word, step 1.

Examination of the parameter estimates for the Poisson prediction model of the percentage of failures at step 1 indicated significant main effects for the predictors word length and word frequency (see Table 5). Children were more likely to have difficulty retrieving semantic information for long words (M = 6.38, SD = 7.61) than short words (M = 3.63, SD = 5.72), $p < .001$, and for low frequency words (M = 8.48, SD = 7.88) than high frequency words (M = 1.53, SD = 2.80), $p < .001$. The only significant interaction effect in the model was between word length and word frequency, $p < .001$, indicating that the effect of word length on the likelihood of not being able to retrieve semantic information about a target word was more pronounced with low frequency words than with high frequency words. Group was not a significant predictor of word retrieval failures at step 1.

Second, a full-factorial Poisson regression analysis was undertaken to examine the prediction of word retrieval failures at step 2 (the retrieval of phonological information) using the independent variables group, word length, and word frequency. The overall fit of the model, including all of the independent variables and interaction terms, was significantly better than the null model, $\chi^2 = 2161.10$, $df = 7$, $p < .0001$. McFadden's ρ^2 was .71 indicating that the full-factorial model accounted for 71% of the variance in percentage of failures to retrieve phonological information for a target word, step 2.

Examination of the parameter estimates for the Poisson prediction model of the percentage of failures at step 2 indicated significant main effects for the predictors group, word length, and word frequency (see Table 6). Dyslexic children (M = 10.59, SD = 12.44) were more likely to fail to retrieve phonological information for target words than control children (M = 6.42, SD = 8.05), $p < .001$. Failure to retrieve phonological information was more likely with long words (M = 9.18, SD = 11.04) than short words (M = 6.55, SD = 8.61), $p < .001$, and for low frequency words (M = 14.92, SD = 9.75) than high frequency words (M = .816, SD = 2.04), $p < .001$. The only significant interaction effect in the model was between word length and word frequency, $p < .001$, indicating that the effect of word length on retrieval of phonological information about a target word was more pronounced with low frequency words than with high frequency words. These results indicate that the second part of Hypothesis 3 was supported. Even when matched for receptive vocabulary, dyslexic children demonstrate more failures in step 2 of word retrieval, the retrieval phonological information for target words. Dyslexic and control children did not differ significantly in the step 1, the retrieval of semantic information.

Hypothesis 4. The final hypothesis predicted that dyslexic children would demonstrate generalized difficulties in word retrieval even when target naming was successful and this would be manifested in long naming latencies. The variable *rt* was the time in milliseconds from the from the onset of the stimulus until a correct picture naming response was recorded. Incorrect naming, tip-of-the-tongue experiences, 'don't know' responses, and errors due to accidental triggering of the SV-1 recorder by extraneous noises or movements were not included. In addition, although the microphone was calibrated for each child at the beginning of the administration, many children touched or moved the microphone during the task or did not respond with a consistent pitch or volume, resulting in many missed response latency measurements. To increase participation, children were tested in their homes; as a result, varying levels of background noise contributed to difficulties calibrating the equipment and obtaining consistent response latency measurements.

Analysis of the response latency data indicated that 36% of response latency measurements were missing from the data set. The distribution of missing data was not uniform. More response latency measurements were missing for low frequency words than high frequency words. In addition, there were more missing response latency measurements for dyslexic children than for control children with 52% of the response latency measurements missing for low frequency long words in the dyslexic group, making meaningful analyses impossible.

Discussion

The observation that dyslexic children are able to retrieve the names of fewer pictures than either chronologically matched or reading-level matched control groups is well established in English and has also been found in other languages (Denkla, 1976; Faust, Dimitrovsky, & Shacht, 2003; Faust & Sharfstein-Friedman, 2003; Katz, 1986; Nation et al., 2001; Snowling, 1988; Swan & Goswami, 1997; Wolf & Goodglass, 1986). Drawing on interpretations of the types of errors children make on picture naming tasks and integrating these findings into the larger body of research on dyslexia, difficulties on picture naming tasks have been interpreted as providing support for the view that dyslexic children demonstrate specific deficits in either encoding or retrieving fully segmented phonological representations of words in their lexicon (Boada & Pennington, 2006; Elbro & Jensen, 2005; Snowling, 2000). However, this interpretation is inferential.

This study sought to provide direct evidence for the conclusion that the picture naming difficulties of dyslexic children are the result of difficulties retrieving accurate phonological representations by applying the Tip-of-the-Tongue paradigm to a picture naming task. A TOT experience is characterized by successful retrieval of semantic information about the target word, which is the first step in word retrieval, and a failure to retrieve the phonological representation of the target word necessary for articulating its name, the second step in word retrieval (Gollan & Brown, 2006; Levelt, 2001; Levelt et al., 1999). Thus, the TOT paradigm provides a means of directly localizing the picture naming difficulties of dyslexic readers. If the naming difficulties of dyslexic readers are indeed due to difficulties retrieving the phonological representation of the target word as has been inferred, then these difficulties should manifest as reports of more TOT experiences in the picture naming task. The TOT paradigm has only been employed with Hebrew speaking dyslexic children (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003); and so, this study sought to extend this research paradigm to English speaking children. Because the behavioral manifestations of dyslexia vary depending on the complexity of the orthography of the language (Ziegler & Goswami, 2005), extending this study to English will identify cognitive deficits that are common to dyslexia in different languages.

In general, the research literature on picture naming has ignored statistical problems presented by ceiling effects with the control group and violations of the assumptions of normality and homogeneity of variance necessary for analysis of variance (Nation et al., 2001; Swan & Goswami, 1997). Studies using the TOT paradigm have had similar issues (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003; Gollan & Brown, 2006). Correct naming of most of the stimuli is common for some word types and TOT experiences are relatively low frequency events especially in the control group. This presents challenges for standard statistical analyses because of floor effects for TOT experiences, ceiling effects for correct picture naming, and overall lack of variability. The only study that has applied the TOT paradigm to dyslexic children (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) used non-parametric statistical analyses because of significant group differences in variance. However, nonparametric statistical analyses also assume homogeneity of variance and are not appropriate when the assumption of homoscedasticity is violated (Kasuya, 2001). Additionally, Mann-

Whitney tests only test for the relationship between two variables. Thus, only the relationship between group membership and TOT experiences can be analyzed and interactions between group and stimulus type cannot be assessed in this type of analysis. In this study, parametric statistical analyses were employed using methods that have been developed specifically for analyzing low frequency count data (Cohen et al., 2003; Dunteman & Moon-Ho, 2006; Fox, 1997, 2002; Gardner, Mulvey, & Shaw, 1995; Hutchinson & Holtman, 2005). Poisson regression permits modeling of low frequency count data and analysis not only of significant main effects but also interactions between predictors.

Word retrieval experiences during a picture naming task. In this study, the children in the dyslexic and control groups did not differ significantly in their receptive vocabularies, suggesting that their word knowledge was comparably well developed. However, group was a significant predictor of tip-of-the-tongue experiences, with dyslexic children reporting significantly more tip-of-the-tongue experiences than control children. When children reported a TOT experience they were able to provide accurate semantic information about the word they were unable to name, indicating that the word was familiar, and the children were actively attempting to retrieve a specific word, but were unable to retrieve sufficient phonological information to generate the name. This finding provides direct evidence to support the view that underlying the picture naming deficits of dyslexic children is a specific difficulty retrieving phonological representations and extends the results found in Hebrew speaking dyslexic children (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) to English speaking dyslexic readers.

In addition to reporting more TOT experiences on picture naming tasks, the phonological representation model also makes more specific predictions. Dyslexic readers are expected to report more TOT experiences with words that are low frequency and less familiar and with phonologically complex long words if, as hypothesized, they have a specific difficulty with phonological representation. In this study, both groups of children reported more TOT experiences for long words and for low frequency words. In addition, the interaction between frequency and length was a significant predictor of TOT experiences, indicating that long and low frequency words presented an increased likelihood of reporting TOT experiences in both groups of children. The predictions that group would interact with both target word frequency and length and that the three-way interaction between the predictors would also be significant was not borne out.

Picture naming studies looking at picture naming directly without employing the TOT paradigm have reported interactions between group, word frequency, and length (Dietrich & Brady, 2001; Nation et al., 2001; Swan & Goswami, 1997). The only other study of picture naming using the TOT paradigm (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003) did not examine the influence of stimulus word characteristics. The absence of significant interactions between group, word frequency, and length in this study may have been due to lack of power, since TOT experiences were low frequency events. In addition, the stimuli in this study were selected because they could be easily represented visually and elicit a dominant response. The impetus for stimulus selection stemmed in part from one aim of the study, which was to measure naming latency. For naming latency measurements it was necessary to ensure that naming latency was not confounded by visual processing of complex pictures. In the Dietrich and Brady study (2001), the picture stimuli were presented in conjunction with a carrier semantic clue. This strategy permitted the use of a wider variety of stimuli and more varied word length (e.g. "*exterminator*" with the carrier sentence "a person who sprays chemicals to get rid of bugs"). Other stimuli were parts of more complex pictures (e.g., a *wick* as part of a larger picture of a candle), which would not have been appropriate for this study. It is possible that less concrete target words, or target words embedded in more complex visual stimuli, would have given rise to more reports of TOT experiences and, thus, increased the potential power to discriminate between dyslexic and control groups.

Another factor that may have contributed to the overall low number of reported TOT experiences is the level of metacognitive awareness of children at this age. Children in this age range may be less experienced at monitoring their memories and discerning precisely whether they are experiencing a TOT. They may have also wished to please the examiner by providing an answer. Thus it is possible that, at times, they may have been attempting to retrieve a specific word, but, rather than report a TOT, they may have named a semantic associate in their eagerness to provide an answer.

Dyslexic children were also predicted to retrieve fewer target words successfully than control children. This hypothesis stems in part from the structure of the experiment. The children did not differ in their receptive vocabularies, thus it was anticipated that they would not differ significantly in the number of target words that they did not know. Further, the sum of the number of TOT experiences, the number of words not known or not correctly named, plus the number of words correctly retrieved is equal to the total number of stimuli. Thus, if a dyslexic child reports more TOT experiences then, it follows, that fewer pictures will be named correctly.

However, in this study examination of the aggregate data revealed that the only significant predictors of successful word retrieval were word frequency and length. Group was not a significant predictor of correct word retrievals. The average number of words correctly retrieved by control children was greater than for dyslexic children, but this trend did not reach significance. It is likely that with greater power this trend would have reached significance.

Three factors influenced the power of this study. One was the sample size. The targeted sample size was 80 children, and indeed, this number of children participated in the study. However, recruitment rates were very low and many children who participated in the study were eliminated from the final sample because they failed to meet the eligibility criteria. Unfortunately, it was not possible to review records prior to soliciting participation and this lead to many children participating in the study who did not meet the strict inclusion criteria. A second way of increasing the power of the study would have been to increase the strength of the manipulation. It is possible that using more complex words would have increased the discrimination between the two groups. Finally, the power could have been increased by decreasing the error variance. One way that this might have been done would have been to narrow the age range of children in the sample; however, given the difficulties recruiting participants this was not a feasible approach.

As the final part of the first hypothesis, group was not anticipated to be a significant predictor of naming failures. This finding was expected because the two groups did not differ significantly in receptive vocabulary. And, as expected, group was not a significant predictor of naming failures. Few stimuli were completely unfamiliar to the children even when children reported not knowing the name during the picture naming task. The stimuli were chosen to be familiar to children in the age range of the study. And although some stimuli may not have been in the children's expressive vocabularies, most stimuli appeared to be familiar to the children and thus recognizable on the receptive vocabulary task. While expected, and confirmed, it must be noted that this is the null hypothesis, with a small sample, so conclusions about the meaning of the lack of significant findings are, of course, purely speculative and without statistical justification.

Resolution of tip-of-the-tongue experiences. The second hypothesis predicted that, when children were provided the opportunity to resolve a TOT experience in a forced-choice recognition task, dyslexic children would make more phonological errors than control children. Dyslexic children were predicted to have difficulty discriminating between the target word and similar sounding word and nonword phonological foils. However, the results indicated that group was not a significant predictor of phonological confusion on the recognition task to resolve TOT experiences. The only predictor of phonological errors was word frequency. Thus, all children were more likely to choose a phonological foil when attempting to recover from a TOT experience induced by a low frequency, less familiar word.

In general, the frequency of TOT experiences was low in both dyslexic and control children, and compounding this low rate of TOT experiences, incorrect responses on the recognition task to resolve the TOT experience were infrequent. Thus, the level of discrimination was low and there was little power to observe differences in this part of the study. All children appeared largely able to discriminate accurately the correct name of the target from the foils when the words were spoken. This suggests that the phonological representations encoded by dyslexic children are not significantly distorted. For both groups of children, the phonological representation that was elusive and causing a tip-of-the-tongue experience was, in most cases, sufficiently well specified to permit identification of the correct target word from the foils on the recognition task. However, in general, phonological representations appear to be less well specified, and thus more likely to result in errors on the recognition task, when the target word is low frequency and, accordingly, less often encountered. These results suggest that children's phonological representations become more fine-grained with repeated exposures to words (Ziegler & Goswami, 2005).

The results of this study support the view that dyslexic children's word retrieval difficulties are restricted to situations in which they are attempting to generate, rather than recognize, a response. Nevertheless, it should be stressed that failure to find differences between the dyslexic and control children on the recognition task does not prove that no differences exist. To be able to assert that dyslexic children do not experience more phonological confusability during recovery from a TOT experience, this study needs to be replicated with more power. As described previously, power could be increased by increasing the sample size or by decreasing the error variance by, for example, studying children in a narrower age range. Power could also be increased by strengthening the experimental manipulation by using more complex words to elicit more TOT experiences. Finally, more complex target words would have provided the opportunity to generate foils with more subtle differences, which would have increased the discrimination of the test.

The finding of no differences between the control and dyslexic children in phonological confusability during recovering from a tip-of-the-tongue experience contrasts with the findings of the study in Hebrew, where dyslexic children made more phonological errors on the recognition task than control children (Faust et al., 2003; Faust & Sharfstein-Friedman, 2003). In their study with younger children, the frequency of TOT experiences was quite high. Twenty percent of the control children's picture naming responses were TOT experiences and one third of the dyslexic children's responses were reports of TOT experiences. These high reports of TOT experiences were found even though the target words were selected as familiar to children in the age range of the study. Nevertheless, the mean number of phonologically related nonword or word errors during the recognition task was very low (0.03 and 0.00 respectively for the control children and 0.09 and 0.01 respectively for the dyslexic children). The authors report that there were significant rank differences between the groups based on a Mann-Whitney test; however, it was not possible to ascertain whether these findings were based on group differences in mean errors or rankings of the aggregate data.

Examining TOT findings from perspective of word retrieval theory. In the third part of this study, children's TOT experiences were evaluated from the perspective of theoretical models of word retrieval. Linguistic theories of word retrieval differ in specific details but are in basic agreement that word retrieval occurs in two broad steps. The first step is activation of a meaning-based or semantic representation of the word. The second step is the activation and retrieval of the sound-based phonological representation of the word. Tip-of-the-tongue experiences have generally been assumed to reflect word retrieval failures. However, when examined through the lens of linguistic models of word retrieval, TOT experiences are regarded as partial successes in word retrieval.

Successes in retrieval of the meaning-based or semantic representation of the target word are reflected by both correct naming of the target, *got*, and reports of tip-of-the-tongue experiences, *tot*. A TOT reflects success at step one because when a TOT is reported children are required to provide semantic information related to the specific target word. Thus, the sum of correct retrievals and TOT experiences reflects the total number of successful retrievals of semantic meaning of the target words. Failures in retrieval of semantic information may be due to lack of familiarity with the word (don't know) or difficulties accessing the meaning of a familiar word (not got) at the time.

In this study, dyslexic and control children were predicted not to differ in the percent of word retrieval failures at step 1. This prediction was based in part on the experimental design which explored TOT experiences in relatively young readers between the age of eight and ten years. Older dyslexic children often demonstrate less well developed vocabularies than their normally developing peers, which has been attributed to the fact that dyslexic children tend to read less and encounter fewer words in print (Shaywitz, 2003). Younger beginning readers have not read as much and their vocabulary development is more related to oral exposure than written. Consequently, younger dyslexic and control readers would be less likely to differ significantly in vocabulary development. In this study, as predicted, the dyslexic and control groups did not differ significantly in receptive vocabulary. In addition, as hypothesized, group was not a significant predictor of failures to retrieve semantic information about the target word, suggesting that both groups did not differ in both receptive vocabulary knowledge and expressive semantic word knowledge. Of course, this hypothesis is a confirmation of the null hypothesis, but it is nevertheless important, for it is the first of a sequence of predicted outcomes, the second being that at step 2, there would be significant group differences.

Word length and word frequency were significant predictors of word retrieval failures at step 1. In addition, the interaction between word frequency and length predicted failures at step 1. It is not surprising that children would find it difficult to retrieve semantic information about less frequently encountered words, and thus, would report fewer TOT experiences or correctly name fewer low frequency words. However, it is less clear why word length would be related to failures at step 1, since semantic representations are not related to word length.

The phonological representation hypothesis posits that dyslexic children have a specific problem with phonological representation and thus would be expected to experience a higher percentage of word retrieval failures at step 2. This hypothesis was supported; group was a significant predictor of the percentage of word retrieval failures at step 2. A distinct advantage of examining the proportion of word retrieval failures at each step in word retrieval, rather than raw counts of TOT experiences, is that this method permits a more precise control of individual differences in vocabulary development. In this study the children did not differ significantly in receptive vocabulary development as measured by the PVVT-III. However, receptive vocabulary, although strongly correlated with expressive vocabulary, is not the same. By examining the proportion of word retrieval failures at each step, this study provided evidence that the children did not differ in their ability to access semantic information about the target words; however, when individual differences in access to semantic information were controlled, dyslexic children demonstrated a specific deficit in the second step in word retrieval, recall of phonological information. Thus, when examining TOT experiences from the perspective of current models of word retrieval, dyslexic children demonstrate a specific deficit in the retrieval of phonological representations. This finding provides direct evidence that dyslexic children demonstrate a specific deficit in phonological representation and supports many previous findings examining dyslexic children's word retrieval using picture naming in which conclusions regarding deficits in phonological representation were inferential (Fowler & Swainson, 2004; Katz, 1986; Nation, 2005; Snowling et al., 1988; Swan & Goswami, 1997).

Not surprisingly, both groups of children experienced a higher proportion of failures to retrieve phonological information for low frequency, less commonly encountered words and for long, phonologically complex words. Although it was predicted that dyslexic children would have experience a higher proportion of failures at step 2 compared to control children with low frequency and long words, these interactions were not significant. However, both groups of children demonstrated the highest proportion of word retrieval failures at step 2 with low frequency, long words. It is possible that the study did not have adequate power to find significant interactions between group and word type.

Phonological representation and naming latency. The goal of the fourth hypothesis was to examine whether deficits in phonological representation are apparent even when word retrieval is successful. It was hypothesized that, in addition to difficulties in word retrieval that result in tip-of-the-tongue experiences, retrieval of phonological information would be effortful and slow even in instances when word retrieval is successful. Thus, dyslexic children were hypothesized to demonstrate longer naming latencies. In addition, it was proposed that dyslexic children's naming latencies would be relatively more delayed when naming objects with long names or infrequently encountered names. However, due to methodological difficulties with data collection over half of the reaction time data was not recovered and, as a result, the data could not be meaningfully analyzed.

Several factors contributed to missing reaction time data. The primary factor was that the recording conditions were not idea. The examiner traveled to participants' homes to conduct the study, and, as a result, the testing conditions varied considerably from one participant to the next and the amount of background noise was variable. The rational for travelling to the participants' homes was to make participation as easy as possible and to increase recruitment rates, which were very low. Ideally, children would be tested in a distraction-free, soundproof room. Under these conditions it would likely not have been as difficult to adjust the sensitivity of the detection hardware from one child to the next to optimize signal detection. In addition, if children were brought to a central testing location, they could have spoke into a large fixed microphone rather than the adjustable microphone affixed to a headset that was used. A number of children were uncomfortable wearing the headset and readjusted it frequently during the administration. In addition, some children moved the microphone or frequently touched the microphone during administration. These problems resulted in the orientation of the microphone changing during the picture naming administration and many signal detection failures and extraneous reaction time measurements.

The presentation software was programmed so that children saw a symbol appear on the computer screen when their response was recorded by the reaction time hardware. The same symbol appeared if a reaction time was recorded in error due to extraneous noise or movement, which permitted the examiner to monitor the data collection and attempt to adjust the sensitivity of the reaction time measurement hardware if necessary. Many children responded to the visual symbol and would speak louder if they noticed their responses were not being recorded. However, some very soft spoken children did not attempt to speak more loudly when the visual symbol did not appear. These children might have responded to a more reinforcing visual signal.

Another problem that contributed to missing data was that each time a child reported a TOT experience or provided an incorrect response, the experiment was paused and the experimenter either probed for another response or asked for semantic information about the target word. Immediately following these responses, the recognition task was administered. During these tasks children engaged in conversation with the examiner and invariably reoriented to speak with the examiner and view the card with the recognition task target word and foils. Frequently, the reaction time detection equipment failed to register the reaction time for the target word immediately following administration of the recognition task. To prevent data loss from children frequently reorienting from the examiner to the computer display, children would ideally be tested over two sessions. The first session would be devoted exclusively to reaction time measurement and the concept of tip-of-the-tongue experiences would not be introduced. Children would not be prompted to provide an alternate response when the target is named incorrectly. The instructions would be to name the target as quickly as possible and to advance to the next stimulus if the target name is not known. In the second session, children would be introduced to the concept of tip-of-the-tongue experiences, encouraged to avoid guessing when uncertain, take their time, and be as accurate as possible. This method would have resulted in more accurate reaction time measurements with less missing data. In addition, if guessing were explicitly discouraged, it is possible that children would have more carefully monitored their recall and reported more TOT experiences.

This study provided partial support for the phonological representation hypothesis, which posits that dyslexic children demonstrate a core deficit in phonological representation. Stemming from this conceptualization are predictions that dyslexic children should demonstrate text independent deficits in the retrieval of familiar words in their expressive vocabulary. Furthermore, these deficits should be localized to the second broad step in word retrieval, the retrieval of the phonological representation necessary to direct articulation of the spoken word. Dyslexic children reported more tip-of-the-tongue experiences than control children, and when tip-of-the-tongue experiences were examined from the perspective of theoretical models of word retrieval, this finding was confirmed. Dyslexic children demonstrated a specific deficit in the retrieval of phonological information for target words compared to their peers. As expected, there were no differences between the two groups in the retrieval of semantic information for target words. Thus, this study adds to the extensive literature reporting word retrieval deficits in children with dyslexia, but extends this area by providing direct evidence that dyslexic children demonstrate a specific deficit in the retrieval of phonological information.

This is the first study to employ the tip-of-the-tongue paradigm to examine word retrieval in English speaking dyslexic children. Previously, studies with Hebrew speaking children and adolescents also reported that dyslexic children reported more tip-of-the-tongue experiences. However, the Hebrew studies and all of the previous research looking broadly at dyslexic readers' deficits in picture naming ignored statistical problems with ceiling effects and violations of assumptions of the statistical tests employed. The current study was the first to employ statistics specifically developed for modeling count data of infrequent events.

In addition to the major hypotheses that dyslexic children will report more tip-of-the-tongue experiences and a greater percentage of word retrieval failures at the second step in word retrieval, several additional predictions stem from the phonological representation hypothesis. Firstly, dyslexic children are predicted to report more tip-of-the-tongue experiences when attempting to retrieve the names of objects that are long and phonologically complex or are less familiar. And although, both groups of children in this study found phonologically complex and less familiar words more difficult to retrieve, support for the predicted interaction between group and word type was not supported. However, the data trends were in this direction and the study lacked power because many children who participated in the study were eliminated from the final sample because they did not meet the specific eligibility requirements. Thus, future studies should address this question with a larger sample. In addition, methods for increasing target word complexity, which were discussed previously, would also increase the power of this analysis.

A second major prediction stemming from the phonological representation hypothesis is that the word naming difficulties of dyslexic should generalize to words that can be named. It was expected that dyslexic children would demonstrate longer naming latencies, and furthermore, longer naming latencies would be more pronounced with long phonologically complex words and with low frequency words. Unfortunately, this hypothesis could not be tested in this study because there was too much missing data due to technical difficulties. Future studies should explore whether naming difficulties are manifested as longer naming latencies generally, and whether naming latencies are correlated with word retrieval failures at the second step.

One of the limitations of this study was the lack of representativeness of the sample. Only a fraction of the children who were recruited for the study participated. Thus, the dyslexic group was a small self-selected group of students who may not be representative of children with dyslexia in general. The control group was a convenience sample recruited through parent contacts in the community and thus was also not a representative cross-section of normally developing children. In general, both the dyslexic and control groups came from families with high socio-economic status. In addition, both groups did not reflect the diversity of children from different ethnic and cultural backgrounds found in the population. Moreover, boys were overrepresented in both the dyslexic and control groups. Finally, the receptive vocabulary of the children in both groups was much better developed than the children in the normative sample of the PPVT-III; the mean score for all children in the study was over one standard deviation above the mean. In the future it will be important to explore whether the findings in this study extend to a more representative sample with a matched control group.

Learning disability theory predicts that dyslexia should be found in all languages and writing systems. Although dyslexia has been found in all languages, the behavioral features vary from language to language and appear to depend to large degree on the consistency and regularity of the spoken language and writing system. One of the major contributions of this study was that it explored the text independent cognitive deficits in phonological representation that are likely core to dyslexic readers' difficulties. To date, underlying deficits in phonological representation have been demonstrated in English and Hebrew and it will be important to determine whether these findings generalize to other languages, in particular more regular and transparent languages such as Spanish or Italian, for which the primary behavioral manifestations of dyslexia are laboriously slow reading and sequential phonological decoding of complex words.

In addition to predictions of universality, learning disability theory predicts that the cognitive deficits associated with dyslexia should also be persistent. Thus, older dyslexic readers should report more tip-of-the-tongue experiences than their peers and experience a larger percentage of word retrieval failures at the second step, accessing the phonological representation of the target word. Future studies should address the generalizability of the findings of this study to older children and adults.

Finally, there is strong agreement in the reading research community that individuals who exhibit a discrepancy between their cognitive ability and word reading skill are dyslexic. However, some researchers argue that the discrepancy definition of reading disability misses individuals who demonstrate poor decoding ability in the context of overall lower cognitive ability and argue that if the cognitive deficits associated with dyslexia are specific then there is no a priori rationale for linking poor decoding with higher overall cognitive skills. This research model provides a means of exploring whether both children with and without discrepancies in their cognitive abilities and word and pseudoword reading demonstrate comparable deficits in retrieval of phonological information.

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Table 1

Poisson regression model for tip-of-the-tongue experiences

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.000	0.088	0.001	0.999	
grp	0.343	0.150	2.285	0.022	*
length	0.530	0.125	4.242	0.000	***
freq	1.920	0.125	15.362	< 2e-16	***
grp:length	0.066	0.212	0.311	0.756	
grp:freq	0.038	0.212	0.178	0.859	
length:freq	-0.381	0.177	-2.158	0.031	*
grp:length:freq	0.085	0.300	0.284	0.777	

Significance codes: *** p < .001; **, $p < .01$; *, $p < .05$

Table 2

Poisson regression model for total words not named

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.250	0.088	2.828	0.005	**
grp	0.235	0.150	1.567	0.117	
length	0.781	0.125	6.246	0.000	***
freq	2.219	0.125	17.748	< 2e-16	***
grp:length	0.189	0.212	0.892	0.372	
grp:freq	0.114	0.212	0.539	0.590	
length:freq	-0.539	0.177	-3.051	0.002	**
grp:length:freq	0.077	0.300	0.256	0.798	

Significance codes: *** p < .001; **, *p* < .01; *, *p* < .05

Table 3

Poisson regression model for words incorrectly named or not known

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.250	0.088	2.828	0.005	**
grp	0.093	0.150	0.620	0.535	
length	0.457	0.125	3.657	0.000	***
freq	1.281	0.125	10.247	< 2e-16	***
grp:length	-0.258	0.212	-1.215	0.224	
grp:freq	0.021	0.212	0.099	0.921	
length:freq	-0.238	0.177	-1.347	0.178	
grp:length:freq	0.466	0.300	1.553	0.121	

Significance codes: *** p < .001; **, *p* < .01; *, *p* < .05

Table 4

Poisson regression model for phonological errors

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.000	0.000	0.000	1	
grp	0.000	0.154	0.000	1.000	
length	0.000	0.127	0.000	1.000	
freq	0.596	0.127	4.690	0.000	***
grp:length	0.000	0.218	0.000	1.000	
grp:freq	0.234	0.218	1.073	0.283	
length:freq	-0.057	0.180	-0.317	0.752	
grp:length:freq	-0.111	0.308	-0.360	0.719	

Significance codes: *** p < .001; **, *p* < .01; *, *p* < .05

Table 5

Poisson regression model for percentage of errors at step 1

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.433	0.088	4.899	0.000	**
grp	0.161	0.150	1.073	0.283	
length	1.098	0.125	8.783	< 2e-16	***
freq	2.165	0.125	17.321	< 2e-16	***
grp:length	0.233	0.212	1.098	0.272	
grp:freq	-0.015	0.212	-0.072	0.943	
length:freq	-0.754	0.177	-4.264	0.000	***
grp:length:freq	0.194	0.300	0.645	0.519	

Significance codes: *** p < .001; **, *p* < .01; *, *p* < .05

Table 6

Poisson regression model for percentage of errors at step 2

Predictor	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*	*Signif*
(Intercept)	0.000	0.088	0.002	0.999	
grp	0.594	0.150	3.958	0.000	***
length	0.918	0.125	7.347	0.000	***
freq	3.359	0.125	26.869	< 2e-16	***
grp:length	0.150	0.212	0.708	0.479	
grp:freq	0.069	0.212	0.327	0.744	
length:freq	-0.594	0.177	-3.363	0.001	***
grp:length:freq	0.306	0.300	1.019	0.308	

Significance codes: *** p < .001; **, *p* < .01; *, *p* < .05

Figure 1

Distribution of count of tip-of-the-tongue experiences, tot

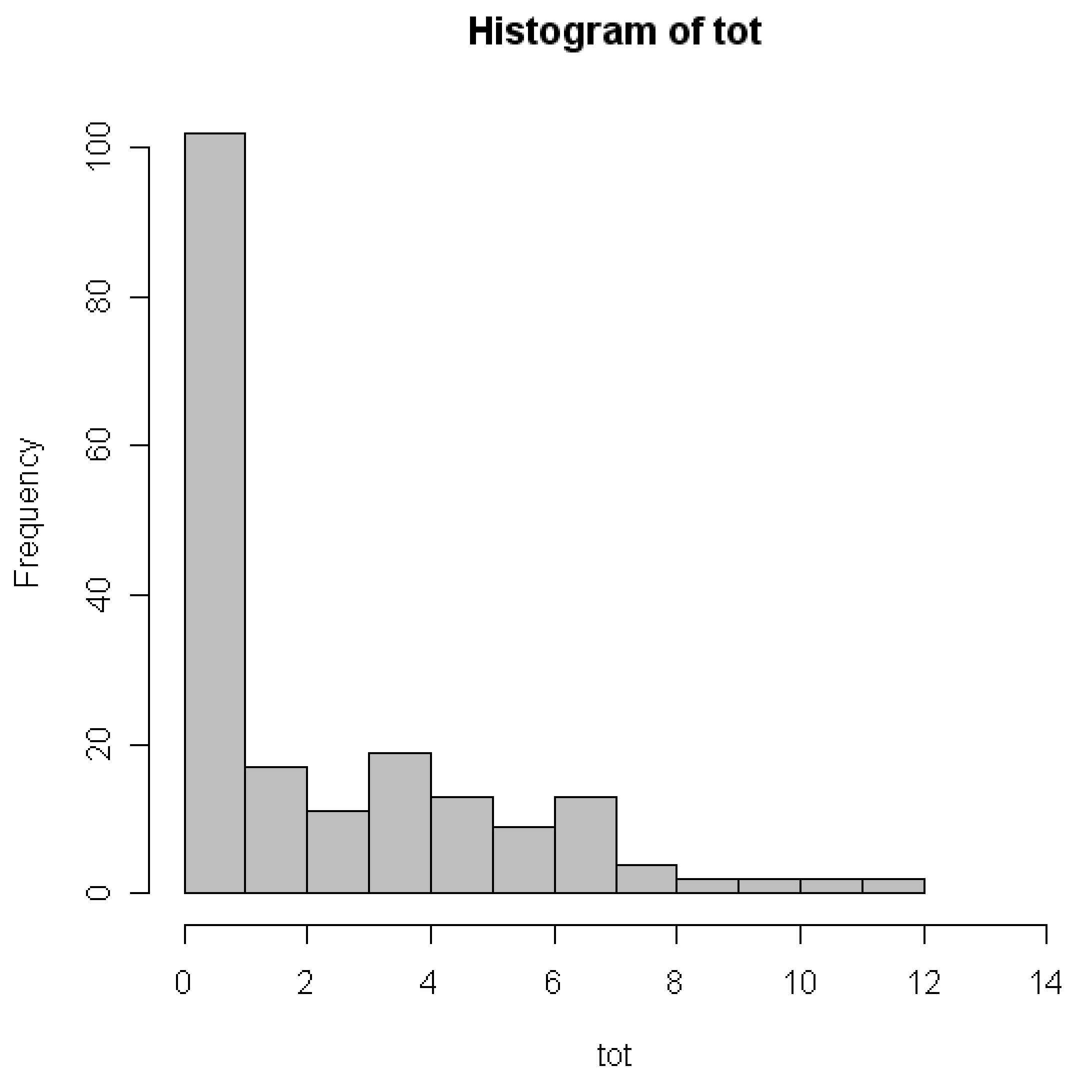


Figure 2

Distribution of count of total words not named, rgot

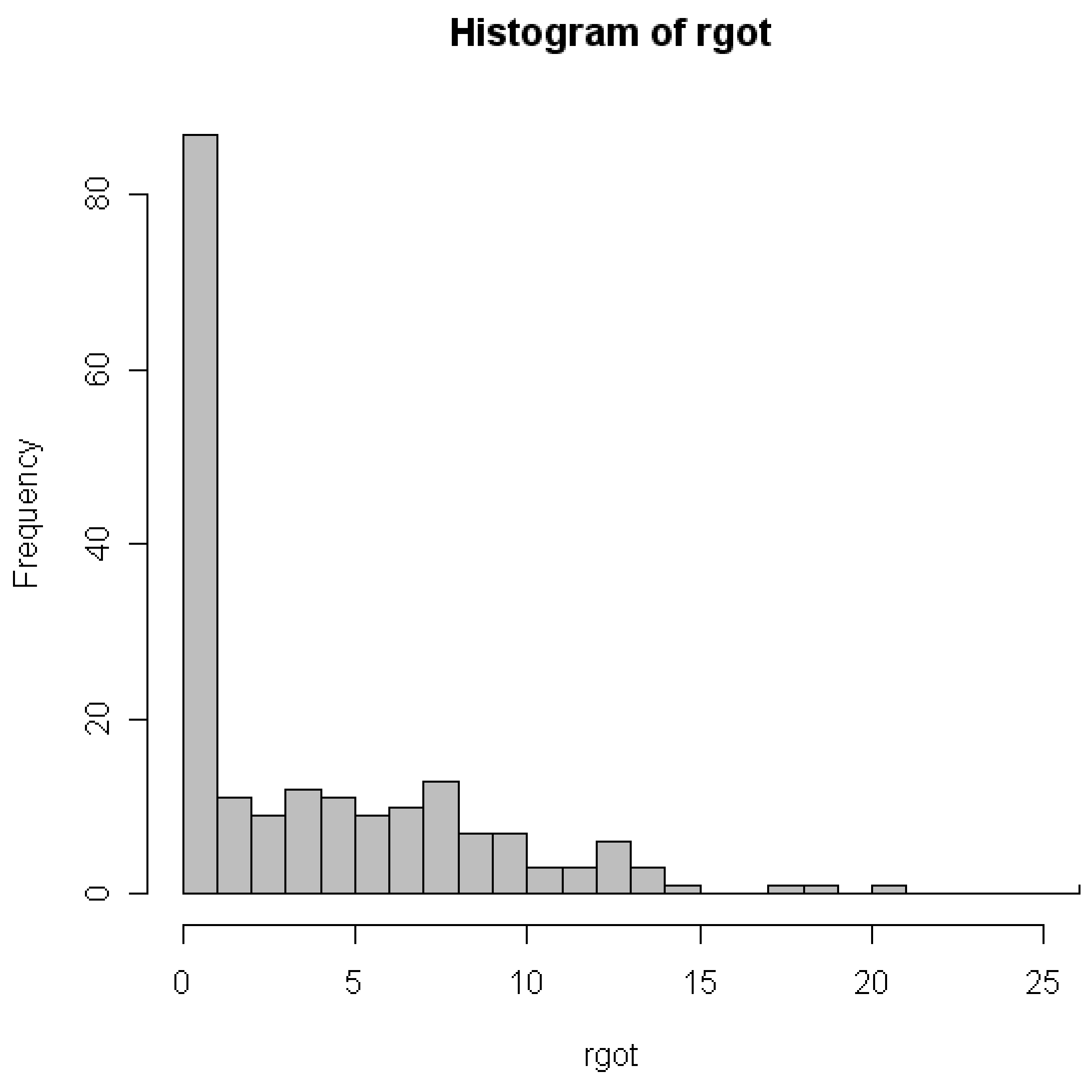


Figure 3

Distribution of count of words incorrectly named or not known, ngpdk

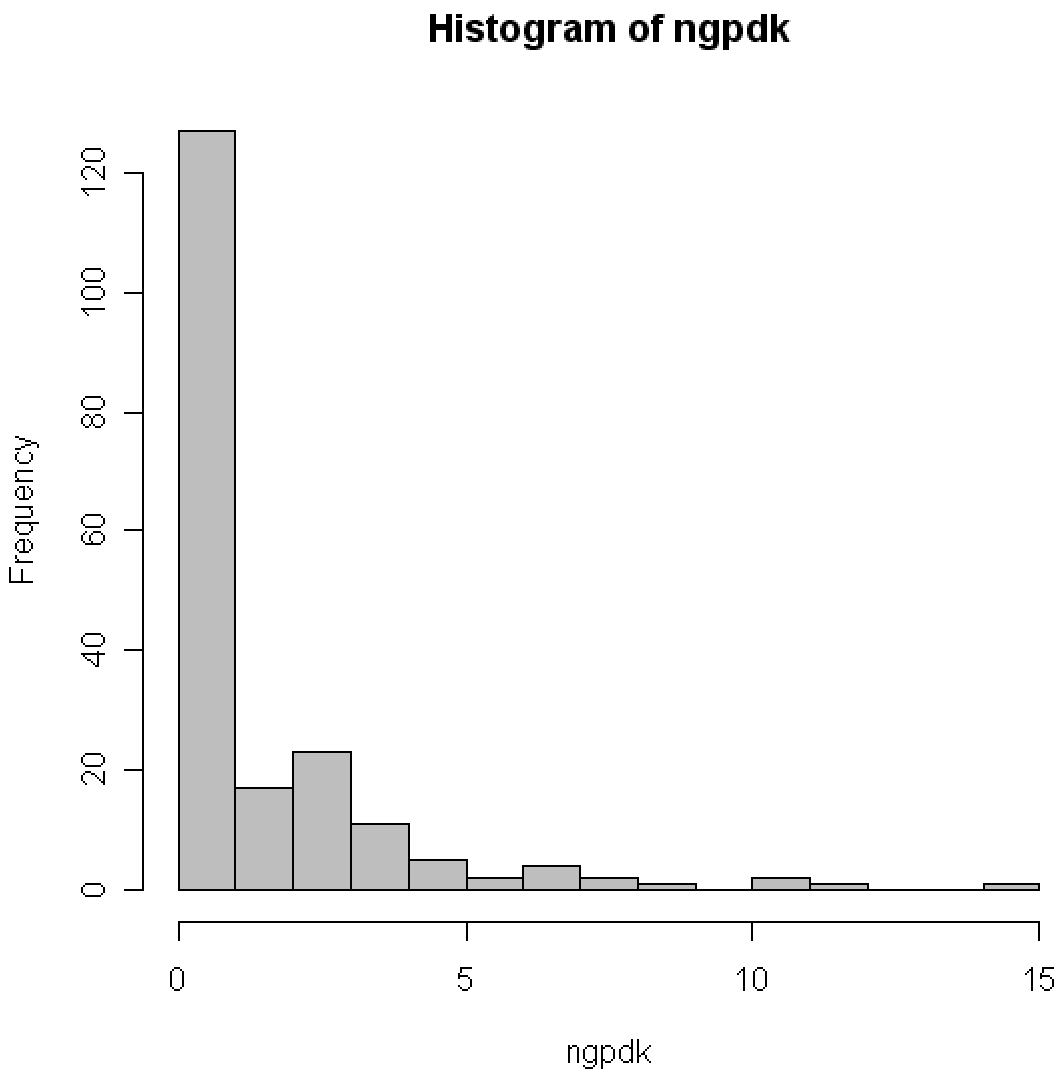
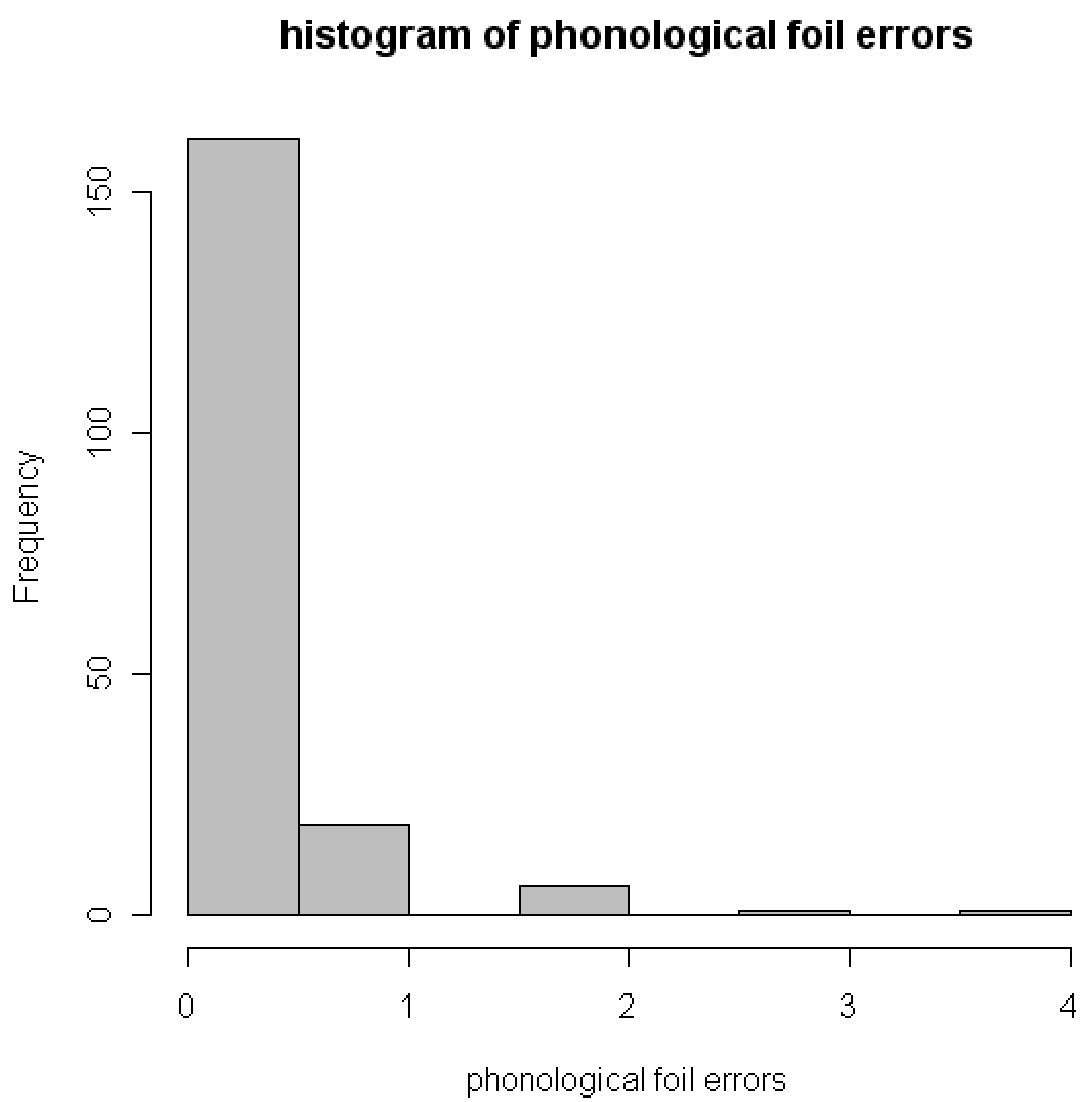


Figure 4

Distribution of count of phonological errors



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