NOVEL SPOKEN WORD LEARNING IN

ADULTS WITH DEVELOPMENTAL DYSLEXIA

by

PEGGY S. CONNER

A dissertation submitted to the Graduate Faculty in Speech-Language-Hearing Sciences
in partial fulfillment of the requirements for the degree of Doctor of Philosophy,
The City University of New York

2013

This manuscript has been read and accepted for the
Graduate Faculty in Speech-Language-Hearing Sciences in satisfaction of the
dissertation requirement for the degree of Doctor of Philosophy.

Loraine K. Obler, Ph.D.

Date	Chair of Examining Committee
	Klara Marton, Ph.D.
Date	Executive Officer Member of Examining Committee
	Martin Chodorow, Ph.D. Member of Examining Committee
	David Share, Ph.D. External Reviewer

THE CITY UNIVERSITY OF NEW YORK

Abstract

NOVEL SPOKEN WORD LEARNING IN

ADULTS WITH DEVELOPMENTAL DYSLEXIA

by

Peggy S. Conner

Adviser: Professor Loraine K. Obler

A high percentage of individuals with dyslexia struggle to learn unfamiliar spoken words, creating a significant obstacle to foreign language learning after early childhood. The origin of spoken-word learning difficulties in this population, generally thought to be related to the underlying literacy deficit, is not well defined (e.g., Di Betta & Romani, 2006; Jakoby, 2010, 2011). Although it is widely accepted that dyslexia is characterized by a core deficit in phonological processing, considerable debate remains regarding the etiology of this deficit and how it hinders reading and writing development. This study investigates two prominent hypotheses about why people with dyslexia struggle with learning to read and write and examines how these may explain spoken-word learning difficulties. These hypotheses are the *phonological representations hypothesis* that proposes poorly specified phonological representations can largely account for the literacy difficulties experienced by people with dyslexia, and the *perceptual anchoring deficit hypothesis* that suggests these challenges stem from a reduced ability to implicitly benefit from repetitions of phonological information.

Thirty-nine individuals, 16 with and 23 without dyslexia were given novel spoken words paired with pictures of novel objects in a story format. The relative contribution of the participants' phonological knowledge (sublexical and lexical representations) and perceptual anchoring (the ability to benefit from stimulus-specific repetitions) to this novel word-learning task was measured by two aspects of a production task. The independent variables of the phonological properties of the word forms and the effects of repetitions over test time informed us about phonological knowledge and perceptual anchoring respectively. The participants' novel word productions in a picture-naming task served as the dependent variable. By measuring the participants' progress in learning words, we quantified the potential benefit provided both by the speech-sound characteristics and by repetitions of the novel words over test time.

The results suggested that deficits in phonological knowledge and perceptual anchoring make independent contributions to novel spoken-word learning and that a combination of deficits in the two areas contribute to word-learning difficulties in learners with dyslexia. The single best predictor for both groups was a task of phonological awareness, phoneme reversal. Apart from this task, a measure of verbal recall of real words appeared to be a better predictor for typical learners whereas a measure of spelling had greater predictor value for the learners with dyslexia. Spoken-word learning as a dynamic interaction of implicit and explicit memory processes is presented and discussed.

Dedication

This dissertation is dedicated to my amazing husband, Marcelo, whose support, love and incredible patience merits beatification and to my four beautiful sons who have endured years of competition for my attention from my computer. Nicolas, you've inspired me with your perseverance and dedication to excellence and love of music. Daniel, thank you for being the catalyst to resume my doctoral studies and for your ability to raise my spirits and make me laugh. David, you taught me that I can learn anything if I try things step by step and not take myself too seriously. Eric, who shares my love of words, you kept the faith, worked alongside me, and helped me take much needed breaks. Marcelo, my rock, this is as much yours as it is mine. Your gift to me of so much time and your faith that I'd find my way to the last key stroke took tremendous courage. I dedicate this dissertation to you, my family.

In honor of my mother, Marcia Conner, who blessed me with my love of teaching and my joy of the English language. In loving memory of my father, Ben Conner, who never stopped encouraging me to finish my doctorate.

Acknowledgments

The breadth of support I have received from friends, family and colleagues has been a huge source of inspiration and sustained me during my studies and the development of this dissertation. Foremost I'd like to thank my advisor, Loraine Obler, who works tirelessly for her students and models all that she expects from us. You challenged me to reach for my best and trusted that I would do just that and I am immensely grateful for your guidance and outstanding leadership in research, in teaching, and in the joy of learning. My committee members have been generous with their time and insightful comments. Klara Marton offered me her expertise in memory and language and I have appreciated her suggestions and constructive feedback throughout the project development and on drafts of the manuscript. Martin Chodorow gave each draft a careful read and pinpointed key revisions needed in my data analyses. Thank you for the many meetings and for posing thoughtful questions to help me integrate my results with existing theory. I would like to extend my gratitude to my outside reader, David Share, for giving his time and offering valuable feedback and comments.

In addition to my committee, I must thank several individuals who gave me critical support in the development of my methodology and materials and in the latter stages of data analyses. Susan DeSanti was instrumental in helping me to conceptualize the experimental task. Holly Storkel generously provided the pictures and stimuli from her previous research studies that I was then able to adapt for this project. Mona Conner, my sister, guided me in revising and creating illustrations for the word learning task. The stimuli and software program for the perceptual anchoring task was given to me by Merav Ahissar who also shared her insights on the theoretical basis of perceptual anchoring. Paul Luce presented me with a database of

calculations of phonotactic probability and neighborhood density for 5,000 nonwords from which I selected my stimuli. Christine Rota-Donahue, Teresa Signorelli and Michelle MacRoy also shared their experiences and expertise during project development. I would like to recognize the late James Jenkins for his help with planning the analyses. Gary Chant and Glenis Long dedicated time to early versions of two of my experimental tasks. I'd like to thank Rita El-Haddad for her assistance with recruiting. I have been blessed with four excellent research assistants who each contributed to a different stage of this project, Yuk Lan Peng, Margaret Parosa, Eli Lazar and Elana Rosen. I am very grateful to Luca Campanelli who rescued me from statistical limbo and advised me on logistic regression and model analysis in r.

I extend sincere gratitude to Mira Goral, an outstanding mentor and researcher for her support and guidance over the years. JungMoon Hyun has been a constant source of inspiration and encouragement and much needed good humor. Kate Dawson, Catharine Castelluccio, Barbara O'Connor, Anthea Vivona, Marie-Michelle Monéreau-Merry, and Susan Gray all offered their time with various aspects of the project including recruitment and inter-rater reliability. The members of the neurolinguistics lab have come and gone and I have benefited from them all. In addition to those I've mentioned I'd like to acknowledge Inge Anema, Amy Vogel, Jungmee Yoon, Youngmi Park, Jungna Kim, Sameer Ashaie, Eve Higby, Avanthi Niranjan and Jet Vonk who have offered their time, comments and suggestions.

To my family and friends, this project's completion is due in large part to all the ways you have supported me. To Amy Gaddes, Cristina Morris, Sarah Rowen and of course Erlise St. Louis, I offer my deepest gratitude. And to my extended family, Olivia and Ricardo, Kit, Kathy, Mona, Miriam, Sergio, Amalia, Oscar, Carmen, David, and Hilda...no hay palabras.

TABLE OF CONTENTS

Page

List of Tables

List of Figures

List of Appendices

Chapter 1: Literature Review

1.1 Introduction:

Learning new words is fundamental to communication. By the age of two, the average child's expressive vocabulary is around 300 words. By 18, that number has burgeoned to 60,000 (Fenson et al., 1993). Vocabulary knowledge continues to grow into mature adulthood, influenced by our evolving language and our changing needs and environment. New words are added to our existing lexicon often after only one or two exposures, spoken (Carey & Bartlett, 1978; Dickinson, 1984; Heibeck & Markman, 1987) or written (Nagy, Herman & Anderson, 1985).

However, individuals with developmental dyslexia have difficulty learning new words that they hear, requiring repeated exposure significantly beyond that of typical learners (Di Betta & Romani, 2006; Mayringer & Wimmer, 2000; Messbauer & DeJong, 2003). This limitation is puzzling given that many people with dyslexia (hereafter 'learners with dyslexia' - LWD) do not have overt speech or verbal language difficulties and appear to acquire their native language or multiple languages with ease when exposed to them in early childhood (e.g., Bishop & Snowling, 2004; Joanisse, Manis, Keating & Seidenberg, 2000). However, in addition to a slower acquisition of unfamiliar words in their native language, school-age children and adults with dyslexia often have inordinate difficulty with foreign language learning (e.g., Crombie, M.A., 1997, 2000; Di Betta & Romani, 2006; Ganschow, et al. 1991; Helland & Kaasa, 2005). Recent evidence confirms the association between the nature of these spoken-word learning difficulties and the challenges LWD face in learning to read (Di Betta & Romani, 2006;

Warmington, 2008).

Children with dyslexia have reading difficulties in accurate and fluent word recognition, decoding of new words, and spelling, despite reading instruction that is effective for most learners[1]. Their reading impairment occurs in the presence of normal vision and hearing, average or above average intelligence, and if speech production difficulties occur, they are typically subtle; (e.g., developmental problems with pronunciation of multisyllabic words such as "aluminum" or "parallelogram" are common in children with dyslexia). By adulthood, through years of instruction and practice, many individuals learn to compensate for their reading difficulties, yet subtle or sometimes obvious deficits remain (i.e., slow reading rate, weak phonological awareness skills, reduced rapid naming ability: Felton, Naylor, & Wood, 1990; Gregg, Hoy, Flaherty, Norris, Coleman, Davis, M., & Jordan, M., 2005; Hatcher, Snowling, & Griffiths, 2002; Holmes & Castle, 2001; Milne, Nicholson & Corbalis, 2003).

The process of learning new spoken words is dependent upon our ability to recognize the speech sounds in words and temporarily hold them in memory as we form a perceptual referent, which we eventually secure in long-term storage. Our lexical and sublexical representations that developed as we acquired our native language(s) support learning and retention. Foreign language learning requires that we attune to the sound system of the language and establish new underlying phonemic representations in our mental lexicon. Deficits in phonological processing and working memory have been well documented in students with dyslexia and are thought to thwart long-term retention and therefore acquisition of novel spoken words, particularly those of a foreign language (e.g., Mayringer & Wimmer, 2000; Di Betta & Romani, 2006).

[1] From the formal definition adopted by the International Dyslexia Association in 2002, used also by the National Institute of Child Health and Human Development (NICHD)

Many theories of spoken-word learning for native and non-native words indicate possible routes to successful long-term retention; however, the complexity of the process and its neurological underpinnings has resisted delineation (e.g., Davis, Di Betta, Macdonald & Gaskell, 2009; Davis & Gaskell, 2009; McMurray, Horst & Samuelson, 2012; Shtyrov, 2012). Obviously, knowledge of a word includes not just the phonological sequence of sounds but encompasses the word's semantic, morphological and syntactic properties as well. Nevertheless, a hallmark of dyslexia is difficulty with phonological processing, which at its roots may not only complicate learning to read and spell but also appears to hinder the learning of spoken novel words; thus, the phonological features of word learning have been emphasized in the current study.

1.2 Phonological Processing in Typical Learners

Speech perception is the first step in word acquisition. The acoustic analysis begins in the auditory cortex. Sounds are processed sequentially in rapid temporal succession. Aspects of auditory stimuli have both steady state and changing characteristics that place different demands on auditory processing and memory, and thus have implications for how we process nonspeech and speech sounds (Scott, 2005). Yet the process of perceiving speech is much more than a summation of the speech sounds or phonemes in a given sequential order. In speech production, coarticulation causes neighboring speech sounds and segments to become more like each other, i.e., to assimilate, rendering a variety of phonetic variations for each phoneme, known as allophones. Infants are instinctually predisposed to respond to certain phonetic categories that are then reinforced through exposure to the phonology of the language(s) in their environment. Babies are charged with extracting, from this stream of allophonic variation, the phonemes that provide meaningful contrast in their language(s). Gradually as they acquire words and build their vocabulary, they automatically compare the phonetic detail of what they hear to prior speech

input, thus integrating a word's phonological form and its meaning into their growing lexical knowledge base.

As children build their vocabulary knowledge, successful spoken-word recognition necessitates the discrimination of a given word from similar sounding words, or lexical neighbors. As the number of words that children comprehend increases, lexical competition also increases due to the increase in *neighborhood density* (ND), thereby affecting the speed of word recognition (Storkel, 2001). These interference effects of neighborhood density for word recognition are generally absent in very young children, but older children and adults respond more slowly to spoken words with high neighborhood density than to those with fewer neighbors. This effect is thought to be directly related to the size of their vocabularies (Garlock, Walley & Metsala, 2001; Krull, Choi, Kirk, Prusick & French, 2010; Munson, 2001), although these effects may be language specific (Vitevitch & Rodriguez, 2005; Wang, Wu & Kirk, 2010).

In addition to the lexical factors such as neighborhood density, speech recognition is also affected by the sublexical characteristics of the spoken item. When infants are exposed to the statistical regularities in the languages they hear, they develop an inherent attunement to the likelihood certain sounds will occur in a given position or sequence in syllables or words, i.e., to the *phonotactic probability* (PP) of words in those languages (Jusczyk, et al., 1993; Jusczyk & Luce, 1994). This predictability of the sublexical characteristics of a language means that words with common sound sequences or high phonotactic probability are processed more quickly than words with less frequent segments (Auer & Luce, 2005).

Although they are usually positively correlated, there is a broad consensus that neighborhood density and phonotactic probability belong to two different levels of representation (lexical and sublexical), although the specificity at each level and the interactivity between the

levels are subjects of debate (see Goldrick & Rapp, 2007, for a review of speech production). As might be anticipated, lexical factors appear to be more influential for real words, whereas sublexical factors primarily affect nonwords. Thus, neighborhood density and phonotactic probability can differentially influence nonword recognition (Vitevitch, Luce, Pisoni & Auer, 1999) and word recognition (Luce & Large, 2001; Vitevitch, 2003).

Furthermore, the influence of neighborhood density and phonotactic probability appears to be task specific. For word recognition in adults there is a high-density disadvantage (e.g., Luce & Large, 2001; Luce & Pisoni, 1998) suggesting competition from a large (dense) neighborhood for this task (e.g., lexical decision). However for production (Gordon, 2002; Stemberger, 2004; Vitevitch, 2002), memory (immediate serial recall -Clarkson, 2013; Roodenrys & Hinton, 2002) and word learning (Heisler, 2004; Storkel et al., 2006) there is a high-density advantage, thought to reflect phonological support from existing lexical representations (Storkel, et al., 2006). In contrast, phonotactic probability shows a high probability advantage for recognition (Vitevitch & Luce, 1998), production (nonword repetition - Edwards, Beckham & Munson, 2004 and Zamuner, 2009; picture naming - Vitevitch, Armbruster, & Chu, 2004) and memory (short-term recognition - Frisch, Large, & Pisoni, 2000; immediate serial recall - Thorn & Frankish, 2005), but a disadvantage for spoken-word learning (Storkel, et al. 2006) in adults (but an advantage for children, Storkel, 2001; MacRoy-Higgins, 2009)[2]. With adults, for example, Storkel and colleagues suggest that new words with low phonotactic probability may trigger word learning due to their novelty and thus higher saliency (Storkel et al., 2006).

The context of use can also influence how we utilize these two word-form properties. Vitevitch (2003) examined task characteristics with the same set of target words in a lexical decision task and found that the non-target stimuli in the task appeared to influence whether the

[2] However, see language-specific differences in Vitevitch & Rodriguez, 2005 and Vitevitch & Stamer, 2006.

participants relied on the properties of neighborhood density or of phonotactic probability. When the words were presented auditorily in a set containing principally nonwords, the target words that had high phonotactic probability were responded to more quickly, suggesting sublexical processing. However, when the same target words were presented within a set that contained a majority of real words, adults responded faster to the target words with high neighborhood density, suggesting a reliance on lexical factors (Vitevitch, 2003; see Shuster for similar evidence for production, 2009).

In sum, as vocabulary knowledge grows, each new word adds to our phonological network and increases the specificity of our phonological representations. Through exposure to multiple exemplars of words from a variety of speakers, we form higher-level abstract representations of phonemes. These phonemes become increasingly well-specified as we generalize from the acoustic and articulatory features of each isolated production and its phonetic detail to those properties common to a given phoneme (Edwards, Beckham & Munson, 2004). One measure of this specificity, phonotactic probability, has a sublexical influence, and facilitates speech recognition, production, and immediate serial memory but has an inhibitory influence for spoken-word learning in adults. In contrast, another measure of phonological knowledge, neighborhood density, has a lexically based, inhibiting word recognition but facilitating speech production, immediate serial memory and word learning. Typically, these two word-form properties are positively correlated, although their underlying representations are thought to be fundamentally independent.

1.3 Phonological Processing and Dyslexia

The acquisition of the phonological representations that underlie word knowledge is multi-faceted. Speech processing requires the rapid discrimination and identification of sequences of phonemes and syllables. Curiously, even in the presence of no noticeable difficulty with first language acquisition, significant challenges with speech processing are common in children and adults with dyslexia (e.g., Joanisse, Manis, Keating, & Seidenberg, 2000). The reason for this poorer performance for individuals with dyslexia than for typical learners in speech discrimination tasks and in the categorization of speech sounds has been the subject of a large body of research. Findings which support speech processing difficulties as a key explanation of the core phonological deficit in individuals with reading disabilities (Bogliotti, Serniclaes, Messaoud-Galusi & Sprenger-Charolles, 2008; Mody, Studdert-Kennedy & Brady, 1997; Nittrouer 1999; Ortiz, Jimenez, Miranda, Rosquete, Hernandez-Valle & Rodrigo, 2007; Paul, Bott, Heim, Wienbruch, & Elbert, 2006; Schulte-Korne, Deimel, Bartling & Remschmidt, 1998a, Share & Stanovich, 1995; Snowling, 2000; Stanovich & Seigel, 1994; Swan & Goswami, 1997; Vellutino, 1979; Vellutino & Scanlon, 1987) often diverge from results which suggest that these difficulties originate from problems with lower level processing, i.e., temporal processing (Rey, De Martino, Espesser, & Habib, 2002; Tallal, 1980; Vandermosten, Boets, Luts, Poelmans, Golestani, Wouters, et al., 2010), processing time for a task such as tonal-pattern discrimination (Tallal, 1980), gap detection (Ludlow, Cudahy, Bassich & Brown,1983; although see Schulte-Korne et al. 1998b), auditory fusion (Farmer and Klein, 1993) and speed of processing and cross-modal integration (Breznitz, 2005, 2006).

In an attempt to link difficulties in lower-level auditory processing and speech discrimination with the literacy challenges faced by individuals with dyslexia, Goswami and

colleagues have suggested that a subtle perceptual deficit could explain the phonological basis for reading difficulties in the absence of overt speech impairment (Goswami, Thomson, Richardson, Stainthorp, Hughes & Rosen, 2002; Pasquini, Corriveau & Goswami, 2007; Thomson & Goswami, 2010; Goswami, 2011; Hamalainen, Rupp, Soltexz, Szucs & Goswami, 2012). These investigators found that children and adults with dyslexia demonstrated a significantly reduced sensitivity to the rise time (i.e., rate of change) of the amplitude envelope (i.e., loudness contour) of vowels than did age-matched controls. Detection of rise time of the amplitude envelope is considered the basis of our perception of speech rhythm, and this perceptual cue or P center is defined as the moment in time when the syllable is perceived. P center detection is thought to occur in the planum temporale and the temporo-parietal cortex, two areas important for encoding and storing sound sequences, where processing as well as structural differences have been found in LWD (Eden & Zaffiro, 1998; Habib, 2000; Pasquini, Carriveau & Goswami, 2007; although see Rosen, 2003 and Mody, 2003a for a different perspective). Recently Goswami and colleagues have presented evidence that individuals with dyslexia have difficulties in processing the rise time (rate of change) of the amplitude onset of the speech signal (Thompson & Goswami, 2010; Goswami, 2011; Hamalainen, Rupp, Soltexz, Szucs & Goswami, 2012). The investigators suggest that poor integration of the amplitude envelope (change over time) of speech in this population can explain many of the classic symptoms of dyslexia (e.g., problems with phonological awareness, rapid automatized naming, etc.) and negatively influence processing at the syllabic and phonetic levels (Goswami, 2011).

The phonological basis of reading difficulties has been supported by other aspects of speech processing that individuals with dyslexia find problematic. An important precursor to learning to read and spell is phonological awareness, the ability to segment, blend and

manipulate the sounds of words. Examples of these tasks include nonword repetition (also considered a task of phonological memory), phoneme elision ("say 'best' without the 's'") and phoneme reversal ("say 'tis' backwards"). Nonword repetition difficulty has been linked to low reading performance in children (Brady et al., 1989; Catts, 1986, 1989; Stone & Brady, 1995), in illiterate adults, (Castro-Caldas, Petersson, Reis, Stone-Elander, & Ingvar, 1998) and in adults with learning disabilities (Apthorp, 1995). Poor phonological awareness is a classic characteristic of children and adults with dyslexia, who commonly have difficulties in identifying and manipulating phonemes in words (e.g., Lyon, Shaywitz, & Shaywitz, 2003; Snowling, 2000; Swan & Goswami, 1997).

One line of research, a focus of the current investigation, is based on the premise that individuals with dyslexia have phonological representations that are not well specified, either lacking detail or containing unnecessary detail. Support for this *phonological representations hypothesis* comes from evidence that children and adults with dyslexia commonly have difficulties in discrimination and categorization of speech sounds (e.g., Swan & Goswami, 1997; Boada & Pennington, 2006; Brady, 1997; Snowling, Goulandris, Bowlby & Howell, 1986). [3] Phonological representations may be "degraded" and phonemes hard to differentiate if speech perception is too "holistic" and representations are not clearly specified (e.g., Swan & Goswami, 1997).

Other researchers suggest individuals with dyslexia have phonological representations that are over-specified, thought to stem from their heightened sensitivity to allophonic variations of phonemes. Examples of these perceptual differences, which could impact later reading ability, include a poorer ability among LWD to differentiate similar phonemes (/b/ and /p/, for example)

[3]Similar hypotheses which I am not differentiating for the purposes of this discussion include the *sub-lexical deficit hypothesis* (Szenkovits & Ramus 2005) and the *distinctness hypothesis* (Elbro, 1996).

yet a better ability to differentiate speech sounds within a phonemic category (e.g., variations of a /p/) as compared to controls (Bogliotti, 2002; Bogliotti et al.,2008; Serniclaes, 2006; Serniclaes, Sprenger-Charolles, Carre & Demonet, 2001 and for commentary see Mody, 2003b). Sprenger-Charolles and colleagues suggest that "allophonic" speech perception could result in relatively typical verbal language development, albeit a heavier memory load, but could create marked difficulty with phonological awareness tasks and learning to read (Sprenger-Charolles, Colé & Serniclaes, 2006).

If phonological representations are incomplete or inaccurate and phonemic categories less well defined, mispronunciation of new words or confusion between similar-sounding words could occur (Elbro, et al., 1998). In addition, if these representations are under- or over-specified, as many researchers suggest, we would expect differences to emerge between typical readers and those with dyslexia in their responses to phonotactic probability and neighborhood density. Sensitivity to these two word properties has not been systematically studied to date in LWD as compared to TL. Among existing studies, differences in age of participants and task demands make any study comparisons tenuous and any conclusions premature regarding how these properties may differentiate LWD and TL groups. For example, in spoken-word learning, a neighborhood density disadvantage was found for adults with dyslexia whereas no density differences were found for the typical readers (Warmington, 2008). In contrast, on a nonword repetition task, Thomson, Richardson & Goswami (2005) found that TL and LWD children responded similarly and, in this case, with a neighborhood rhyme-density advantage (number of words that rhyme with the target word). A neurophysiological study of implicit processing of phonotactic probability of spoken novel words in children with and without dyslexia demonstrated an increased sensitivity to high phonotactic probability for the TL group and an

opposite tendency to low phonotactic probability for the LWD group (Bonte et al., 2007). No differences between the TL and LWD groups, however, were found in children to a measure of phonotactic probability in a syllable-counting task (Maïonchi-Pino, Taki, Yokoyama, Magnan, Takahashi, Hashizume, Écalle, Kawashima, 2013), nor in a nonword repetition task (Roodenrys and Stokes, 2001).

What does seem clear, nonetheless, is that individuals with dyslexia demonstrate impaired performance on the tasks just discussed, particularly those that tax phonological memory. A strong association between nonword repetition and novel word learning has been found in both children and in adults for native and non-native words (e.g., Gathercole 2006; Di Betta and Romani, 2006). The poor performance of LWD on tasks of nonword repetition, phoneme identification, and other tasks of phonological knowledge that are highly correlated with reading and spoken-word learning difficulties in older children and adults has led researchers to suggest this performance is reflective of a "quality" difference in the phonological representations of LWD (Elbro, et al., 1998; Elbro & Jensen, 2005; Warmington, 2008).

The degraded phonological representations hypothesis has also been called into question by Ramus & Szenkovits (2008) who contest its premises point by point with extensive empirical evidence, suggesting that instead the phonological deficit of people with dyslexia manifests only under specific task requirements that tax working memory. They propose that dyslexia does not stem from a problem with the integrity of the phonological representations but rather with an ability to access them. The authors suggest that the selective appearance of the phonological deficit under certain task conditions, such as in a perceptual anchoring task, contradicts the hypothesis of a deficit in quality of the representations and supports a task-specific phonological access deficit.

Also evident, is that the tasks of low-level and higher level speech processing can load differently on working memory and influence phonological processing. Although the relationship between the two is complex, the role of working memory in phonological processing is central to understanding spoken-word learning.

1.4 Phonological Processing and Word Learning: The Role of Working Memory

Learning a word requires stages of encoding, storage and retrieval. The process of learning an arbitrary sequence of sounds and mapping them onto a specific semantic concept requires a means to manage the input, hold it in *short-term memory*, or brief storage, and somehow transfer this information into the network of long-term lexical representations. *Working memory* is a process which "involves [not only] the temporary storage [but also the] … manipulation of information that is assumed to be necessary for a wide range of complex cognitive activities" (p. 189, Baddeley, 2003b). Although there are different models to describe aspects of working memory (e.g., Cowan, 1999,; Jarrold & Towse, 2006; Kane & Engle, 2002; Kieras, Meyer, Mueller & Seymour, 1999; Miyake and Shah, 1999; Oberauer, 2009), the Baddeley & Hitch multi-component model of working memory is presented for the purposes of illustration (Baddeley & Hitch, 1974). In this model, input enters via two domain-specific "slave-systems", the visual-spatial sketchpad and the phonological loop, both controlled by a domain-general central executive system that is responsible for focusing and shifting attention. A fourth component, the episodic buffer, added in an updated model acts as a temporary way-station to integrate the information received from one or both of the slave systems and *long-term memory*, a more permanent storage system that supports short-term retention (Baddeley, 2000).

In the instance of learning a new word, the verbal material is retained in the phonological store but decays after about 2-3 seconds. Longer storage necessitates active articulatory rehearsal

via the phonological loop that can refresh memory but also has a limited capacity (Baddeley, 2003a). When decay degrades the signal in the phonological store, information from long-term memory can be used to *redintegrate* the signal i.e., fill in the remaining incomplete phonological traces (Alloway, 2007). Articulatory rehearsal allows the incoming signal a longer stay in the phonological loop. However, this is only an initial step to word learning.

The integration of the phonemes of a verbally presented word is dependent upon several processes: the analysis of the acoustic signal, low-level pre-attentive processing of the phonetic features (Winkler, et al., 1999), an abstraction or generalization away from the individual productions (phonetic realizations) toward the common properties (phonemes), phonemic segmentation, and higher-level articulatory indexing (Edwards, Beckham & Munson, 2004). In addition, if the original signal matches the sublexical rules that are stored in long-term memory, redintegration is facilitated. However, if the signal contains phonemes that are unfamiliar, as when learning a foreign language, the system can overload, fail to reconstruct the original signal, and any stored representations will likely be faulty and unstable (Kovacs & Racsmany, 2008).

Differentiating working memory and phonological processing is challenging. Many of the tasks used to assess phonological processing also tax working memory (Ramus & Szenkovits, 2008; Ahissar, et al., 2006) and there is strong evidence of working memory difficulties for phonological tasks in readers with dyslexia (Smith-Spark & Fisk, 2007). Greater attention recently has led researchers to try and to determine the relative contribution of working memory to reading difficulties, separate from phonology (Roodenrys and Stokes, 2001; Ramus & Szenkovits, 2008; Ahissar, et al., 2006). Recent investigations into memory difficulties in adults with dyslexia have found both verbal and spatial working memory impairments, suggesting a more general memory deficit that is not limited to phonological tasks (Smith-Spark

& Fisk, 2007; Swanson, Zheng, & Jerman, 2009). In sum, impaired working memory has been identified as characteristic of LWD and consideration of the cognitive demands and the load on working memory in a spoken-word learning task is of key importance.

1.5 Perceptual Anchoring, Dyslexia, and Spoken-word Learning

Successful encoding, storage and retrieval depend not only on the quality of the initial signal, but the ability of the system to retain the word long enough for long-term consolidation, a process Baddeley attributes to the episodic buffer (Baddeley, 2000). Typically developing two and three year olds learn new words rapidly, sometimes after only one or two exposures. This rapid lexical learning or *fast mapping* (Carey, 1978) facilitates the children's ability to then use the new words, compare them with words they know, and refine their knowledge of the words with experience (Werker & Curtin, 2005). In very young children the ability to "fast map" may be directly related to extended practice with contextually related novel words (Gershkoff-Stowe & Hahn, 2007), demonstrating the importance of an underlying vocabulary base for word acquisition.

The ability to use recent information is dependent upon our ability to create an abstract mental trace of the stimulus-specific referent. Stimulus-specific adaptation, also known as repetition suppression, induces a decrease in cortical activity and is associated with improved performance following stimulus-specific repetition (Grill-Spector, Henson & Martin, 2006). Measured with fMRI, adaptation paradigms have confirmed this robust phenomenon in the frontal lobe for tasks such as object naming (Turennout, Bielamowicz & Martin, 2003) and in the medial temporal lobe for picture encoding (Stern, 1996). Chandrasekaran et al. (2009) found similar sensitivity to stimulus-specific repetition in typically developing children for brainstem

measurements of acoustic encoding of speech syllables, a phenomenon that was reduced in their sample of children with dyslexia.

Ahissar and colleagues propose that LWD are challenged by a deficit in what they refer to as perceptual anchoring, the process by which we tune to a repeated incoming stimulus and form a perceptual "anchor", a mental abstract representation of the stimulus (e.g., Ahissar, et al., 2006, Ben-Yehudah & Ahissar, 2004; Banai & Ahissar, 2006; 2010). For auditory tasks, this perceptual anchor helps us make automatic predictions about future repetitions of the same stimulus, increasing our accuracy and rate of response. These researchers found that unlike controls, who performed faster on speech and pure-tone tasks that contain a repeated stimulus, young adolescents with dyslexia failed to benefit from such repetitions[4]. They designed a two-tone frequency discrimination task and asked listeners with and without dyslexia to choose the higher pitched tone. For one of the sessions one of the two tones was always the same, i.e., a reference tone. The test was self-adjusting and measured the participants' Just Noticeable Difference (JND) for frequency. Typical listeners, although unaware of the presence of a reference tone, were able to use this repeated tone to improve their performance during the session with a reference relative to the no-reference condition. LWD performed similarly with and without a reference tone, failing to benefit from the repeated stimulus. In another task, participants were asked to repeat nonwords they heard in a background of noise. In one set, the nonwords were a finite set and were repeated. In the other set, there were no repeated items. Again, the TL performed better on the set that had the repeating items; the LWD did not.

This *perceptual anchoring deficit hypothesis* is not without controversy. Ahissar and colleagues propose that perceptual anchoring, an implicit memory deficit, can affect working

[4] The authors revised their earlier description of this deficit from affecting both the visual and auditory modalities to one that is limited to the auditory modality.

memory and phonological processing but the underlying deficit for LWD is itself domain-general and independent (e.g., Ahissar, et. al. 2006; Banai & Ahissar, 2004). Proponents of the phonological representations hypothesis, Di Filippo, et al. (2008) and Ziegler (2008) have disagreed with this claim and questioned the hypothesis, citing evidence that if the deficit was domain general then these children should perform equally poorly on measures of signal intensity (loudness judgment), not just frequency. Ahissar & Oganian (2008) in their response article countered, asserting that JND measurements of intensity are not typically reliable.

A crucial component of word learning is the ability to hold on to the phonological information for recognition, integration and retrieval. A failure to anchor to the stimulus suggests that LWD would be less able to use novel word repetitions to learn new words. Novel spoken-word learning has been the subject of several recent investigations that have confirmed word-learning difficulties in children and adults with dyslexia as well as a reduced benefit from word repetitions. In one such study, Mayringer and Wimmer (2000) taught a series of names to young German-speaking boys (aged 9) with and without dyslexia. In one of two experiments, the names were either of complex (CVCVCV) or simple (CVC) structures and were novel, unfamiliar or familiar. Although both the children with dyslexia (N=20) and control (N=20) children could repeat the names easily and had initial difficulty learning the complex novel names, with subsequent exposure and repetitions of the names the typical learners improved significantly but the children with dyslexia did not. Based on these results as well as an error analysis that showed the latter group's production errors were principally phonological distortions (e.g., categorized as the substitution of a novel word that was either close or distant phonologically) rather than any other error type (e.g., misnamings, refusals), the authors

concluded these children had a phonological learning difficulty that thwarted the retention of novel words over time.

Messbauer and de Jong (2003) also found a similar reduced learning curve for their Dutch-speaking children with dyslexia (aged 8-11, N = 21) but came to different conclusions. In their study, the investigators included two control groups, one matched for chronological age (CA) the other for reading age (RA). On the paired-associate verbal learning tasks using picture pairings with real and novel words, the group with dyslexia and their RA-matched cohorts performed significantly worse than the CA group, differences which were also found on tasks of phonological awareness. When the researchers controlled for phonological awareness and the group differences on the verbal learning tasks disappeared, they proposed verbal learning (of both real and novel words) is dependent upon the quality of the children's phonological representations, the latter likely heavily influenced by the orthographic transparency of the Dutch language. A word-learning retention task revealed an equal proportion of attrition among all three groups of children. These results led Messbauer and de Jong to conclude that the difficulty with verbal learning lies not in long-term retention but rather with the process of linking orthography to the phonological forms.

Novel word learning in adults with dyslexia was addressed by Di Betta and Romani (2006) for both novel spoken and written words, as well as for "foreign" words. In this extensive study of 22 adults with developmental dyslexia, on paired-associate word learning tasks, the learning curve of the group with dyslexia was consistently lower from the first trial for spoken novel words and foreign words. Although performance improved, it did not improve at the same rate as for the controls. They contrasted their participants' performance for word learning with their performance on the *Rey Test* (Rey, 1964) a word-list recall test, and the *Doors and People*

Test (Baddeley, et al., 1994) that examined visual recognition and recall. On these latter tests, their participants performed equally well, suggesting that the LWD's learning difficulties were limited to lexical learning and not reflective of a generalized learning deficit.

In addition to a reduced learning curve for spoken-word learning, differences for individuals with dyslexia have been found in their sensitivity to neighborhood density. In a series of experiments looking at neighborhood density, serial recall, and word learning, Warmington (2008) compared young adults with and without dyslexia to test the hypothesis that underspecified phonological representations account for word-learning difficulties in adults with dyslexia. In one experiment, her participants were asked to learn 16 novel spoken words paired with novel objects and an invented definition. In contrast to the typical participants (N=12) who were given 10 trials and learned all 16 novel words, only 7 of the 10 participants with dyslexia learned the 16 novel words to criterion after 15 trials. Excluding the three LWD who did not learn to criterion, the rest of this group showed a neighborhood density disadvantage, (i.e., they learned low neighborhood-density novel words with fewer repetitions than high neighborhood-density novel words). Although in Warmington's study the control group did not show neighborhood-density differences, typical participants in other studies have shown a neighborhood-density advantage (e.g., Storkel, et al. 2006).

In sum, two hypotheses that propose an explanation for the phonological deficit also provide predictions for spoken-word learning performance in LWD. The phonological representations hypothesis suggests that if the representations of speech sounds in words are poorly specified (i.e., either under- or over-specified) for readers with dyslexia, the sensitivity to a word's properties of neighborhood density and phonotactic probability may be reduced for this population. According to the perceptual anchoring deficit hypothesis, individuals with dyslexia

are less able to implicitly use repetitions of a given stimulus to form a perceptual referent, affecting their ability to retain information for later retrieval. This second hypothesis suggested that the rate of learning for participants with dyslexia would not only be reduced, but that their ability to learn would be progressively less with subsequent repetitions. In the word-learning paradigm for the current study, discussed below, these hypotheses are not mutually exclusive. Nevertheless, the results of the effects of the word-form properties and the novel word repetitions can clarify the relative importance phonological knowledge and perceptual anchoring have for individuals with and without dyslexia.

1.6 Research Design and Objectives

The current study presented novel spoken words and their referents in a narrative context, a word-learning paradigm developed by Storkel and colleagues (Storkel, 2000, 2001; Storkel, Armbruster & Hogan, 2006). Their research is outlined here, as it served as a basis for the current methodology. To investigate the influence of neighborhood density and phonotactic probability on word learning ability, Storkel, Armbruster & Hogan (2006) presented 38 young adults with novel spoken words and their referent objects in a story context, using 16 novel words, orthogonally controlled for neighborhood density and phonotactic probability. In the first episode of each of the two stories, the objects were presented once, and in the second and third episodes they were repeated 3 times (for a total of 7 repetitions per novel word). At the initial stages of learning words measured by the number of partially correct words, the adults' performance was better on low probability words, suggesting that novelty was important in triggering new word learning. In later stages following more repetitions of the word and measured by completely correct productions, those target words with high density (i.e., with

many similar sounding words in English) were learned better suggesting, according to the authors, that existing word representations supported the stabilization of new word forms.

The effects of phonological knowledge and perceptual anchoring (independent variables) were examined on the word learning performance (dependent variable) in adults with and without dyslexia. Phonological knowledge was assessed by the effects of neighborhood density and phonotactic probability on the ease with which the novel words were learned. Perceptual anchoring was assessed by the word accuracy across repeated exposures to the novel words. In addition, independent behavioral measures, e.g., phonological awareness subtests and a pure tone task for perceptual anchoring were employed as predictor variables for spoken-word learning performance.

The influence of two types of implicit phonological knowledge (phonotactic probability and neighborhood density) in a word learning task had not been investigated previously in adults with dyslexia to our knowledge. Adults were examined rather than children because they provided the opportunity to assess word learning in the context of an established vocabulary base. This study examined the process of learning spoken novel words in young adults with and without dyslexia. Through selection of target novel words that varied orthogonally in *neighborhood density* (the number of words that vary from the target by one phoneme) and *phonotactic probability* (the probability that given sound sequences will occur in their respective positions), we looked at how these two properties of phonological knowledge differentially facilitated word learning for each group. These results informed us about the quality of the participants' already established phonological representations and the contribution these word-form properties made in triggering new word learning. In addition, by periodically measuring the naming of pictures corresponding to the novel words during the word learning task, we probed

each group's ability to benefit from the repetitions of the target words over test time, i.e., to form a *perceptual "anchor"*, or abstract referent to aid retention.

Objectives:

Research Question: What are the relative contributions of phonological knowledge and perceptual anchoring to a novel word-learning task for adults with dyslexia?

Hypotheses:

1) Adults with dyslexia would learn fewer novel spoken words than control participants.
2) If phonological knowledge is a principal factor in word learning difficulty, adults with dyslexia would show a weaker effect of neighborhood density and phonotactic probability than control participants.
3) If perceptual anchoring is a principal factor in word learning difficulty, adults with dyslexia would show proportionately less improvement across repetitions of a given novel word than control participants.

Chapter 2: Method

2.1 Participants

The 39 young adults (aged 18 to 25) of the present study were recruited from postings in the support services' centers and student unions at local universities and on-line. In addition, alumni from private schools that specialize in educating students with learning disabilities were contacted by email through the schools' alumni divisions. All participants were monolingual[5] native speakers of American English without a history of specific language impairment, hearing impairment, hyperactivity, head trauma, or other neurological impairment apart from a diagnosis of dyslexia. The two groups, a group of 16 adults (M_{age} = 26.94 ± 4.0 SD years of age, 10 females and 6 males, 14 right-handed, two left-handed), with dyslexia and a control group of 23 adults (M_{age} = 25.43 ± 4.2 SD years of age, 11 females and 12 males, 21 right-handed, one left-handed, one ambidextrous), were matched for age and education as well as for non-verbal IQ scores, as measured by the *Test of Nonverbal Intelligence, Third Edition* (TONI-3, Brown, Sherbenou & Johnsen, 1997). All participants passed a hearing screening at 20 dB for 500, 1,000, 2,000 and 4,000 Hz and achieved a score of 96% or better on the W-22 Speech Discrimination Test. In addition, the *Peabody Picture Vocabulary Test-R* (PPVT-R, Dunn & Dunn, 1981) confirmed normal vocabulary comprehension with no significant differences between the two groups (see Table 1).

Participants selected for the group with dyslexia had a self-reported history of reading and spelling difficulties that significantly affected their education. In addition, three screening measures were administered: the spelling subtest of the *Wide Range Achievement Test (WRAT*,

[5] Defined as not currently or in the past having a working fluency in another language. All participants were from a home environment where only American English was spoken.

Wilkinson, 1993*)*, the reading rate subtest (for oral reading) of the *Nelson-Denny Reading Test* (Brown, Fishco & Hanna, 1993), and the *Test of Word Reading Efficiency* (TOWRE, - Torgesen, Wagner, & Rashotte, 1999).). All participants with dyslexia either had been independently diagnosed with dyslexia (N = 8) or their performance on two of the three measures was 1.5 standard deviations below the mean (of the typical learners). Given that people with compensated dyslexia who have received extensive intervention often perform within the normal range on real word measures, those participants[6] with an independent diagnosis of dyslexia were included if two of the three measures were one standard deviation or more below the mean. The control participants selected had no history of reading or spelling difficulties and their performance was at or above one standard deviation below the standardized mean[7] for all three screening measures.

Adults were examined rather than children because they provided the opportunity to assess word learning in the context of an established vocabulary base. Participant selection was based on criteria for individuals with dyslexia, rather than the broader "learning disabled" group used in most studies that have failed to find a higher incidence of foreign-language learning difficulties in LD students than in typical learners (e.g., Ganschow, Sparks & Schneider, 1995; Ganschow et al., 1991; Sparks, et al., 2006). Given these considerations, the current experiment, which tested two of the presiding hypotheses regarding the underlying deficit of LWD, was designed to evaluate why this population has difficulty with spoken-word learning.

Measuring participant progress in word learning quantified potential benefit of the phonological properties and repetitions of the novel words across testing times. Additional

[6] Two additional participants, diagnosed with dyslexia, were not included in the study because their reading and spelling measures were less than one standard deviation below the mean.

[7] The *Nelson-Denny Reading Test* is standardized on silent reading and not oral reading performance. To ensure typical reader selection, participants for the "TL" group were included only if their oral reading was at or above 130 wpm, which is the silent reading cutoff for the young adult age group.

measures of phonological awareness and perceptual anchoring and their relationship to spoken-word learning accuracy provided potential predictor variables for spoken-word learning difficulties in young adults with dyslexia.

For the present study, Storkel et al.'s (2006) story paradigm and stimuli were modified to teach novel word-object pairs to young adults with and without dyslexia. These modifications were made to accommodate the anticipated slower learning curve of the experimental group. Because the maximum performance for typical adults on the original tasks reached just over 60% accuracy after the last (3rd) episode, the picture stimuli and the length of the stories were changed to enhance the opportunity for word learning. After consulting with a visual arts specialist, the pictures were modified to make the objects more distinctive and salient. In addition, a fourth episode was added to each of the two stories to increase the number of presentations for the 16 stimuli. Four of Storkel et al.'s original words were changed, two after pre-piloting indicated they might be too "word-like": /mug/ (moog synthesizer) and /naʊt/ ("snout") and two additional words to satisfy the novel-word selection criteria (see Method section).

2.2 Testing Procedure:

Participants were initially screened with a telephone questionnaire (see Appendix A) to verify the selection criteria mentioned above. The first one-hour session, consisting of the hearing screening, vocabulary and reading measures (presented in randomized order), confirmed the participants' reported history of reading/spelling difficulties (or typical performance for the TL group) and ensured that vocabulary was within normal limits. A second session of two to three hours was scheduled and completed on the same day or on a subsequent day, but within two weeks of the first session. The word-learning task was always given at the beginning of the

second session, and the two stories were separated by the administration of the nonverbal IQ measure, the *TONI-3*. The remaining behavioral measures were given in a randomized order. Breaks were offered and included as needed.

2.3 Behavioral Measures:

The following formal and informal measures were given to address the research questions and permit a multiple logistic regression analysis to test for predictor variables. The subtests are described by category.

2.3.1 Phonological awareness

Phonological awareness was measured by four tasks: First, on the Nonword Repetition subtest of the *Comprehensive Test of Phonological Processing* (CTOPP, Wagner, Torgesen & Rashotte, 1999) participants repeated nonwords of increasing length. The test's eighteen nonwords ranged from one to seven syllables and all phonemes of each word had to be pronounced accurately for the word to be considered correct. On a second task, the Phoneme Reversal subtest, also of the CTOPP, participants listened to 18 nonwords of one to two syllables and reversed them to produce real words. A third task consisted of nonwords from the "Spelling of Sounds" subtest of the *Woodcock Johnson III Tests of Cognitive Abilities* (WJII, Woodcock, McGrew & Mather, 2001). A fourth task, Spoonerisms, required the transposition of the first phoneme in a pair of words (*Chuck Berry --- Buck Cherry*), (Perin, 1983).

2.3.2 Working memory

The tasks in this section were selected to address visual-spatial and verbal working memory. The first was a modified version of the spatial short-term memory task from the

Working Memory Test Battery (Lewandowsky, Oberauer, Yang & Ecker, 2010). In this task, the participant replicated a series of dots that appeared sequentially on a 10 X 10 cell grid on a computer screen. Anywhere from 2 to 6 dots were presented, each dot for one second with a 100 msec interstimulus interval. The participant was cued with a written statement to reproduce the pattern of dots by clicking on the cells of the grid with the mouse. The cue was preceded by a visual mask. In addition, for half of the items, a single red dot appeared after each black dot and served as a distractor[8]. The participants were instructed to ignore the red dots if they appeared and to replicate only the black dot patterns. The order of dot selection did not have to correspond to the order presented in the trial and the participants could erase and move the dots until they were satisfied with their answer. The trials with a distractor were randomly intermixed with the non-distractor trials. Prior to the task a series of instructions were given to the participants explaining the task procedure and each participant completed ten practice trials, 5 with only black dots and 5 with red dots. The task included six trials each of 2, 3, 4, 5, and 6 dots for a total of 30 trials.

The second measure was an unpublished listening span task[9], an adaptation of the reading span tasks (RST) described by Daneman & Carpenter (1980). Rather than reading sentences, the participant listened to a series of recorded sentences (e.g., "We use air conditioners when it is cold.") and identified each as either true or false with a button press, while recalling the last word of each sentence. Three sets each containing a series of one to seven sentences were randomly presented, such that the participant was unaware of how many sentences were contained in a given set. Then, when cued with a tone and question mark on the screen, the participant had to produce the last word of each of the sentences in the set, in the order presented. Two scores

[8] Red dots were presented with the same duration and ISI as the black dots.
[9] Adapted from a task developed in the Language-in-the-Aging-Brain Laboratory by Obler, Albert, Goral and colleagues, Boston University School of Medicine, Boston, MA.

were calculated, the number of final words recalled in the correct order and the total number of final words recalled. As with the visual working memory task, this verbal working memory task was preceded by a series of instructions to explain the nature of the task and give the participants practice both in responding to the veracity of the sentence and in holding the final word in memory.

2.3.3 Perceptual Anchoring

The perceptual anchoring task consisted of a comparison of two 'just-noticeable-difference' (JND) tasks with and without a reference tone[10]. The JND was calculated as the smallest differential between two tones that could be distinguished. For each trial the task began with the presentation of pairs of steady pure tones that had obvious differences in pitch for the listener and, following accurate responses, the differential became progressively smaller. When the participant was presented with two brief tones, corresponding icons on the computer were simultaneously illuminated. After the participant selected the higher pitched tone of the pair with a mouse click, the participant received visual feedback (a smiley face or a frowning face) regarding response accuracy.

To determine the baseline differential between the tones in a pair, practice items were given with an initial frequency differential of a ratio of 1.5 between each set of paired tones (e.g., 1000Hz and 1500Hz). The practice items were given until the participant responded correctly to ten consecutive items. If this baseline was not achieved after thirty practice items, the ratio differential was widened by .5 and the practice items repeated until the required 10-item basal accuracy was reached. Next, the first of the 80-item test began at the baseline ratio indicated by the practice items. The ratio was adjusted adaptively to the participant's responses by a 3 down,

[10] The JND task was generously shared by Ahissar.

1 up staircase. In other words, each time the participant correctly responded to 3 items in a row the test became harder and the ratio was decreased. Following a single error, the ratio between the tones was widened. Feedback was continued throughout the test.

Two different 80-item tests were given. One of the two tests had a reference tone (1000Hz) in each presentation of the tone pairs, either as the first tone or the second, while the other tone was always of a higher frequency. On the other test, the tone pairs were within the 600 to 1400 Hz range but the frequency of the initial tone of the pair was randomly selected and there was no reference tone. In both trials, each tone was 50 msec in duration with an interstimulus interval of 1000ms. The eighty trials were expected to converge on a level of 80% accuracy. The Just Noticeable Difference (JND) was calculated by averaging the last 6 reversals (steps up or down). Each of the two test types was given twice in an ABAB or BABA order with half of the participants receiving one order or the other in each of the two groups. The mean JND for the pair of trials was calculated for each of the two conditions (reference and no reference), and the two conditions were compared to calculate a reference advantage.

2.3.4 Repetitions of real words

The *Rey Auditory Verbal Learning Test* (RAVLT, Schmidt, 1996) was selected to measure recall of real words repeatedly presented. In this task participants listened to a list of 15 pre-recorded words each spoken at one-second intervals and repeated back as many words as they could recall. The words were all common nouns of high frequency and imageability. The list of words was presented in the same order four times[11]. A second list was then presented and recalled in the same manner. The items in the second 15-item list were designed to interfere in syllable structure and semantic category with the first list, thereby influencing recall of the

[11] Due to time constraints, we reduced the number of repeated presentations to four from the original five.

second list. In this regard, proactive interference by recently learned items can hinder the learning of a new list due to the retention of traces of the previously reviewed material (Jonides & Nee, 2006; Kane & Engle, 2000; Postman & Keppel, 1977). Following the presentation and recall of the second list four times, the participants were asked to name all the items they could from the first list. Here, the disruption of previously learned material by the introduction of newly learned information or retroactive interference is measured.

2.4 Experimental Measure: Word Learning

2.4.1 Stimulus materials

Sixteen novel words with low and high neighborhood density and phonotactic probability were selected as target words (Table 2). Twelve of the novel words were selected from Storkel, et al. (2006) and four were chosen to be commensurate with the original measures of phonotactic probability and neighborhood density reported by them. The objects depicted by the novel words belonged to one of four semantic categories: toys, musical instruments, candy or pets. The specific measures of neighborhood density and phonotactic probability for all words were calculated from a 1964 Merriam-Webster dictionary of approximately 20,000 words from which computer-readable transcriptions of the pronunciations were derived and checked by qualified researchers (see Vitevitch & Luce, 2004, and Luce & Large, 2001 for further details).[12] Neighborhood density measures had been made by counting the number of words that could be made by adding subtracting or substituting one phoneme from the word or nonword. Phonotactic probability measurements were based on two measurements, the positional segment frequency or the probability that a given phoneme would occur in that position in a syllable or word, and the

[12] Calculations of neighborhood density and phonotactic probability were provided by Paul Luce.

biphone probability or the likelihood that the given phoneme pair would occur in a given position in a word or syllable (Table 3).

From a list of 5,316 novel words with neighborhood density and phonotactic probability calculations, high and low neighborhood density and phonotactic probability were determined by a median split using the procedures outlined in Storkel et al. (2006). In addition to the measurements of high and low phonotactic probability and neighborhood density, the novel words for the present study were selected such that no words within a semantic category began with the same consonant or had the same vowel sound, as both referent similarity and phonological similarity may interfere with word learning (e.g., Zhao, 2013)

The sixteen novel words were pseudo-randomly paired with pictured novel objects and presented via stories with still drawings and audio files using Direct RT presentation software (adapted from Storkel, 2006). Each scene in a given episode presented two characters interacting with a pair of objects from one of the four category types (see Appendices B and C). As the scenes did not have an inherent order, their presentation was randomized by the Direct RT software to reduce the possibility of an order effect in learning. Furthermore, the order of presentation of each set of eight words and the pairing of the 2 sets of eight words with the objects were pseudo-randomized within each group.

2.4.2 Procedure

Prior to presenting the stories containing the target words, the participants were introduced to the task with a practice story. Four items were presented within the context of a one-episode story following the procedures discussed below. All participants completed this practice story and were given the opportunity to ask questions (see Appendix A).

The sixteen target words were randomly presented within two blocks of 8 words in the context of two stories. The participants were told that the objective of the task was for them to learn the names of the novel objects. Prior to the story sequence, each pictured object was presented in the same manner as in testing to familiarize the participants with the pictures and reinforce the procedural aspects of the task. Word learning was measured four times during the experiment by the picture-naming task after each of the four episodes of the stories and then a fifth time two hours after the second story had been presented. The first episode contained one exposure to the eight words to measure the participants' ability to fast map and produce the novel word after a single exposure. Within each of the three remaining episodes, three exposures to each word were presented. Therefore testing took place after 1, 4, 7 and 10 exposures to the novel words. The participants were not told they would be tested a fifth time. During the two-hour period between test times 4 and 5 the participants completed other behavioral measures, (e.g., additional measures of perceptual anchoring, phonological awareness, etc.).

The participants' responses to the picture-naming task following each episode of the story were recorded and transcribed. All three phonemes had to be correct and in the correct sequence for the item to be scored as correct. The principal investigator scored the responses and 15% of the responses were judged by two independent listeners trained in phonetic transcription for inter-rater reliability. Any discrepancies were discussed and mutually agreed upon. Inter-rater reliability among the two judges and the PI for scoring of responses was 97%.

2.5 Data Analyses

To address the effects of neighborhood density and phonotactic probability across testing times for the two groups, the data were analyzed using multilevel mixed-effects modeling. This analysis was considered preferable over the more traditional repeated measures ANOVA for a

number of reasons. Foremost, the dependent variable, novel word productions, was scored as correct or incorrect and consequently a binary outcome. As such, the response type violated the assumptions of ANOVA that requires a continuous dependent variable (Jaeger, 2008). Secondly, a multilevel model could accommodate both the mixed design of the study (with participants nested within groups and target words orthogonally balanced for word properties and repeatedly tested across a series of testing times) as well as the unbalanced number of subjects per group. A third consideration was the ability of the multilevel mixed effect model to account for the variable performance characteristic of LWD, by including random effects and slopes in the analysis. Rather than ignoring participant-level differences by aggregating the data as is typical in the traditional ANOVA analysis, mixed effects and other hierarchical models separate the individual and group effects on the outcome (dependent) variable. (See Quene & van den Bergh, (2008) and Woltman, Feldstain, MacKay & Rocchi, (2012) for further discussion of advantages of multilevel modeling vs. ANOVA.)

2.5.1 Experimental Data Analysis

The data were analyzed by with R statistical software (R Core Team, 2013) using the lme4 package, version 0.999375 - 42 (Bates, Maechler & Bolker, 2011), as well as the languageR, version 1.4 (Baayen, 2011), and influence.ME, version 0.9.2 packages (Nieuwenhuis, Pelzer, te Grotenhuis, 2012). A generalized mixed-effect logistic model was fitted with a binary dependent variable (correct, incorrect) with participants and target items treated as random factors effects. A third random factor of picture was initially placed into the model but then excluded because the variance of the picture intercepts was negligible. Level 1 factors of phonotactic probability, neighborhood density and testing time were treated as fixed effects and entered first into the model followed by the Level 2 factor, group, in a theoretically

constrained stepwise fashion for logistic regression analysis (Hosmer, Lemeshow & Sturdivant, 2013, p.125). The baseline intercept (i.e., reference category) was "high" against "low" for both phonotactic probability and neighborhood density, and was "TL" (typical learners) against "LWD" for Group. The baseline for Testing Time was adjusted (e.g., Testing Time - 1) to provide a meaningful zero baseline statistic. Beginning with a null model with participants and target items as random factors, by-participant random slopes were added for testing time, phonotactic probability and neighborhood density as each was systematically entered into the model. By-item random slopes were included only for testing time because the items were orthogonally balanced for neighborhood density and phonotactic probability. The best model fit was selected among the lowest AIC-valued[13] that performed best in model comparison (as indicated by a chi-square test).

Based on the curvilinear shape of the aggregated data, a quadratic factor of time was added that significantly improved model fit (Testing Time_Q). Random slopes were included for Testing Time but not for Testing Time_Q, given the high correlation between the two and convergence problems.

2.5.2 Behavioral Data and Regression Analysis

The Mann-Whitney U test was performed on each of the behavioral and screening measures to test for group differences. In addition, each of the behavioral measures that were selected a priori as predictors of phonological knowledge and perceptual anchoring were centered and entered as independent variables into a stepwise linear regression analysis for the LWD group with the proportion of correct novel word productions collapsed across the first four

[13] The Akaike information criterion (AIC) is a measure for model selection. The lowest AIC score reflects the best, most parsimonious model, because the measure incorporates two key factors; it rises as the complexity of the model rises and decreases as the goodness of fit improves.

testing times as the dependent variable. Linear regression on the proportion of correct responses was preferred over logistic regression of the binary outcome due to problems inherent in the interpretation of logistic regression as well as recent evidence that suggests linear regression models may be preferable to logistic regression when the distribution of the outcome variable is not restricted to a narrow range (see Mood, 2010).[14]

Prior to the statistical analysis of the perceptual anchoring measure (Just Noticeable Difference or JND), the mean JND (in Hz) for each of the two conditions was transformed into (base-10) logarithmic units. The need for log-transformation of frequency is motivated by the tendency of the standard deviation in Hz to increase as the frequency increases. When measuring JND, the difference between the tone pairs is increased or decreased not by a constant amount in Hz but by a factor, based on a ratio differential. These differences were corrected for using the log transformation (e.g., as in Micheyl, Xiao, & Oxenham, 2012). Outliers were identified and removed if necessary using the Median Absolute Deviation (Leys, Ley, Klein, Bernard & Licata, 2013) calculated by the Median $\mp$ 2*MAD.

Given the small sample size, one phonological awareness predictor and one perceptual anchoring predictor was selected from the behavioral measures in the testing protocol and were then entered into a hierarchical linear multiple regression analysis. A three-step analysis was performed for the LWD group to see how well these two variables could predict accuracy on the word learning task and what their unique contribution was to the regression equation.

[14] The logit transformation of the regression equation does not necessarily result in a dependent variable that has a linear relationship with the predictor variables. In addition, the interpretation of log odds ratio is problematic as it does not reflect the effect size statistic characteristic of linear regression. Thirdly, the coefficients of the predictor variables depend upon unobserved hetereogeneity and the value of interdependent variables not included in the regression model for which the residual variance is not fixed (see Mood, 2010 for examples and further discussion).

Chapter 3: Results

3.1 Results: Spoken word learning

As predicted, the LWD performed more poorly overall than the TL group and produced fewer correct novel words than the TL on the word-learning task. Across the first four of the five testing times, 30% of the LWD group's responses were correct vs. 53% for the TL group. The best model fit included significant effects for Group (z = -4.345, $p < 0.0001$), Testing Time (z = 6.38, $p < 0.0001$) and Testing Time_Q (z = -2.56, $p < 0.05$), as well as a two-way interaction for Testing Time_Q and Group (z = -2.90, $p < 0.01$), consistent with a slower learning rate for the LWD group (Table 4). These results support my prediction that the LWD group would show proportionately less improvement across repetitions of a given novel word than the control participant group (TL). As such, by the fourth testing time the TL group produced an average of 80% of the novel words whereas the LWD produced 51%, the latter proportion equivalent to the TL group at testing time 2. (See Figure 1[15].) A fifth testing time given 2 hours after the word-learning task yielded significant group differences but word attrition was proportionately equivalent.[16]

With regard to word properties, phonotactic probability (PP) reached borderline significance (z = -1.96, p = 0.05), with an advantage for words with high phonotactic probability over low. An interaction between Group and PP was significant (z = 2.94, p < 0.01), Testing Time_Q-Group-PP (z = 3.03, p < 0.01), as well as Testing Time-Group-PP (z = 2.89, p < 0.01), (Table 5). Therefore, in addition to a general difficulty with spoken novel-word learning, the LWD group demonstrated poorer performance on low phonotactic probability words,

[15] For ease of illustration of binary response data, the graphs show overall proportion of correct responses for the two groups.
[16] The fifth testing time was not included in the analyses reported.

particularly at the third testing time (Figures 2, 3). Neighborhood density (ND) did not contribute to model fit either as a main effect or as an interaction and was therefore not included in the final model (Figure 4).

3.2 Results: Behavioral Measures

Summary statistics for each group are provided in Table 1. The results of the Mann-Whitney U test confirmed significant group differences, as expected, on reading rate, reading efficiency (TOWRE) , spelling, spelling of nonwords (spelling of sounds), rapid automatized naming, spoonerisms and phoneme reversal and no significant differences for age, education, vocabulary, or IQ. Surprisingly, there was no group difference on nonword repetition, typically a task that is harder for adults with dyslexia than typical readers. Spatial working memory did not distinguish the groups but group differences on verbal working memory were significant.

Perceptual anchoring, as measured by the JND for frequency, yielded significant group differences with poorer performance (higher scores) by the LWD group compared to the TL group in both the number of practice trials and starting ratio as well as in the average JND score for the reference condition. The LWD group required 30% more practice trials to reach the starting criterion than the TL group. Consequently, 49% of the LWD participants required a factor above 1.5 between tone pairs (2.0 and above) as compared to 13% of the TL group. On the task itself, the LWD group had a significantly larger mean JND score (log-transformed) for the reference condition (*Mdn* = 1.18) compared to the control participants (*Mdn* = 0.66, , $U = 79$, $z = -2.43$, $p < 0.05$) and a larger mean JND score on the no-reference condition (LWD, *Mdn* = 1.23; TL, *Mdn* = 0.86), but this latter difference did not reach significance ($U = 100$, $z = -1.75$, $p = 0.08$). (Figure 4)

On the measure of perceptual anchoring, there was a wide range of scores in both groups. One participant in the LWD group could not perform the no-reference condition even after four factor increases and 80 practice trials and was excluded from the JND analyses. In addition, one outlier in each of the two groups was removed prior to the analyses.

To measure the relative benefit of the reference tone the two conditions were compared within each group with a Wilcoxon signed-rank test for related samples. The LWD group did not differ on the two conditions (*Mdn* = 1.18, *z* = -1.60, *p* = 0.11) whereas the TL group differed significantly (*Mdn* = 0.66, z = -2.65, p < 0.01). A two-way repeated measures ANOVA was conducted to compare the groups on the reference and no-reference conditions. There was no significant interaction between group and condition, Wilks Lambda = .97, $F(1, 34) = 1.12$, $p = 0.30$. There was a substantial main effect for condition, Wilks Lambda = .62, $F(1, 34) = 20.80$, $p < 0.0001$, with both groups performing better on the reference condition than on the no reference condition (Figure 5). A significant main effect for group, $F(1, 34) = 5.04$, $p < 0.05$ was noted with the TL group performing better (i.e., lower JND) at *M* = 0.63 (*SE* = 0.12) than the LWD group (*M* = 1.05, *SE* = 1.41). Thus, the groups differed with regard to the JND measures but both demonstrated perceptual anchoring to the reference tone. Moreover, the LWD and TL groups benefited similarly from the reference tone, results that are inconsistent with those of Ahissar and colleagues of a reduced benefit for the reference tone for LWD (e.g., Ahissar, 2007; Banai & Ahissar, 2006, 2010; Oganian & Ahissar, 2012).

3.3 Results: Predicting Word Learning

A hierarchical linear regression analysis was performed for the LWD group to assess whether measures of phonological awareness and perceptual anchoring were significant predictors of word learning performance. The dependent variable was the total number of correct

productions of the novel words across the first four testing times divided by the total number possible. In an effort to keep the number of independent variables to a minimum given the small sample size, one predictor variable was selected for each of the two measures. Both theoretical and statistical characteristics were considered in the selection.

The spelling of sounds was excluded because collinearity diagnostics in SPSS revealed an eigenvalue greater than 3 among the spelling of sounds variable and the two JND factors (with and without a reference). This multicollinearity might have impeded identification of independent contributions of perceptual anchoring and phonological awareness had this measure been included. Additionally, phoneme reversal was selected over nonword repetition as the best factor of phonological awareness, because nonword repetition did not distinguish the groups and was not significantly correlated with word learning. For a measure of perceptual anchoring, a reference advantage variable was computed by subtracting the reference JND score from the no-reference JND score to reflect the relative benefit of the reference tone.

Prior to entering the measures of phonological awareness and perceptual anchoring, verbal working memory was entered into the equation to control for the effect of working memory on word learning, accounting for 25 % of the variance ($F_{change} = 3.98,\ p = 0.07$). The perceptual anchoring measure, reference advantage, when added in step two, accounted for an additional 27% of the variance ($F_{change} = 6.04,\ p < 0.05$), and phonological awareness (phoneme reversal) when added in step three accounted for an additional 39% of the variance ($F_{change} = 38.67,\ p < 0.001$). Perceptual anchoring and phonological awareness contributed independently for significant *F* change and overall model fit of 90% of the variance (87% adjusted). (See Table 6.)

Noteworthy was the marked difficulty on the JND task for the poorest spoken word learners in the LWD group. Seven of the eight lowest performing participants on the spoken word-learning task (below the median score for the LWD group) were also among the eight poorest performers on the JND task in this group (i.e., had the highest JND scores).

A Spearman Rho correlation matrix was constructed for each of the two groups to examine the remaining behavioral measures and their relationship to word learning. Spearman's correlation coefficient was selected over Pearson product-moment correlation due to the group size differences and heterogeneity of scores and standard deviation. Although the participant selection criteria were designed to equate the participant groups for education and vocabulary, significant correlations to word learning for the LWD group were noted on both, although education and vocabulary were not correlated to word learning for the TL group. The highest correlation for the behavioral measures to word learning in the LWD group was for spelling ($\rho = .83$, $p < 0.001$) followed by spatial working memory ($\rho = .65$, $p < 0.01$), and Rey Verbal Learning List B (proactive interference), $\rho = .57$, $p < 0.05$), but not for reading ($\rho = .27$, $p = 0.31$). (See Table 7.) Performance on the spoken word-learning task for the TL group was correlated with Rey Verbal Learning, List B, proactive interference ($\rho = .71$, $p < 0.001$), spelling ($\rho = .60$, $p < 0.01$) and reading ($\rho = .54$, $p < 0.01$). (See Table 8.)

Chapter 4: Discussion

4.1 Introduction

The present study investigated novel spoken-word learning in adults with dyslexia, asking whether two hypotheses developed to explain reading and spelling difficulties could also explain problems with novel spoken-word learning in people with dyslexia. If degraded phonological representations (e.g., Swan & Goswami, 1997) thwarted word learning, a weaker effect of the novel word properties of phonotactic probability and neighborhood density in the word learning task could be expected. In addition, if the LWD did not benefit from the repetitions of the word due to an anchoring deficit (e.g., Ahissar, 2007), a shallower learning curve over testing time was anticipated as compared to the control group.

The expected differences on productions of low and high neighborhood density and low and high phonotactic probability in the TL group were not observed (e.g., Storkel et al., 2006). Neighborhood density differences were also not seen in the LWD group; however, contrary to the prediction of the degraded phonological representations hypothesis that LWD would show a weaker effect of the phonological properties of novel words, the LWD group demonstrated a greater difficulty with learning low phonotactic probability words as compared to high.

Supporting the perceptual anchoring hypothesis, the results confirmed a significant word learning impairment in the LWD, who recalled and produced proportionately fewer novel words over testing times (i.e., additional repetitions) as compared to their control counterparts, without the difficulty in nonword repetition often characteristic of people with dyslexia. In this discussion, I examine the evidence for both degraded phonological representations and an anchoring deficit as catalysts for the word learning challenges of people with dyslexia and

propose a framework for assessing the likelihood an individual will have difficulties with spoken-word learning.

4.2 Phonological Representations – Quality vs. Access

Knowledge of phonotactic probability aids our implicit predictions regarding the position and sequence of phonemes and syllables in words and aids us in perceptually parsing, recognizing, and remembering new words (Edwards, Beckman & Munson, 2004). The absence of significant differences between high and low exemplars of phonotactic probability and neighborhood density in word learning for the typical group, a finding that is contrary to a number of studies in typical learners (Hoover, Storkel & Hogan, 2010; Storkel, Armbruster and Hogan, 2006; Storkel & Maekawa, 2005) suggests that the current set of data may have insufficient power to detect within group effects, despite the addition of a fourth episode to Storkel and colleagues' original three. The incongruent performance of the LWD group on words of high and low phonotactic probability suggests that the phonological representations in LWD are at least as well-specified as in TL for spoken-word learning (and perhaps more so), although an alternative is that the LWD group was more task-sensitive to sublexical influence.[17][18]

What is evident, however, is that the differences between the two groups cannot be adequately (solely) attributed to a poorer performance on words of low phonotactic probability for the LWD. Moreover, in contrast to sensitivity to low and high phonotactic probability and the level of specificity of phonological representations that entails, the LWD group's difficulties with phonological awareness tasks, and in particular, phoneme reversal, suggest that

[17] i.e., Vitevitch (2003) noted differential effects for neighborhood density or phonotactic probability dependent upon the prevalence of words or nonwords as the contextual base, suggesting lexical or sublexical influence. LWD may be more sensitive to sublexical influence, reflected in the phonotactic probability word-learning advantage.
[18] The current study design and data were not designed to disentangle the nature of the degraded phonological representations in the LWD, i.e., either under- or over-specified.

phonological representations, as they are reflected in sensitivity to word-form properties, are dissociable from phonological awareness.

This dissociation of phonological knowledge and phonological awareness has been noted in other studies of people with dyslexia. Typical responsiveness to phonotactic probability in native French-speaking adults with dyslexia in both perception and production was found despite marked difficulties in these same individuals with phonological awareness (Szenkovits, Darma, Darcy & Ramus, 2008). Thomson & Goswami (2010) in their investigation of novel word learning did not find group differences in responsiveness to neighborhood density of words in children with and without dyslexia despite the latter subjects' difficulties with phonological awareness. The tasks of phonological awareness that differentiated our groups –spoonerisms, spelling of sounds, and phoneme reversal – all require "conscious access to phonological representations" (Ramus & Szenkovits, 2008, p. 137). Requisite to this conscious access for both phonological awareness and novel word learning, as mentioned in Chapter 1, is the internal mapping of acoustic input to phonological output while holding a word(s) in working memory for further processing.

The lack of a significant group difference on nonword repetition was surprising. Nonword repetition impairment is typically found in individuals with dyslexia (e.g., Bishop & Snowling, 2004; Kovelman, Norton, Christodoulou, Gaab, Lieberman, Triantafyllou, et al. 2012; Ramus et al., 2003; Szenkovits & Ramus, 2005) and evidence suggesting a genetic basis for nonword repetition difficulties has been found in LWD with a strong familial history of dyslexia (Brkanac, Chapman, Igo, et al., 2008) as well as in children with specific language impairment and familial history of SLI (Gathercole, 2006; Falcaro, Pickles, Newbury, Addis, Banfield, Fisher, et al., 2008). A recent meta-analysis of studies regarding nonword repetition and

dyslexia, Melby-Lervåg and Lervåg (2012) noted that an important predictor of the severity of nonword repetition across the studies was oral language skills. In an attempt to identify shared and distinguishing characteristics of the phonological deficit in specific language impairment vs. dyslexia, Ramus, Marshall, Rosen & van der Lely (2013) recently found non-word repetition did not distinguish the children with dyslexia from the control group[19]. In the present study, exclusion criteria (i.e., history of speech and language difficulties) reduced the likelihood that spoken-word learning difficulties were related to a history of phonological or articulation disorders or specific language impairment. The groups were also matched on a measure of vocabulary. Controlling for these variables may have reduced the probability of nonword repetition difficulties in the participants with dyslexia.

The importance of distinguishing between phonological representations and the access to those representations has recently been highlighted (Perrachione, 2011, 2012; Ramus, Marshall, Rosen & van der Lely, 2013). Although the results of the present study do not discount atypical phonological representations as a reason for word learning difficulties in LWD, the unique contribution of phoneme reversal to the variance in the word learning task suggests a distinction should be made between a deficit in the multilevel requirements of this task of phonological access (i.e., discrimination, parsing, metalinguistic demands, etc.) vs. a deficit in the quality of the intrinsic phonological representations themselves (Perrachione, 2012). A key component of phoneme reversal, working memory, will be discussed next.

4.3 The Role of Working Memory in Word Learning

In order to retain and recall novel words, one has to be able to maintain them in working memory. The TL group outperformed the LWD group on verbal working memory as measured

[19] although the authors suggest a standardized nonword repetition task would have improved discriminability among the groups

by a listening span task. Nevertheless, the measure did not account for any additional variance for word learning over and above the measure of phonological awareness that distinguished both groups, phoneme reversal. The reason verbal working memory may not have accounted for additional variance may lie, in part, in the difference between maintaining real words and novel words in working memory. Short-term maintenance of auditory information in working memory (via the phonological store and articulatory rehearsal) can facilitate recall of items, particularly when familiarity with those items provides associative links. Words therefore have an advantage over nonwords because, through the process of redintegration, or the ability to reconstruct a whole from a part, we are able to use stored lexical representations to refresh our phonological store internally (e.g., Gathercole, 2006).

However, when we learn novel words, we must be able to recognize, store and recall the phonological sequence without the benefit of redintegration. One method is through active top-down rehearsal, using the phonological loop. This facilitates initial processing and may in turn aid in the storage and recall of the sublexical properties of novel words with high phonotactic probability (Gathercole, 2006; Majerus, van der Linden, Mulder, Meulemans, & Peters, 2004; Vitevitch & Luce, 2004). If our LWD participants had had difficulty with nonword repetition, then we would expect poorer performance in the recall of novel words rehearsed in the phonological store. However, unlike previous studies demonstrating nonword repetition difficulties in people with dyslexia, our LWD group did not differ from the control group in this task. Furthermore, the groups did not differ on a measure of spatial working memory, despite the presence of distracter items. Therefore, difficulties with immediate recall cannot explain the novel word-learning challenges of our LWD group. A second process involved in recalling a phonological sequence lies in the creation of an active memory trace and is dependent upon both

implicit and explicit memory processes. These processes facilitate the perceptual anchoring and retention of the active memory trace and are discussed below.

4.4 Perceptual anchoring – Explicit and Implicit Processes

Perceptual anchoring, the ability to build an internal abstract representation of an external stimulus from item-specific repetitions, entails the processing and retention of a stimulus through top-down explicit and bottom-up implicit properties. Perceptual anchoring as measured by the slope of novel word learning was reduced in the LWD group, who, moreover, showed enhanced learning for words of high phonotactic probability over low phonotactic probability. The interaction between phonotactic probability and testing time suggests both properties are influential in word learning.

When an external stimulus such as a novel word is presented, the attention to the word and its active rehearsal increases neural activation. In addition, the auditory-specific repetition leads to an implicit stimulus processing resulting in neural adaptation or repetition suppression (e.g., Buchsbaum & D'Esposito, 2008). Refreshing the stimulus trace relies on the consistency of the repetition and the integrity of the neural suppression. If the suppression is less robust due to impairment in processing or in neural responsiveness, there is more opportunity for interference and less anchoring, thus degrading the specificity of the internal referent and interfering with recall of the next repetition of the external stimulus (Chandrasekaran, et al., 2009). The timing and context of stimulus presentation seem to be particularly important. For example, competition due to close phonological similarity between a target novel word and other concurrently presented words can interfere with trace recall and perceptual trace formation for both known word cohorts (Kapnoula, Packard, Apfelbaum, McMurray & Gupta, 2012) and novel word cohorts (Zhao, 2013). High phonotactic probability sequences have an advantage

over low ones for memory recall and retention (Frisch, Large, & Pisoni, 2000; Thorn & Frankish, 2005) and may be less vulnerable to this interference. Nevertheless, processing involves attention as well as a neural response to the regularities of the speech stimulus. Focused attention, silent rehearsal, and mnemonic or other associative learning skills are explicit processes that can facilitate word learning (Gupta, 2003; McMurray, Horst & Samuelson, 2012; van Hell & Mahn, 1997) and support the recall of novel words.

Whereas the word-learning task involved both explicit and implicit processes, the pure-tone JND frequency discrimination task was largely implicit. Upon completion of the task, the participants were asked if they noticed any differences between the trials. Two participants (one in each group) noted the repetition of one of the tones, but neither was able to explain whether or how that knowledge might have improved their performance.

Inconsistent with Ahissar and colleagues' findings of reduced perceptual anchoring in adult LWD (Oganian & Ahissar, 2012)[20], the LWD and TL groups of the current study both demonstrated a perceptual anchoring benefit on the JND task and did not differ with regard to the degree of benefit. Nevertheless, the LWD group's performance on the JND task for the reference advantage measure significantly improved model prediction, thus accounting for unique variance on the word-learning task. Impaired frequency discrimination in individuals with dyslexia has been well documented (e.g., Sebastian & Yasin, 2008). Not surprisingly, therefore, the LWD group had significant difficulty performing this task and received higher JND scores than the TL group. Moreover, the poorest word learners in the LWD group were also the poorest at the JND task, whereas this was not the case for the TL group. The LWD group's reduced performance on word learning across testing times relative to the TL group and

[20] rather than their earlier findings in young adolescents with a history of reading and/or other learning disabilities of an absence of perceptual anchoring (Ahissar, 2007; Banai & Ahissar, 2006)

the variance explained by the reference advantage measure suggest that LWD do benefit from stimulus-specific repetitions but require more repetitions to amalgamate and produce novel words accurately.

The results of this study also point to the interactive role of explicit and implicit processing given repeated stimuli. Unlike the novel spoken-word learning task with its string of phonemes to parse and recall, the RAVLT task involved repetitions of real words as the participants were asked to hold in memory and repeat back a list of common nouns. The first list of words did not significantly distinguish the TL and LWD groups, but the second set that contained very similar stimuli to the first, but in the presence of proactive interference, did. The LWD may have experienced an anchoring disadvantage due to interference from previous semantic and phonological traces.

When phonological awareness was factored out as a predictor for the LWD group, the best predictor for word learning accuracy was spelling. This relationship, while obvious, appears to be more crucial for the LWD than the TL group. The ability to segment and spell words may positively influence word learning by creating an associative basis for recall and difficulties with spelling can negatively affect word learning. Howland and Liederman (2013) recently employed Storkel et al.'s (2006) testing protocol to investigate both written and spoken pseudoword learning in young adults with dyslexia. The authors presented a set of two stories of six episodes each to the participants, half the time with written words presented first and half the time with spoken words first. When the irregularly spelled words were presented first in written form and then in the spoken modality, the adults with dyslexia –but not those without-- performed significantly more poorly than in the spoken-first condition. Group differences were not noted

for regularly spelled words. The authors suggested that seeing the irregular spellings thwarted verbal learning for the LWD group.

4.5 Clinical Implications

To return to the research question regarding the relative contributions of phonological knowledge and perceptual anchoring to novel spoken-word learning in adults with dyslexia, both processes appear to be instrumental in novel spoken-word learning whether they are involved implicitly (phonotactic probability and reference advantage) or explicitly (phoneme awareness and a verbal learning task) or both. The relative strength of underlying skills such as working memory, spelling and phoneme awareness, attention and inhibition (i.e., as in interference) for individuals with language learning challenges may differentially affect novel spoken-word learning.

The results of this investigation can inform teachers in helping LWD with second language-learning difficulties. Tasks of verbal learning (RAVLT) and phoneme awareness -as measured by phoneme reversal- should be included as subtests to screen for language learning difficulties. Dynamic assessment of word learning, i.e., measuring the rate of change in performance following instruction, could also be utilized, much the same way as in the spoken-word learning paradigm used in this study. Good spatial working memory was correlated with word learning in my LWD group, so further study to investigate the role of spatial working memory in language learning could be explored.

An important aspect of second language learning that was not addressed by this study is the influence on word learning that a new system of phonemes has, one with unfamiliar phonotactic probability. Training in speech discrimination and phoneme recognition with the new sound system would be particularly important for the LWD population. Access to a second

language for school-age children and adults is routinely through literacy instruction. The traditional multi-sensory instruction for reading instruction in the first language in LWD would also apply for the new language.

4.6 Conclusion

A principal goal of this investigation was to elucidate the process of novel spoken-word learning in LWD and how that process differed from that of TLs. Specifically, The LWD in this study were carefully screened to ensure that their vocabulary performance was comparable to the TL and that none of the participants had any history of speech or language difficulties or ADHD. Nonetheless, word learning was harder for LWD and they learned progressively fewer words over time. They produced more words of high phonotactic probability than low, but this did not account for the spoken-word learning deficit observed. LWD required more repetitions to learn words and relied more heavily on verbal working memory than TL. Spelling ability was positively correlated with word learning in the LWD, as was spatial working memory, although to a smaller degree than verbal working memory. For the TL, sensitivity to phonotactic probability did not influence accuracy in spoken-word learning, which was highly correlated with verbal learning of real words.

A second objective was to determine if current hypotheses regarding the basis of reading difficulties could explain why LWD have difficulty with spoken-word learning. The results suggested that a combination of the two hypotheses studied better accounted for LWD performance. Support for the phonological representations hypothesis was seen in measures of phonological access (Ramus & Szenkovits, 2008) such as poorer performance relative to TL on phoneme reversal and spelling of sounds, but not on phonological knowledge (PP or ND) or phonological memory (nonword repetition). Support for the perceptual anchoring hypothesis

was provided by the reduced rate of word learning in the experimental task for LWD, but not by their results on the JND frequency task. A concern with this latter task is the issue of separating frequency discrimination ability from perceptual anchoring ability. Poorer results or a smaller gap between the two conditions (as noted by Ahissar, 2006, 2007) for LWD relative to controls might be reflective of a greater difficulty with the task itself and not of anchoring in general. This point was recently addressed by Oganian & Ahissar (2012) who employed three tasks (tones, orally presented syllables and written words) to detect and measure anchoring ability, each with a pair of conditions of repeating vs. non-repeating stimuli. LWD were compared with a TL and an ADHD group on these and other tasks to differentiate the effects of attention and anchoring. In contrast to the TL and ADHD groups, the LWD group demonstrated a difficulty with anchoring independent of attention and for all three tasks, suggesting the anchoring challenge for LWDs is not limited to frequency discrimination. (See Perrachione, 2012.)

The results of the current study highlight the complexity of spoken-word learning. The list of processes involved is imposing; concentration, attention to detail, attunement to phonological sequences, forming the perceptual referent, holding novel words in memory, preserving their sounds, resisting interference, inhibiting other related real words, recalling the words for articulatory production. Trying to pull apart the relative contributions of phonological knowledge and perceptual anchoring to spoken-word learning may be too simplistic.

There is recent evidence to suggest that the development of phonological knowledge in people with dyslexia can occur normally despite impairment in phonetic discrimination (Berent, et al., 2012). Indeed, a phonetic deficit has recently been highlighted in work by Perrachione (2012) who demonstrated a voice recognition deficit in people with dyslexia. In his study, young adults with dyslexia were as accurate as controls in distinguishing voices of people speaking an

unfamiliar language, Chinese, but were significantly poorer than controls in recognizing speakers' voices in English, their native language. The accurate recognition of a speaker's identity in one's native language is dependent upon the detection of fine prosodic and phonetic differences and thus the difficulty of their group with dyslexia was thought to be related to a low-level phonetic deficit. Perrachione suggests that the implicit processing of the acoustic detail of phonetic information is disrupted in dyslexia, leading to deficits in neural adaptation. This returns us to the two hypotheses of the current study and the question of where the deficit in LWD lies. Is the deficit in neural adaptation (as in perceptual anchoring) a precursor to, or the result of, the problem of oversensitivity to phonetic detail (possibly leading to poorly specified representations)? A step toward answering this question would be to extend this study's investigation of the effects of phonotactic probability and neighborhood density by examining the performance of different age groups of LWD under a variety of task conditions using behavioral and neurophysiological measures.

Tables

Table 1: Participant Data[21]

Biographical & Behavioral Data		TL			LWD			Group Differences
Behavioral Data	**Measure**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Independent Samples Median Test**
Age	in years	25.43	4.24	23	26.94	4.01	16	*0.58*
Education	in years	15.26	1.84	23	15.69	2.91	16	*0.83*
Vocab	PPVT-R	161.22	8.00	23	157.19	9.85	16	*0.25*
IQ	TONI-3	35.13	5.45	23	34.27	5.05	16	*0.69*
Reading Rate*** (wpm)	Reading Rate* (wpm)	177.13	22.72	23	114.56	23.16	16	*p < 0.0001*
Reading Efficiency***	TOWRE	158.52	7.31	23	115.06	16.04	16	*p < 0.0001*
Spelling Words***	WJ-III	49.48	3.72	23	41.06	5.23	16	*p < 0.0001*
Spelling Sounds***	WJ-III	35.95	1.89	22†	29.88	4.50	16	*p < 0.0001*
Spoonerisms*	Perin	34.39	2.37	23	28.67	9.65	15	*p < 0.05*
Nonwd Rep	CTOPP	13.00	2.49	23	12.07	2.66	16	*0.26*
Phoneme Reversal***	CTOPP	12.91	2.83	23	7.07	3.24	15	*p < 0.00001*
Spatial WM	Lewandowsky et al.	166.81	18.86	21†	159.40	16.53	16	*0.40*
Verbal WM*	Obler et al.	67.00	11.39	23	58.73	8.96	16	*p < 0.05*
Verbal Learning 1	Rey's Verbal Learning_A	37.26	5.56	23	34.27	5.89	16	*0.09*
Verbal Learning 2 - Interference*	Rey's Verbal Learning_B*	35.57	7.42	23	29.73	7.28	16	*p < 0.05*
Verbal Learning 3 - Recall of List A	Rey's Verbal Learning_C	2.96	2.62	23	3.44	2.68	16	*0.58*
Perceptual Anchor – No Reference* (log)	Ahissar et al., Roving	0.86	0.58	22‡	1.23	0.54	14‡	*0.08*
Perceptual Anchor – Reference (log)	Ahissar et al., Standard Lower	0.63	0.62	22‡	1.06	0.57	14†	*p < 0.05*
*p < 0.05 ***p < 0.00001	†missing data ‡outliers							

[21] Scores are raw scores unless otherwise noted.

Table 2: Novel words by phonotactic probability and neighborhood density

Semantic Category	HighPP HighND	HighPP LowND	LowPP HighND	LowPP LowND
candy	pim	hɑn	jeɪm	faʊg
toy	joʊn	nɛp	feɪg	wib
music	mɛk	paɪb	ʧop	jʌd
pet	wæd	jɪb	lʊd	fuv

Table 3: Phonotactic probability and neighborhood density of novel words

High-Probability Novel Words				
Nwd	**D-PP**	**Density**	**PosPP***	**BPhPP***
pim	H-H	13	0.1656	0.0035
joʊn	H-H	12	0.1533	0.0027
mɛk	H-H	14	0.1836	0.0130
wæd	H-H	17	0.1377	0.0031
Mean	H-H	14	0.1601	0.0056
SD	H-H	2.16	0.0194	0.0050

Low-Probability Novel Words				
Nwd	**D-PP**	**Density**	**PosPP***	**BPhPP***
jeɪm	H-L	13	0.0865	0.0017
feɪg	H-L	12	0.0937	0.0022
lʊd	H-L	13	0.0823	0.0016
ʧop	H-L	15	0.0953	0.0014
Mean		13.25	0.0895	0.0017
SD		1.26	0.0061	0.0003

Nwd	**D-PP**	**Density**	**PosPP***	**BPhPP***
hɑn	L-H	4	0.1960	0.0156
nɛp	L-H	6	0.1338	0.0052
jɪb	L-H	4	0.1301	0.0026
paɪb	L-H	5	0.1447	0.0028
Mean	L-H	4.75	0.1512	0.0066
SD	L-H	0.96	0.0305	0.0061

Nwd	**D-PP**	**Density**	**PosPP***	**BPhPP***
faʊg	L-L	4	0.0742	0.0006
jʌd	L-L	4	0.0851	0.0013
wib	L-L	6	0.0781	0.0015
fuv	L-L	4	0.0923	0.0007
Mean		4.5	0.0824	0.0010
SD		1.00	0.0080	0.0004

Table 4: Best Fit Model

Novel word production accuracy (correct, incorrect)

Fixed effects		Coef	Std. Error	*z*	*p*
Intercept		-1.56	0.30	-5.28	<0.00001
Group		-2.74	0.62	-4.43	<0.00001
TT (testing time)		1.73	0.30	5.86	<0.00001
TT_Q (testing time quadratic)		-0.18	0.09	-1.95	=0.05
PP		-0.93	0.41	-2.28	<0.05
GroupxTT		1.98	0.70	2.84	<0.01
GroupxTT_Q		-0.56	0.19	-2.98	<0.01
TTxPP		0.85	0.45	1.88	=0.06
TT_QxPP		-0.22	0.14	-1.61	=0.10
GroupxPP		2.03	0.74	2.76	<0.01
GroupxTTxPP		-2.96	0.90	-3.27	<0.01
GroupxTT_QxPP		0.76	0.25	3.02	<0.01
Random effects		**Variance**	**Std. Dev.**	**Corr**	
Part	Intercept	0.48	0.69		
	PP	0.17	0.41	0.22	
	TT	0.02	0.14	0.93	-0.142
Target_No	Intercept	0.25	0.50		
	TT	0.01	0.10	1.00	

Table 5: Model Selection

Novel word production accuracy (correct, incorrect)								
							LR test	
Model	Fixed Effects (re - random effects)	Deviance	df	AIC	BIC	Comparison	$\chi^2(df)$	p
m0	(re:part, items)	3091	3	3097	3114	--	--	--
m1	TT (re:part, items)	2441	8	2457	2503	m0-m1	650.28(5)	< 0.00001
m2	TT, TT_Q(re:part, items)	2408	9	2426	2478	m1-m2	33.14 (1)	< 0.00001
m3	TT, TT_Q, PP, (re:part, items)	2403	13	2429	2505	m2-m3	4.62(1)	(ns)=0.33
m4	TT, TT_Q, ND†, (re:part, items)	2395	13	2421	2496	m2-m4	12.99(4)	<0.05
m5	Group, TT, TT_Q, (re:part, items)	2391	10	2411	2469	m2-m5	16.51(1)	<0.0001
m6	Group, TT, TT_Q, PP, (re:part, items)	2387	14	2415	2496	m5-m6	4.49(4)	(ns)=0.34
m7	Group, TT, TT_Q, ND†, (re:part, items)	2375	14	2403	2485	m5-m7	15.713(4)	<0.01
m8	Group, TT, TT_Q, ND, PP, (re:part, items)	2371	19	2409	2519	m7-m8	4.78(5)	(ns)=0.44
m9	Group, TT, TT_Q, PP, GroupxPP, GroupxTT_QxPP, TTxPP, TT_QxPP, (re:part, items)	2383	19	2421	2532	m5-m9	7.93(9)	(ns)=0.54
m10	Group, TT, TT_Q, ND, GroupxND, GroupxTT_QxND, TTxND, TT_QxND (re:part, items)	2370	19	2408	2519	m7-m10	5.12(5)	(ns)=0.40
m11	**Group*TT*PP, TT_Q, GroupxTT_Q, PPxTT_Q, GroupxTT_QxPP(re:part, items)**	**2371**	**21**	**2413**	**2536**	**m5-m11**	**19.84(11)**	**<0.05**
m12	Group*TT*ND, TT_Q, GroupxTT_Q, NDxTT_Q, GroupxTT_QxND(re:part, items)	2370	21	2412	2534	m7-m12	5.40(7)	(ns)=0.61
	†Non-significant main effect							

Table 6: Regression Analysis- LWD

This table summarizes the effects of the predictors of verbal working memory, perceptual anchoring (reference advantage) and phonological awareness (phoneme reversal) for the LWD group.

Model Summary For Learners With Dyslexia

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					ANOVA	
					R Square Change	F Change	df1	df2	Sig. F Change	F	Sig
1	.499	.249	.186	.1378875	.249	3.976	1	12	.069	3.976	.069
2	.718	.515	.427	.1157100	.266	6.041	1	11	.032	5.843	.019
3	.949	.900	.870	.0550077	.385	38.673	1	10	.000	30.128	.000

1. Predictors: Verbal Working Memory
2. Predictors: Verbal Working Memory, Reference Advantage
3. Predictors: Verbal Working Memory, Reference Advantage, Phoneme Reversal

Coefficients For Learners With Dyslexia

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	.325	.041		7.946	.000					
	C_VerbalWM	.008	.004	.499	1.994	.069	.499	.499	.499	1.000	1.000
2	(Constant)	.361	.037		9.669	.000					
	C_VerbalWM	.008	.003	.492	2.345	.039	.499	.577	.492	1.000	1.000
	RefAdv	-.242	.098	-.516	-2.458	.032	-.522	-.595	-.516	1.000	1.000
3	(Constant)	.453	.023		19.620	.000					
	C_VerbalWM	.003	.002	.182	1.630	.134	.499	.458	.163	.800	1.250
	RefAdv	-.331	.049	-.706	-6.766	.000	-.522	-.906	-.675	.914	1.094
	C_PhonRev	.031	.005	.719	6.219	.000	.613	.891	.621	.746	1.340

a. Dependent Variable: Correct

Table 7: Correlation Matrix - Typical Learners

Spearman Correlation																		
TL Group																		
Vocab	Corr Coeff	1.000																
	Sig. (2-tailed)																	
IQ	Corr Coeff	-.090	1.000															
	Sig. (2-tailed)	.683																
Education	Corr Coeff	-.103	-.162	1.000														
	Sig. (2-tailed)	.640	.461															
ReadingRate	Corr Coeff	.115	-.171	.289	1.000													
	Sig. (2-tailed)	.603	.434	.181														
Spelling	Corr Coeff	**.480***	-.148	-.063	-.005	1.000												
	Sig. (2-tailed)	**.021**	.501	.774	.983													
TOWRE	Corr Coeff	.405	-.363	-.091	0.38	**.561****	1.000											
	Sig. (2-tailed)	.055	.089	.679	.077	**.005**												
NonwordRep	Corr Coeff	**.445***	.153	.071	.179	**.641****	.348	1.000										
	Sig. (2-tailed)	**.033**	.487	.749	.413	**.001**	.104											
PhonReversal	Corr Coeff	.385	0.25	-.172	.036	.378	.144	.334	1.000									
	Sig. (2-tailed)	.070	.248	.434	.871	.076	.513	.119										
SpellingSounds	Corr Coeff	.311	.192	.101	.161	.111	.169	.326	.335	1.000								
	Sig. (2-tailed)	.159	.393	.654	.475	.623	.453	.139	.128									
SpatialWM	Corr Coeff	-.051	.341	-.249	-.144	.243	.125	.213	.051	.177	1.00							
	Sig. (2-tailed)	.827	.130	.276	.534	.289	.588	.354	.827	.442								
VerbalWM	Corr Coeff	**.444***	.065	-.356	.011	.380	.313	**.493***	**.430***	.352	.395	1.000						
	Sig. (2-tailed)	**.034**	.768	.096	.959	.074	.146	**.017**	**.041**	.108	.076							
ReyListA	Corr Coeff	.060	.023	-.048	.022	.345	.265	.139	.001	.130	**.656****	.400	1.000					
	Sig. (2-tailed)	.786	.916	.827	.921	.107	.222	.528	.998	.565	**.001**	.058						
ReyListB	Corr Coeff	.099	-0.27	.301	.205	.215	.111	.016	.293	.302	.096	.379	**.464***	1.000				
	Sig. (2-tailed)	.652	.210	.163	.348	.324	.613	.943	.175	.172	.680	.075	**.026**					
ReyRecallA	Corr Coeff	.295	.147	-.068	-.277	.314	.019	.345	.363	.143	**.566****	.217	.286	.051	1.000			
	Sig. (2-tailed)	.171	.504	.758	.200	.145	.933	.107	.089	.525	**.008**	.319	.185	.818				
Correct	Corr Coeff	.303	-.274	.115	.228	**.597****	**.542****	.291	**.562****	.321	-.012	**.448***	.397	**.708****	.122	1.000		
	Sig. (2-tailed)	.160	.206	.602	.295	**.003**	**.008**	.179	**.005**	.145	.959	**.032**	.060	**.000**	.580			
LogRef	Corr Coeff	-.259	-.254	-.262	-.305	-.039	-.109	-.263	-.278	**-.560****	.186	-.043	.028	-.154	.046	-.139	1.000	
	Sig. (2-tailed)	.232	.242	.227	.158	.860	.619	.225	.199	**.007**	.420	.847	.898	.483	.833	.528		
LogNoRef	Corr Coeff	-.316	-.085	.079	**-.476***	-.286	**-.426***	-.381	-.322	**-.457***	-.120	-.400	-.088	-.213	-.041	-.264	**.717****	1.000
	Sig. (2-tailed)	**.142**	.700	.722	**.022**	.185	**.042**	.073	.134	**.033**	.604	.058	.689	.328	.853	.224	**.000**	
		Vocab	IQ	Education	Reading Rate	Spelling	TOWRE	Nonword Rep	PhonReversal	Spelling of Sounds	SpatialWM	VerbalWM	ReyA	ReyB	ReyF	Correct	LogRef	LogNoRef

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 8: Correlation Matrix - Learners with Dyslexia

Spearman Correlation																		
LWD Group																		
Vocab	Corr Coeff	1.000																
	Sig. (2-tailed)																	
IQ	Corr Coeff	**.675****	1.000															
	Sig. (2-tailed)	**.004**																
Education	Corr Coeff	.451	**.527***	1.000														
	Sig. (2-tailed)	.079	**.036**															
ReadingRate	Corr Coeff	**.517***	.419	.414	1.000													
	Sig. (2-tailed)	**.040**	.106	.111														
Spelling	Corr Coeff	**.695****	**.500***	**.665****	.374	1.000												
	Sig. (2-tailed)	**.003**	**.048**	**.005**	.153													
TOWRE	Corr Coeff	.407	**.627****	.040	**.649****	.184	1.000											
	Sig. (2-tailed)	.117	**.009**	.882	**.007**	.495												
NonwordRep	Corr Coeff	-.025	.182	.178	-.333	.029	-.287	1.000										
	Sig. (2-tailed)	.928	.500	.509	.207	.914	.281											
PhonReversal	Corr Coeff	.470	**.805****	.419	.243	.352	.474	.271	1.000									
	Sig. (2-tailed)	.066	**.000**	.107	.365	.181	.064	.310										
SpellingSounds	Corr Coeff	.109	.050	.157	.022	.440	.015	-.121	.244	1.000								
	Sig. (2-tailed)	.689	.855	.562	.935	.088	.957	.655	.362									
SpatialWM	Corr Coeff	**.703****	**.775****	**.500***	.240	**.590***	.465	.371	**.619***	.024	1.000							
	Sig. (2-tailed)	**.002**	**.000**	**.048**	.371	**.016**	.069	.157	**.011**	.931								
VerbalWM	Corr Coeff	**.713****	**.630****	.294	.294	**.562***	**.510***	.056	.338	.021	**.701****	1.000						
	Sig. (2-tailed)	**.002**	**.009**	.268	.269	**.024**	**.044**	.838	.201	.939	**.003**							
ReyListA	Corr Coeff	**.603***	**.606***	**.704****	**.722****	**.601***	.426	-.011	.237	.097	**.515***	.432	1.000					
	Sig. (2-tailed)	**.014**	**.013**	**.002**	**.002**	**.014**	.100	.967	.377	.721	**.041**	.095						
ReyListB	Corr Coeff	.392	**.702****	.472	.491	.418	**.594***	-.086	**.507***	.173	.364	.361	**.684****	1.000				
	Sig. (2-tailed)	.133	**.002**	.065	.053	.107	**.015**	.751	**.045**	.523	.165	.169	**.003**					
ReyRecallA	Corr Coeff	**.590***	.274	**.512***	.359	.369	-.008	.036	.137	-.089	.327	.167	**.572***	.340	1.000			
	Sig. (2-tailed)	**.016**	.304	**.043**	.172	.160	.978	.896	.612	.744	.216	.536	**.021**	.198				
Correct	Corr Coeff	**.691****	.610*	**.691****	.334	**.830****	.272	.225	**.564***	.372	**.652****	**.617***	**.539***	**.571***	.487	1.000		
	Sig. (2-tailed)	**.003**	.012	**.003**	.206	**.000**	.307	.402	**.023**	.156	**.006**	**.011**	**.031**	**.021**	.056			
LogRef	Corr Coeff	**-.528***	-.403	-.238	-.237	-.477	-.414	-.265	-.486	-.205	**-.634****	-.394	-.250	-.199	-.133	**-.600***	1.000	
	Sig. (2-tailed)	**.036**	.121	.375	.377	.061	.111	.321	.057	.447	**.008**	.131	.351	.461	.624	**.014**		
LogNoRef	Corr Coeff	-.399	-.272	-.076	-.040	-.243	-.217	-.266	-.129	-.375	-.339	-.104	-.249	.040	-.498	**.867****	1.000	0.064
	Sig. (2-tailed)	.140	.326	.787	.889	.382	.436	.337	.647	.168	.216	.712	.371	.887	.059	**.000**		0.820
		Vocab	IQ	Education	Reading Rate	Spelling	TOWRE	Nonword Rep	PhonReversal	Spelling of Sounds	SpatialWM	VerbalWM	ReyA	ReyB	ReyF	Correct	LogRef	LogNoRef

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Figures

Figure 1: Word Learning – Correct Productions by Group

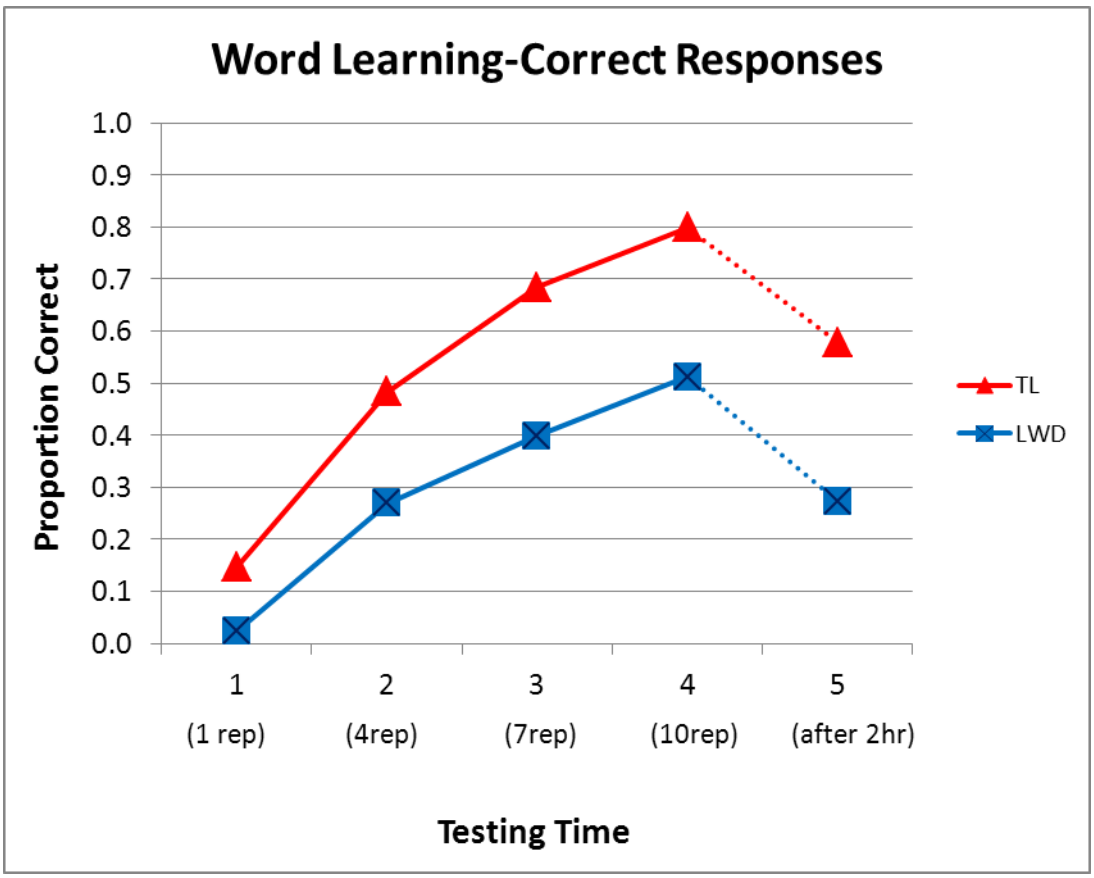


Figure 2: Phonotactic Probability over Testing Time by Group

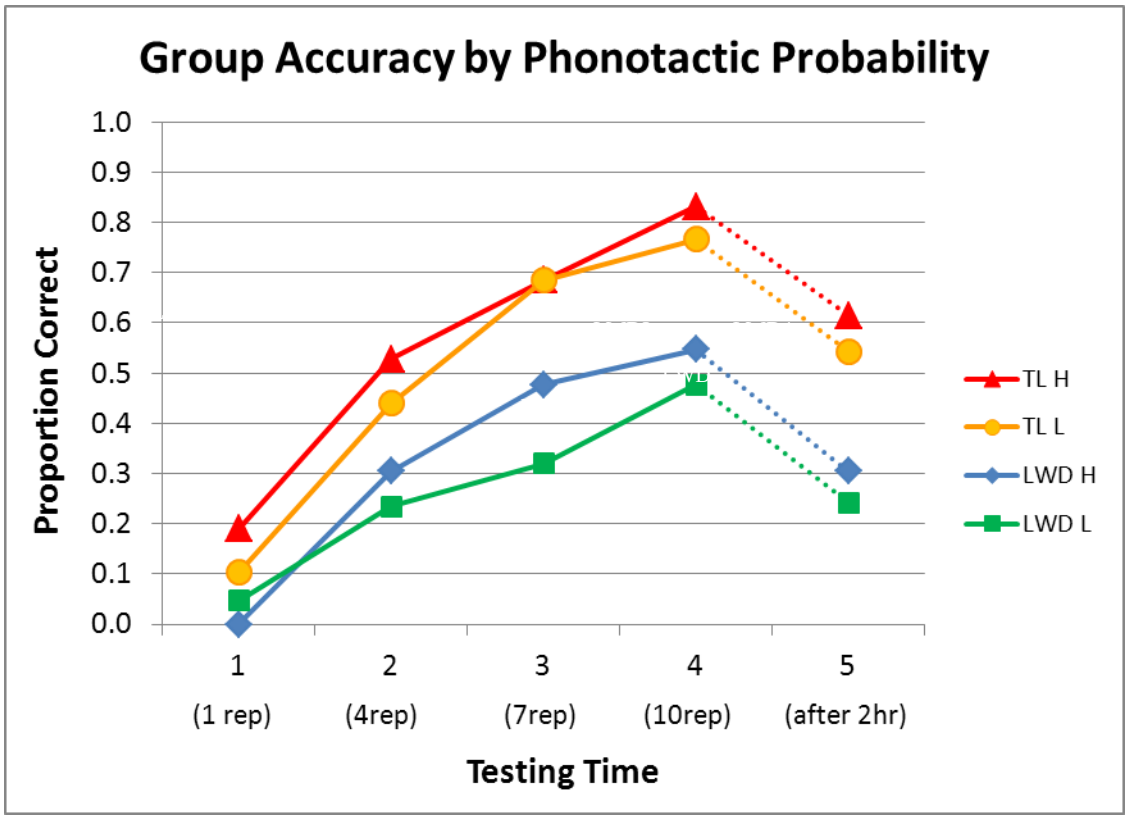


Figure 3: Neighborhood Density over Testing Time by Group

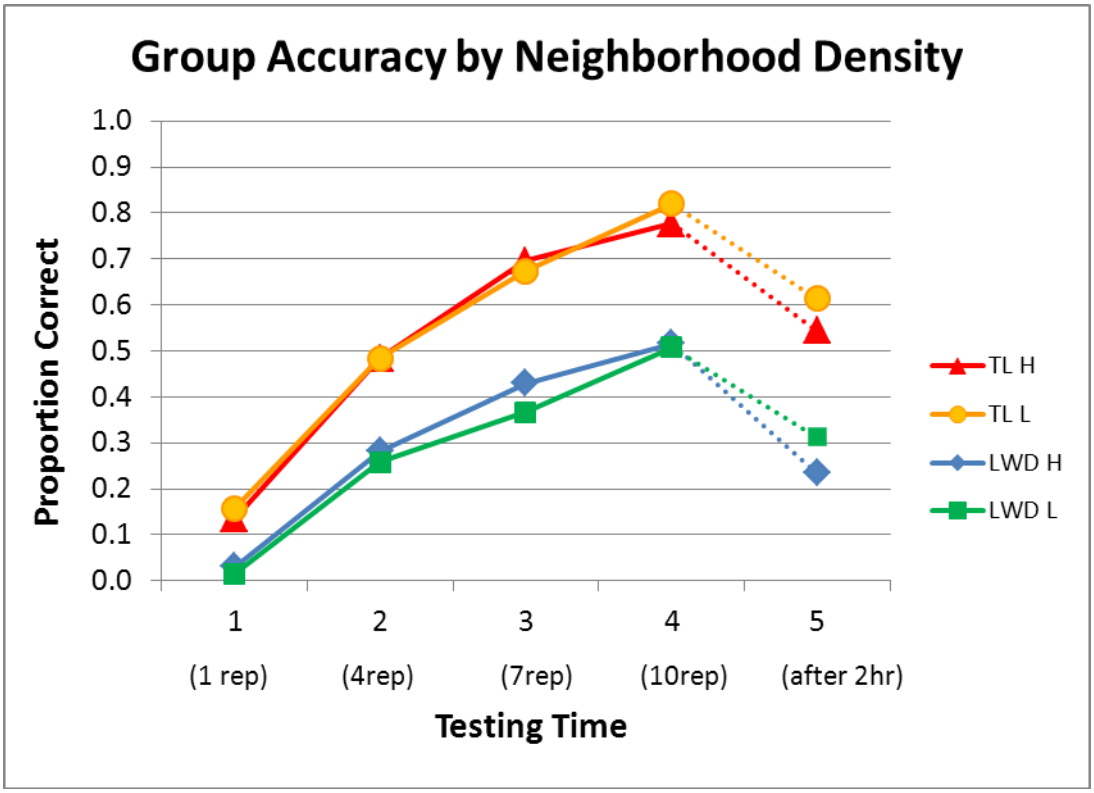


Figure 4: Best Fit Model: Observed vs. Fitted Values

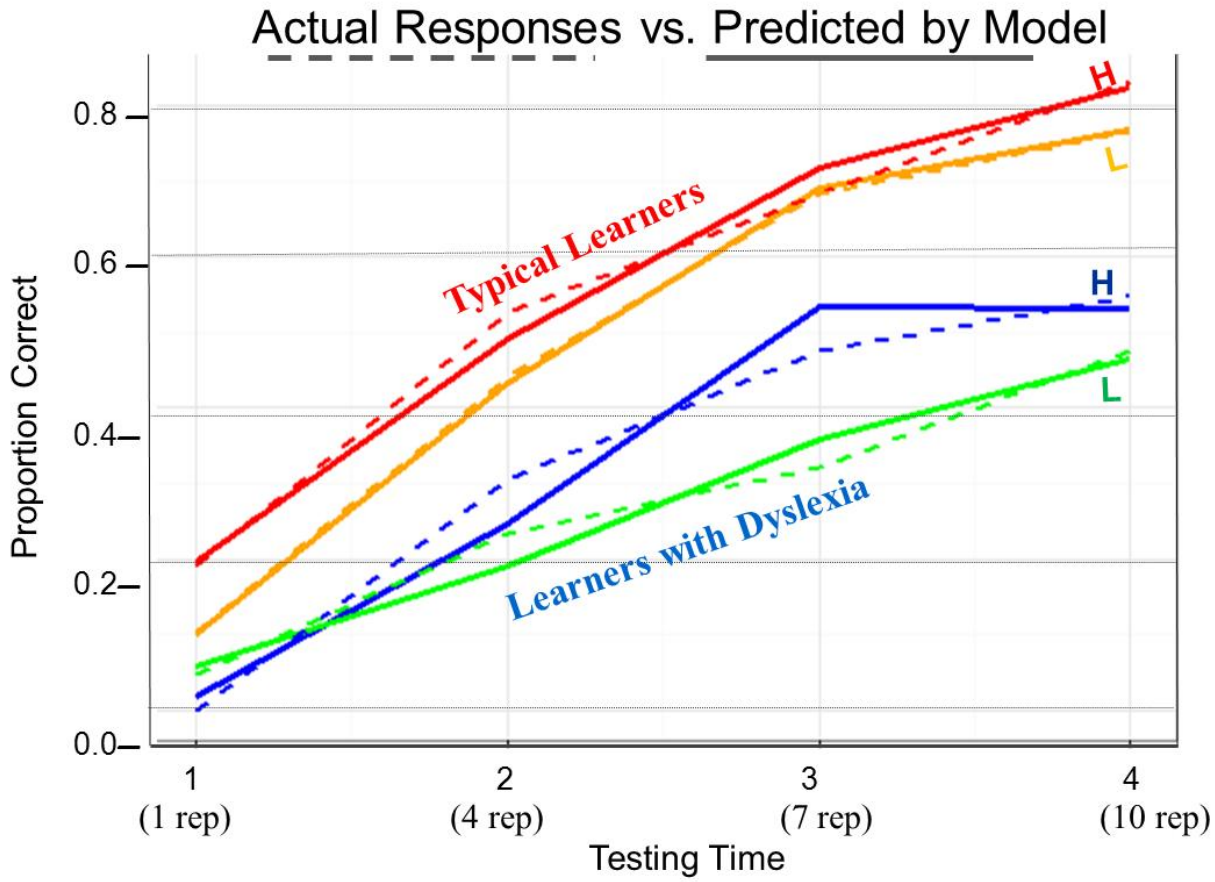
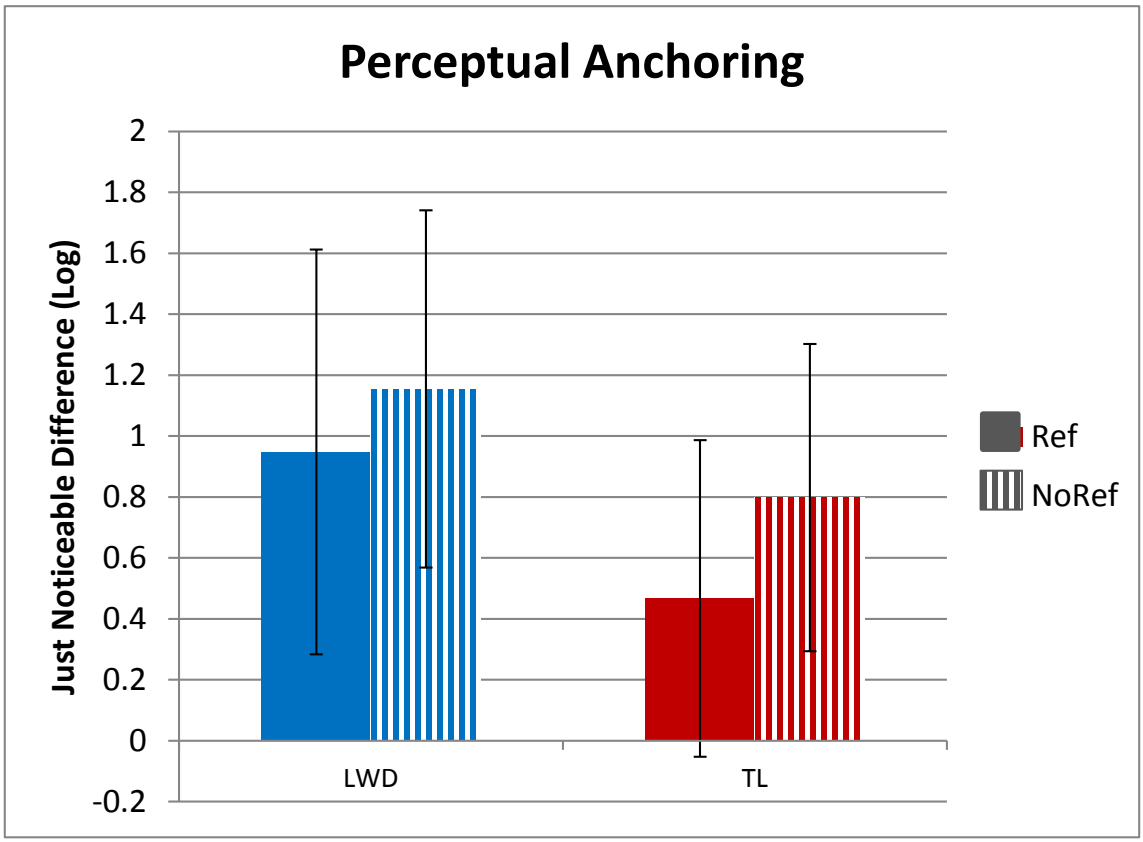


Figure 5: Perceptual Anchoring Results – Two-tone comparison



***Error bars represent standard deviation**

Appendices

Appendix A: Contact Sheet and Questionnaire

Today's Date: _____ Participant Number: _____

Your Date of Birth: _____ Gender M F

Years of Education completed: _____ High school (#yrs)
_____ College (# years)
_____ Advanced degree (2 M.S., 5 PhD)
_____ total

Occupation (current) _____
(former) _____

Is American English your native language? _____
If not what language did you first speak? _____

Where were you born? _____
(Followup) When did you move here? _____

Was any other language spoken in your home when you were growing up? _____
If yes which language? _____

What other languages have you studied? [Place rating next to each language as below]
_____ _____ _____ _____ _____

Rate how well you speak each of them.

1. _____not well
2. _____fair (I can speak but my grammar is poor)
3. _____ ok (I make errors but can communicate pretty well)
4. _____ very well (fluent or like a native speaker)

How old were you when you spoke each language the best? [Note rating for each at best age]
_____ _____ _____ _____ _____

Did you ever live abroad? _____ If so, for how long? _____

What is your handedness? _____left _____right _____ ambidextrous

Did you have difficulty learning to speak growing up? _____Yes _____No

Learning to read? ____Yes _____No

If yes for either please describe _____

How is your spelling? _____

Have you received tutoring in elementary or high school or college? Y or N

For what academic subjects?_____
_____

_____

(Followup:) Have you ever been told you were dyslexic? _____

Do you currently receive accommodations in college/school? _____

_____

Does anyone in your family have speech or reading difficulties? _____

Have you ever been diagnosed with a problem of attention or concentration (ADHD)?

Are you currently taking medication that could interfere with your attention/concentration?

_____

Have you ever had a head injury or concussion? _____

A stroke or other neurological problem? _____

If yes, please describe _____

Have you played a musical instrument or sing? _____# yrs_____

Have you ever participated in a study at the CUNY Graduate Center and if so how long ago?

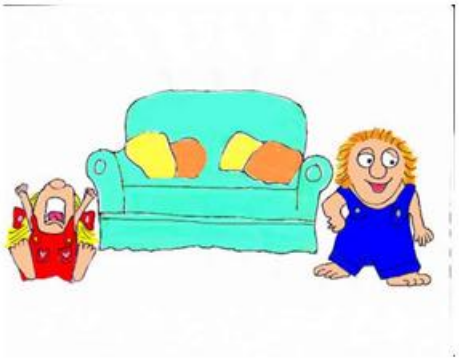
Why have you decided to participate today? _____

Additional Comments:

Appendix B: Word Learning Task Pictures

Story 1A: Word Learning Task

Intro: Ep 1



Conc: Ep 1

Intro: Ep. 2

Conc: Ep. 2

Story 1A: Word Learning Task

Intro: Ep 3

Conc: Ep 3

Intro: Ep 3

Conc: Ep 4

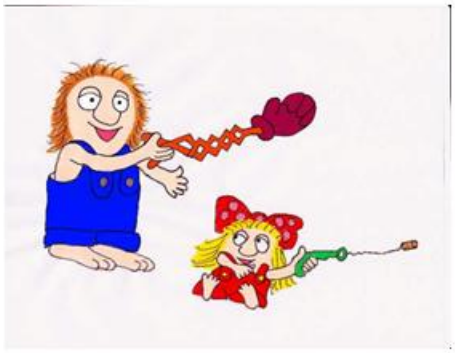
Story 1A: Word Learning Task

pets

candy

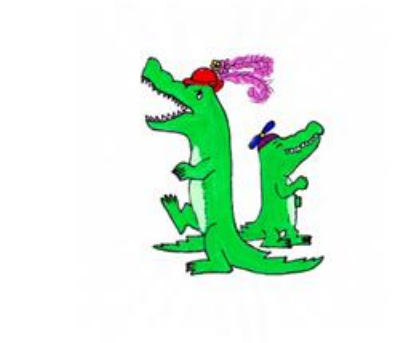
toys

music



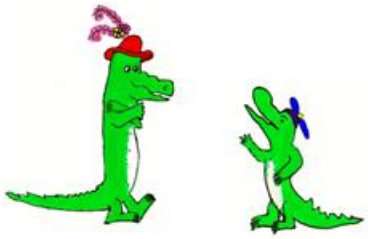
Story 2: Word Learning Task

Intro: Ep. 1

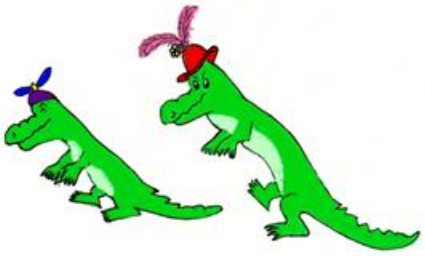


Conc: Ep. 1

Intro: Ep. 2



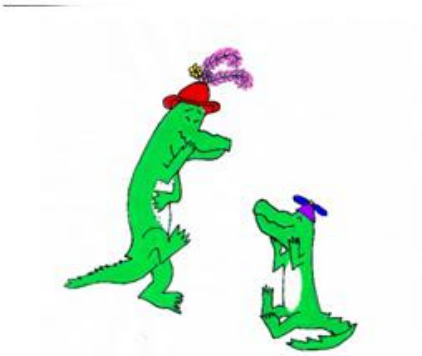
Conc: Ep. 2



Story 2: Word Learning Task

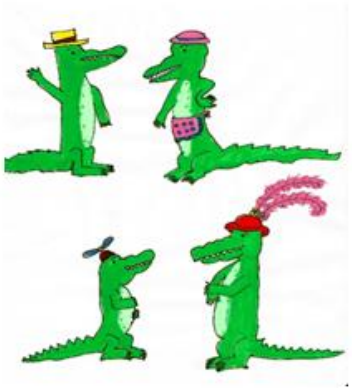
Intro: Ep. 3

Conc: Ep. 3



Intro: Ep. 4

Conc: Ep. 4



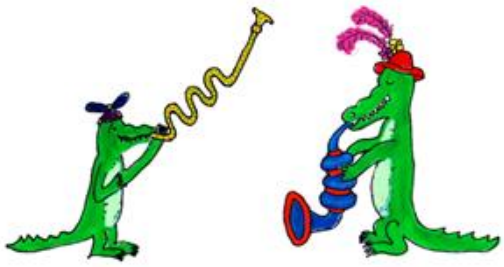
Story 2: Word Learning Task

candy

pets

toys

music



Appendix C: Story Scripts

Story 1+ Template

Episode 1

Plate 1. Mom and dad were at work. Big brother had to take care of little sister. Little sister was crying. Big Brother said "I'll take you to the park if you stop crying."

Plate 2. Big Brother said, "We can go to the candy machines at the park." "My favorite is the_____." Little Sister said, "My favorite is the_____."

Plate 3. Little Sister asked "Can we bring some toys." Big Brother said, "Yes. I'm bringing my _____." Little Sister said, "I'm bringing my _____."

Plate 4. Big Brother said, "We can play music at the park." "I'm taking my _____," Little Sister said, "I'm taking my _____.".

Plate 5. Little Sister asked "What about the pets?" Big Brother said "We'll take them with us. I'll get _____." Little Sister said "I'll get _____."

Plate 6. "Let's go!" said Big Brother. "Yeah!" said Little Sister. They ran all the way to the park. What will they do at the park?

Episode 2

Plate 1. Big Brother and Little Sister were swinging. Big Brother said "I can go higher than you!" Big Brother went very high. Little Sister said "I can go higher than that." Big Brother pushed her very high.

Plate 2. Little Sister said, "I can play music louder than you". Big Brother said "No, you can't." "Listen to me blow my _____," He blew his _____. "See how loud my _____ is?" Little Sister said "Oh, yeah? Listen to me blow my _____" She blew her _____. "See how loud my _____ is?"

Plate 3. Big Brother said "I can eat more candy than you." Big Brother ran to the _____. He got candy from the _____. He stuffed all the candy from the _____ in his mouth. "Can you eat that much?" Little Sister ran to the _____. She got candy from the _____. She stuffed all the candy from the _____ in her mouth. Then, they got more candy for later.

Plate 4. Little Sister said “I can make our pets do more tricks than you.” Big Brother said, “Uh-uh,” Big Brother made _____ do tricks. He made _____ roll-over. He made _____ jump up and down. Next, it was Little Sister’s turn. Little Sister made _____. do tricks. She made _____ roll-over. She made _____ jump up and down.

Plate 5. Big Brother said “I can hit more rocks with my toy than you.” Big Brother set up the rocks. Big Brother got out his _____. He pointed the _____ at the rocks. He hit a rock with his _____. Little Sister put the rock back. Little Sister got out her _____. She pointed the _____ at the rocks. She hit a rock with her _____.

Plate 6. Big Brother looked at his watch. “It’s time to go home.” They walked home hand in hand. What will they play when they get home?

Episode 3

Plate 1. Big Brother and Little Sister were playing hide n’ seek in the back yard. Little Sister was hiding. Big Brother was trying to find her. “Where’s Little Sister?” There she is, behind the tree!

Plate 2. Big Brother said, “Let’s hide our pets.” “I’ll hide _____. Don’t make any noise _____. I bet you won’t be able to find _____” Little Sister looked and looked. “Here he is!” Little Sister said, “I’ll hide _____. Don’t make any noise _____. I bet you won’t be able to find _____” Big Brother looked and looked. “I found him.”

Plate 3. Little Sister said, **“**Let’s hide the horns.” Big Brother blew the _____. Then, he hid the _____ behind a rock. Where’s the _____? “I see it!” said Little Sister. Little Sister blew the _____. Then, she hid the _____ behind a tree. Where’s the _____? “I got it!” said Big Brother.

Plate 4. Big Brother said **“**Let’s hide the toys.” Big Brother looked for a place to hide his _____. He found a good hiding place for his _____. No one will be able to find the _____. Little Sister looked and looked. She yelled “Here it is.” Little Sister looked for a place to hide her _____. She found a good hiding place for her _____. No one will be able to find the _____. Big Brother looked and looked. He yelled “Here it is!”

Plate 5. Little Sister said “Let’s eat our candy.” Big Brother opened the _____. He ate some candy from the _____. “MMM” he said, “the candy from the _____ is really good.” Little Sister opened the _____. She ate some candy from the _____. “MMM” she said, the candy from the _____ is really good.”

Plate 6. Just then mom and dad came home. “It’s time to come inside now” said mom. “We need to make dinner.” Little Sister cried again.

Episode 4

Plate 1. Big Brother and Little Sister ran down to the dinner table. “What have you been up to?” asked their mother. “Where did you go?” asked their father. Big Brother and Little Sister smiled. “We can show you,” they said.

Plate 2. Big Brother said to Little Sister. “I hit more rocks with my toy than you.” Big Brother got out his _____. He pointed the _____ at his sister. He pretended to aim with his _____. Little Sister said, “No, I hit more rocks with my toy.” She got out her _____. She pointed the _____ at Big Brother. She pretended to aim with her _____.

Plate 3. Big Brother said “I can make my pets do tricks.” Big Brother made _____ do tricks. He made _____ roll-over. He made _____ jump up and down. Little Sister said, “My pet does more tricks.” Little Sister made _____ do tricks. She made _____ roll-over. She made _____ jump up and down.

Plate 4. Big Brother said “She ate more candy than I did.” Big Brother showed his candy from the _____. He held up his _____. “See I still have candy in my_____.” Little Sister said, “That’s not true. He ate the most candy.” She showed her candy from the _____. She held up her _____. See I still have candy in my _____.

Plate 5. Little Sister said, “I can play my music louder than Big Brother”. Big Brother said, “No you can’t.” “Listen to me play my _____,” He blew his _____. “See how loud my _____ is?” Little Sister said “Oh, yeah? Listen to me play my _____” She blew her _____. “See how loud my _____ is?”

Plate 6. Big Brother and Little Sister looked at their parents. They were not happy. “We better put these things away, said Big Brother.” “We’re sorry,” said Little Sister. They smiled as they put their things under their chairs. What will they play when they finish dinner?

Story 2+ Template

Episode 1

Plate 1. Mary and Joe crocodile were getting ready to go to school. Today was a big day. It was show & tell day. Joe couldn’t decide what to bring for show & tell. Mary said, “I’ll help!”

Plate 2. Mary said “We can stop at the candy machines on the way to school,” “My favorite is the _____.” Joe said, “My favorite is the _____.”

Plate 3. Joe asked “Can we bring some toys,” asked Joe. Mary said, “Yes,” “I’m bringing my _____.” Joe said, “I’m bringing my _____.”

Plate 4. Mary said “We can play music at show & tell. “I’m taking my _____,” Joe said, “I’m taking my _____”.

Plate 5. Joe asked, “What about our pets?” Mary said, “We’ll take them with us” “I’ll get _____.” Joe said “I’ll get _____.”

Plate 6. “Let’s go!” said Mary. “Yeah!” said Joe. They climbed in the car to go to school. What will happen at show and tell?

Episode 2

Plate 1. Mary and Joe were at school. It was time for show & tell. Mary said “All the kids are going to like my show & tell things better than yours” Joe said “No they won’t. The kids will like what I brought better than what you brought.” Mary said “Well we’ll see about that.”

Plate 2. Joe said, “I can play music very loud” Mary said “So can I” “Listen to me blow my _____,” She blew her _____. “See how loud my _____ is?” Joe said “Oh, yeah? Listen to me blow my _____” He blew his _____. “See how loud my _____ is?”

Plate 3. Mary said, “I have the best candy.” Mary pulled out her candy from the _____. “See my candy from the _____.” She ate some candy from the _____. Joe said “Mine is better than that”. Joe pulled out his candy from the _____. “See my candy from the _____.” He ate some candy from the _____.

Plate 4. Joe said, “My pet does more tricks than yours,” Mary said, “Uh-uh,”. Mary made _____ do tricks. She made _____ roll-over. She made _____ jump up and down. Next, it was Joe’s turn. Joe made _____do tricks. He made _____ roll-over. He made _____ jump up and down.

Plate 5. Mary said “I can hit more rocks with my toy than you,”. Mary set up the rocks. Mary got out her _____. She pointed the _____ at the rocks. She hit a rock with his _____. Joe put the rock back. Joe got out his _____. He pointed the _____at the rocks. He hit a rock with his _____.

Plate 6. Show & tell was over. All the kids had a really great time. Mary was mad at Joe so she hid all the things Joe brought for show & tell. Joe was mad at Mary so he hid everything Mary brought. Will Mary and Joe be able to find all the things they brought for show & tell?

Episode 3

Plate 1. School was over and it was time to go home. Mary and Joe couldn’t find all the things they brought for show & tell. Where are all the fun things they brought from home?

Plate 2. Mary said, “Where are the pets?”. “I can’t find _____. Please make some noise _____. I hope I am able to find _____. Mary looked and looked. “Here he is!” Joe said, “I can’t find _____. Please make some noise _____.” I hope I am able to find _____. Joe looked and looked “I found him.”

Plate 3. Joe said **“**What happened to the horns?”. Mary said “Where’s my _____. She found the _____ behind a rock. Mary blew the _____. She was so glad she found it. Joe said “Where’s my _____. He found the _____ behind a tree. He blew the _____. Joe was happy he found it.

Plate 4. Mary said **“**Where are the toys.” Mary looked and looked for her _____. Where would be a good hiding place for the _____? I hope I can find the _____.” Mary looked very hard. She yelled “Here it is!” Joe looked and looked for his _____. Where would be a good hiding place for the _____. I hope I can find the _____.” Joe looked very hard. He yelled “Here it is!”

Plate 5. Joe asked, “What happened to the candy”. Mary looked for her candy from the _____. She said, “the candy from the _____ is really good.” Here it is. She some candy from the _____. Joe looked for his candy from the _____. He said, “the candy from the _____ is really good.” He ate some candy from the _____.

Plate 6. Just then mom and dad drove up. “It’s time to go home now,” said Mom. Dad asked, “How was show & tell?” Mary and Joe agreed it was great!

Episode 4

Plate 1. Mary and Joe jumped into the car. They told Mom and Dad about all the things the children brought to school. When they got home they were still talking about show and tell.

Plate 2. Mary said, “Everyone loved our toys.” “I hit the most rocks with _____.” _____. She pointed the _____ at her brother. She pretended to aim with her _____. Joe said, “No, I hit more rocks with my toy.” He got out his _____. He pointed the _____ at his sister. He pretended to aim with his _____.

Plate 3. Mary said “I made my pet do the best tricks.” Mary made _____ do tricks. She made _____ roll-over. She made _____ jump up and down. Joe said, “My pet does better tricks.” Joe made _____ do tricks. He made _____ roll-over. He made _____ jump up and down.

Plate 4. Mary said “He ate more candy than I did.” Mary showed her candy from the _____. She held up her _____. “See I still have candy in my_____.” she said. Joe said, “She ate the most candy.” Joe showed his candy from the _____. He held up his _____. See I still have candy in my _____.

Plate 5. Joe said, “I can play my music louder than Mary”. Mary said, “No you can’t.” “Listen to me play my _____,” She blew her _____. “See how loud my _____ is?” Joe said “Oh, yeah? Listen to me play my _____” He blew his _____. “See how loud my _____ is?”

Plate 6. Mom and Dad were not happy. Mom said, “Ok, show and tell is over. It’s time to put your things away. Dad said, “Go clean up while I make dinner.” Mary and Joe looked at each other and smiled. “Sure, we’ll put them away. What’s for dinner?”

Appendix D: Novel words by story version and order of presentation

Story 1A			
Ep1	candy	pim	faʊg
	toys	wib	nɛp
	music	ʧop	paɪb
	pets	wæd	jɪb
Ep2	music	ʧop	paɪb
	candy	pim	faʊg
	pets	wæd	jɪb
	toys	wib	nɛp
Ep3	pets	wæd	jɪb
	music	ʧop	paɪb
	toys	wib	nɛp
	candy	pim	faʊg
Ep 4	toys	wib	nɛp
	pets	wæd	jɪb
	candy	pim	faʊg
	music	ʧop	paɪb

Story 1B			
Ep1	candy	faʊg	pim
	toys	nɛp	wib
	music	paɪb	ʧop
	pets	jɪb	wæd
Ep2	music	paɪb	ʧop
	candy	faʊg	pim
	pets	jɪb	wæd
	toys	nɛp	wib
Ep3	pets	jɪb	wæd
	music	paɪb	ʧop
	toys	nɛp	wib
	candy	faʊg	pim
Ep4	toys	nɛp	wib
	pets	jɪb	wæd
	candy	faʊg	pim
	music	paɪb	ʧop

Story 1C			
Ep1	candy	yelm	han
	toys	joʊn	feɪg
	music	mɛk	jʌd
	pets	fuv	lʊd
Ep2	music	mɛk	jʌd
	candy	jeɪm	han
	pets	fuv	lʊd
	toys	joʊn	feɪg
Ep3	pets	fuv	lʊd
	music	mɛk	jʌd
	toys	joʊn	feɪg
	candy	jeɪm	han
Ep4	toys	joʊn	feɪg
	pets	fuv	lʊd
	candy	jeɪm	han
	music	mɛk	jʌd

Story 1D			
Ep1	candy	han	jeɪm
	toys	feɪg	joʊn
	music	jʌd	mɛk
	pets	lʊd	fuv
Ep2	music	jʌd	mɛk
	candy	han	jeɪm
	pets	lʊd	fuv
	toys	feɪg	joʊn
Ep3	pets	lʊd	fuv
	music	jʌd	mɛk
	toys	feɪg	joʊn
	candy	han	jeɪm
Ep4	toys	feɪg	joʊn
	pets	lʊd	fuv
	candy	han	jeɪm
	music	jʌd	mɛk

Story 2A			
Ep1	candy	han	jeɪm
	toys	feɪg	joʊn
	music	jʌd	mɛk
	pets	lʊd	fuv
Ep2	music	jʌd	mɛk
	candy	han	jeɪm
	pets	lʊd	fuv
	toys	feɪg	joʊn
Ep3	pets	lʊd	fuv
	music	jʌd	mɛk
	toys	feɪg	joʊn
	candy	han	jeɪm
Ep 4	toys	feɪg	joʊn
	pets	lʊd	fuv
	candy	han	jeɪm
	music	jʌd	mɛk

Story 2B			
Ep1	candy	jeɪm	han
	toys	joʊn	feɪg
	music	mɛk	jʌd
	pets	fuv	lʊd
Ep2	music	mɛk	jʌd
	candy	jeɪm	han
	pets	fuv	lʊd
	toys	joʊn	feɪg
Ep3	pets	fuv	lʊd
	music	mɛk	jʌd
	toys	joʊn	feɪg
	candy	jeɪm	han
Ep4	toys	joʊn	feɪg
	pets	fuv	lʊd
	candy	jeɪm	han
	music	mɛk	jʌd

Story 2C			
Ep1	candy	faʊg	pim
	toys	nɛp	wib
	music	paɪb	ʧop
	pets	jɪb	wæd
Ep2	music	paɪb	ʧop
	candy	faʊg	pim
	pets	jɪb	wæd
	toys	nɛp	wib
Ep3	pets	jɪb	wæd
	music	paɪb	ʧop
	toys	nɛp	wib
	candy	faʊg	pim
Ep4	toys	nɛp	wib
	pets	jɪb	wæd
	candy	faʊg	pim
	music	paɪb	ʧop

Story 2D			
Ep1	candy	pim	faʊg
	toys	wib	nɛp
	music	ʧop	paɪb
	pets	wæd	jɪb
Ep2	music	ʧop	paɪb
	candy	pim	faʊg
	pets	wæd	jɪb
	toys	wib	nɛp
Ep3	pets	wæd	jɪb
	music	ʧop	paɪb
	toys	wib	nɛp
	candy	pim	faʊg
Ep 4	toys	wib	nɛp
	pets	wæd	jɪb
	candy	pim	faʊg
	music	ʧop	paɪb

Appendix E: Test Protocol and Instructions

Test Protocol: General Instructions:
Consent Form: Go over the consent form and make sure that the participant understands what we will be doing during the session. Have the participant sign two copies, and give him/her one to take home.

Instructions:

The first part of the session will take about an hour. We will test your hearing and do some paper and pencil tasks. We'll also listen to you read. After this part we can see if you'll be a good fit for the second part of our research study. The second part lasts 2 ½ hours. Let us know whenever you want to take a break.

1. **Screening Test – 40 minutes**

    a. Hearing Screening – Pure tone testing in each ear at 20dB for 500, 1K, 2K and 4K. Word discrimination W-22 form List A and B (one in each ear) – 15 minutes

    b. Spelling – WRAT (10 seconds to write each word): -10-15 min

    c. Reading Rate- (Nelson-Denny Reading Test) - 1 minute

    d. TOWRE – 5 minutes

    e. PPVT-R - 10min

2. **Test Protocol – 2 hours, 30 minutes**

Instructions:

We see that you qualify for the second part of our study. The second part of the session will take about 2 ½ hours. In this part you'll be learning some new words, listening to musical tones, and recalling words we've read to you. We'll also be looking at your recognition of words and patterns. Most of these tasks will take you from things that are relatively easy to the point where you are unable to answer correctly. This is part of the study and does not mean you are not doing well. Again please let us know if you want to take a break.

2. Test Protocol (cont.)

a. Word Learning (see instructions below) (20 min)
    1) Practice Test
    2) Story 1
b. TONI-3

    ……..……..BREAK if needed…….
c. Word Learning (20 min)
    3) Story 2
d. Perceptual Anchoring – Trials 1 and 2 (see instructions below) (15 min)
e. Spatial Working Memory
f. Perceptual Anchoring – Trials 3 and 4
g. Verbal Working Memory
h. Spelling of Sounds
i. CTOPP –phoneme reversal
j. Trail-making task
k. Handedness questionnaire
l. CTOPP – nonword repetition
m. Spoonerisms
n. Rey Auditory Verbal Learning Test
o. Post-test Story 1 and 2
p. Post-test questionnaire

Perceptual Anchoring and Word Learning Tasks: Protocols

Perceptual Anchoring Task – ABAB or BABA where A is roving and B is standard lower. Each takes 6 minutes for a total of 30 minutes (includes practice items)

Step 1: Select “shortcut to test” from the icons on the desktop. Input the participant’s number followed by SL or R for Standard Lower or Roving and 1 or 2 for the first or second trial (i.e., 204R2). For the first trial change the demo to “15”. Make sure that the last ten responses are all

correct. If the participant does not get all ten correct, select "start over" and go back, review the instructions and run the demo again.

Instructions:

1. *You are going to hear pairs of musical tones. One tone will be higher in pitch than the other. Click with your mouse on the tone that is higher in pitch.*
2. *Let's do some practice items. First listen to the high, medium and low tones. Tell me if the volume is too loud or too soft.*

(Practice Items as per protocol)

3. *Ok now that you've done the practice items, let's try a first round. We'll be doing four of these. There are eighty items in this one. You can see how many you have done by looking at the count here. Any questions?*

Steps 2, 3, and 4
Select "start over" and choose the next test (if you did roving before, do standard lower; if you did standard lower, do roving). Put in the participant's name and R or SL and 1 or 2. Choose "demo" for each run.

Instructions:

Let's try another one. This has eighty items as well. Any questions?

Word Learning Task – Story A, B, C, or D

1. PRACTICE TEST

Step 1: Practice Test:

- Open DirectRT and select "Select and run input file" from the menu
- Go to the Practice Test folder and run "Practice Test". You will not need headphones for the practice, but you will need the microphone.

Instructions:

You will be seeing some novel objects and learning names for them. These are words that you haven't heard before. Your task is to learn the names of these new objects. Let me show you an example. First let's look at the items you'll be learning the names of. Because you don't yet know the names of these items please say, "pass" into the microphone.

Step 2: Practice Story:

- Check the volume to make sure it is on a good level.
- "Select and run input file" and run Practice Story.

Instructions:

Listen to the story. The characters will talk about the objects you just saw. See if you can remember the names of these new objects.

Step 3: Practice Test:

- "Select and run input file" and run Practice Test.

Instructions:
Now let's look at the objects again. Say the name of the object. If you're not sure take your best guess. If you can't remember anything say "pass".

2. TESTING AND STORY 1

Instructions:
As before, you will be seeing some novel objects and learning names for them. These are words that you haven't heard before. Your task is to learn the names of these new objects. We will look at the items you'll be learning the names of. Because you don't yet know the names of these items please say, "pass" into the microphone.

Step 2: Story: (use a second computer if it is available)

Instructions:
Listen to the story. The characters will talk about the objects you just saw. See if you can remember the names of these new objects.

Step 3: Story Test:

Instructions:
Now let's look at the objects again. Say the name of the object. If you're not sure take your best guess.

Note: Don't tell the participant that we are doing a posttest.

Instructions for delayed posttest:
Now let's look at the objects again. Say the name of the object. If you're not sure take your best guess.

Post-test: As listed in the protocol above (k). Give the test for Story1 and then for Story2.

References

Ahissar, M. (2007). Dyslexia and the anchoring-deficit hypothesis. *Trends in Cognitive Sciences, 11*(11), 458-465.

Ahissar, M., Lubin, Y., Putter-Katz, H., & Banai, K. (2006). Dyslexia and the failure to form a perceptual anchor. *Nature Neuroscience, 9*(12), 1558-1564.

Ahissar, M., & Oganian, Y. (2008). Response to Ziegler: The anchor is in the details. *Trends in Cognitive Sciences, 12*(7), 245-246.

Alloway, T. (2007). Investigating the roles of phonological and semantic memory in sentence recall. *Memory, 15*(6), 605-615.

Amitay, S., Ahissar, M., & Nelken, I. (2002). Auditory processing deficits in reading disabled adults. *Journal of the Association for Research in Otolaryngology, 3,* 302–320.

Apthorp, H. (1995). Phonetic coding and reading in college students with and without learning disabilities. *Journal of Learning Disabilities, 28,* 342–352.

Auer, E. T., & Luce, P. A. (2005). Probabilistic phonotactics in spoken word recognition. In D. B. Pisoni & R. A. Remez (Eds.), *The Handbook of Speech Perception* (pp.610-630). Oxford, UK: Blackwell Publishing.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Science, 4*(11), 417-423.

Baddeley, A. (2003a). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Baddeley, A. (2003b). Working memory and language: An overview. *Journal of Communication Disorders, 36*(3), 189-208.

Baddeley, A.D., Emslie, H. & Nimmo-Smith, I. (1994). *Doors and People: A Test of Visual and Verbal Recall and Recognition.* Bury St. Edmunds: Thames Valley Test Company.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158-173.

Baddeley, A., & Hitch, G. (1974). Working memory, In, GH Bower (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory, 8*, 47-89.

Banai, K., & Ahissar, M. (2006). Auditory processing deficits in dyslexia: Task or stimulus related? *Cerebral Cortex, 16*(12), 1718-1728.

Banai, K., & Ahissar, M. (2010). On the importance of anchoring and the consequences of its impairment in dyslexia. *Dyslexia, 16*(3), 240-257.

Bates, D., Maechler, M., & Bolker , B. (2011). lme4: Linear mixed - effects models using S4 classes. R package version 0.999375 - 42. http://CRAN.R project.org/package=lme4

Baayen, R. H. (2011). R package language, version 1.4. Available: http://cran.r-project.org/web/packages/languageR/index.html

Beattie, R.L., & Manis, F.R. (2013). Rise time perception in children with reading and combined reading and language difficulties. *Journal of Learning Disabilities, 46*(3), 200-209.

Ben-Yehudah, G., & Ahissar, M. (2004). Sequential spatial frequency discrimination is consistently impaired among adult dyslexics. *Vision Research, 44*(10), 1047-1063.

Berent, I., Vaknin-Nusbaum, V., Balaban, E., & Galaburda, A. M. (2012). Dyslexia impairs speech recognition but can spare phonological competence. *PLoS One, 7*(9), e44875.

Bishop, D. V. M., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin, 130*(6), 858-886.

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*(3), 153-193.

Bogliotti, C., Serniclaes, W., Messaoud-Galusi, S., & Sprenger-Charolles, L. (2008). Discrimination of speech sounds by children with dyslexia: Comparisons with

chronological age and reading level controls. *Journal of Experimental Child Psychology, 101*(2), 137-155.

Bonte, M. L., Poelmans, H., & Blomert, L. (2007). Deviant neurophysiological responses to phonological regularities in speech in dyslexic children. *Neuropsychologia, 45*(7), 1427-1437.

Brady, S. A. (1997). Ability to encode phonological representations: An underlying difficulty of poor readers. In B. Blackman (Ed.), *Foundations of Reading Acquisition and Dyslexia: Implications for Early Intervention* (pp. 21-48). New York: Routledge.

Brady, S., E. Poggie and M.M. Rapala, 1989. Speech repetition abilities in children who differ in reading skill. *Language and Speech, 32*,109-122.

Breznitz, Z. (2006). *Fluency in Reading: Synchronization of Processes:* Lawrence Erlbaum and Associates. Mahwah, NJ.

Brown, J. I., Fishco, V.V., & Hanna, G. (1993). *The Nelson-Denny Reading Test*. Chicago: Riverside Publishing.

Brown, L., Sherbenou, R. J. & Johnsen, S. K. (1997) *Test of Nonverbal Intelligence, Third Edition (TONI-3).* Austin, TX: PRO-ED.

Brkanac, Z., Chapman, N., Igo, R., Matsushita, M., Nielsen, K., Berninger, V., et al. (2008). Genome scan of a nonword repetition phenotype in families with dyslexia: Evidence for multiple loci. *Behavior Genetics, 38*(5), 462-475.

Buchsbaum, B.R., & D'Esposito, M. (2008). The search for the phonological store: From loop to convolution. *Journal of Cognitive Neuroscience, 20*(5), 762-778.

Carey, S. (1978). The child as word learner. In M. Halle, J. Bresnan & G. A. Mille (Eds.), *Linguistic theory and psychological reality* (pp. 264-293). Cambridge, MA: MIT Press.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Proceedings of the Stanford Child Language Conference 15*, 17-29.

Castro-Caldas, A., Petersson, K. M., Reis, A., Stone-Elander, S. & Ingvar, M. (1998). The illiterate brain: Learning to read and write during childhood influences the functional organization of the adult brain. *Brain, 121,* 1053–1063.

Catts, H.W. (1986). Speech production/phonological deficits in reading-disordered children. *Journal of Learning Disabilities, 19*(8), 504-508.

Catts, H. (1989). Speech production deficits in developmental dyslexia. *Journal of Speech and Hearing Disorders, 54,* 422–428.

Chandrasekaran, B., Hornickel, J., Skoe, E., Nicol, T., & Kraus, N. (2009). Context dependent encoding in the human auditory brainstem relates to hearing speech in noise: Implications for developmental dyslexia. *Neuron, 64*(3), 311-319.

Clarkson, L. (2013). *The Phonological Neighbourhood Effect on Short-Term Memory for Order,* (Ph.D.), School of Psychology, University of Wollongong. http://ro.uow.edu.au/theses/3841

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 62-101). Cambridge, U.K: Cambridge University Press.

Crombie, M. A. (1997). The effects of specific learning difficulties (dyslexia) on the learning of a foreign language in school. *Dyslexia, 3*, 27-47.

Crombie, M. A. (2000). Dyslexia and the learning of a foreign language in school: Where are we going? *Dyslexia, 6*(2), 112-123.

Davis, M.H., Di Betta, A.M., Macdonald, M.J.E., & Gaskell, M.G. (2009). Learning and consolidation of novel spoken words. *Journal of Cognitive Neuroscience, 21*(4), 803-820.

Davis, M.H., & Gaskell, M.G. (2009). A complementary systems account of word learning: Neural and behavioural evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1536), 3773-3800.

Di Betta, A. M., & Romani, C. (2006). Lexical learning and dysgraphia in a group of adults with developmental dyslexia. *Cognitive Neuropsychology*, *23*(3), 376-400.

Di Filippo, G., Zoccolotti, P., & Ziegler, J. C. (2008). Rapid naming deficits in dyslexia: A stumbling block for the perceptual anchor theory of dyslexia. *Developmental Science, 11*(6), F40-F47.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450-466.

Desroches, A. S., Newman, R. L., Robertson, E. K., & Joanisse, M. F. (2013). Electrophysiological indices of phonological impairments in dyslexia. *Journal of Speech-Language-Hearing Research, 56*(1), 250-264.

Dickie, C., Ota, M., & Clark, A. (2013). Revisiting the phonological deficit in dyslexia: Are implicit nonorthographic representations impaired? *Applied Psycholinguistics, 34*(04), 649-672.

Dickinson, D.K. (1984). First impressions: Children's knowledge of words gained from a single exposure. *Applied Psycholinguistics, 5*(4), 359-373.

Dobel, C., Lagemann, L., & Zwitserlood, P. (2009). Non-native phonemes in adult word learning: Evidence from the N400m. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1536), 3697-3709.

Downey, D. M., & Snyder, L. E. (2000). College students with LLD: The phonological core as risk for failure in foreign language classes. *Topics in Language Disorders, 21*(1), 82-92.

Dunn, L. M., & Dunn, L. M. (1981). *Peabody Picture Vocabulary Test - Revised*. Circle Pines, MN: American Guidance Service.

Eden, G. F., & Zeffiro, T. A. (1998). Neural systems affected in develop-mental dyslexia revealed by functional neuroimaging. *Neuron,21*(2), 279–282.

Edwards, J., Beckman, M. E., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. *Journal of Speech Language and Hearing Research, 47*(2), 421-436.

Elbro, C., & Jensen, M. N. (2005). Quality of phonological representations, verbal learning, and phoneme awareness in dyslexic and normal readers. *Scandinavian Journal of Psychology, 46*(4), 375-384.

Elbro, C., Borstrom, I., & Dorthe Klint, P. (1998). Predicting dyslexia from kindergarten: The importance of distinctness of phonological representations of lexical items. *Reading Research Quarterly, 33*(1), 36-60.

Falcaro, M., Pickles, A., Newbury, D.F., Addis, L., Banfield, E., Fisher, S.E. (2008). Genetic and phenotypic effects of phonological short-term memory and grammatical morphology in specific language impairment. *Genes, Brain and Behavior, 7*(4), 393-402.

Farmer, M.E., & Klein, R.M. (1993). Auditory and visual temporal processing in dyslexic and normal readers. *Annals of the New York Academy of Sciences , 682*, 339-341.

Felton, R. H., Naylor, C. E., & Wood, F. B. (1990). Neuropsychological profile of adult dyslexics. *Brain and Language, 39,* 485–497.

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., Pethick, S., & Reilly, J. S. (1993). *The MacArthur Communicative Development Inventories: User's Guide and Technical Manual.* San Diego: Singular Publishing Group.

Frisch, S.A., Large, N.R., & Pisoni, D.B. (2000). Perception of wordlikeness: Effects of segment probability and length on the processing of nonwords. *Journal of Memory and Language, 42*(4), 481-496.

Ganschow, L., Sparks, R., & Scheider, E. (1995). Learning a foreign language: Challenges for students with language learning difficulties. *Dyslexia, 1*(2), 75-95.

Ganschow, L., Sparks, R. L., Javorsky, J., & Pohlman, J. (1991). Identifying native language difficulties among foreign language learners in college: A 'foreign' language learning disability? *Journal of Learning Disabilities, 24*(9).

Garlock, V.M., Walley, A.C., & Metsala, J.L. (2001). Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language, 45*(3), 468-492.

Gathercole, S.E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics, 27*(4), 513.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A.-M. (2006). Working memory in children with dyslexia. *Journal of Experimental Child Psychology, 93*(3), 265-281.

Gershkoff-Stowe, L., & Hahn, E. R. (2007). Fast mapping skills in the developing lexicon. *Journal of Speech-Language-Hearing Research, 50*(3), 682-697.

Goldrick, M., & Rapp, B. (2007). Lexical and post-lexical phonological representations in spoken production. *Cognition, 102*(2), 219-260.

Gordon, J.K. (2002). Phonological neighborhood effects in aphasic speech errors: Spontaneous and structured contexts. *Brain & Language, 82*(2), 113-145.

Goswami, U. (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences, 15*(1), 3-10.

Goswami, U., Thomson, J., Richardson, U., Stainthorp, R., Hughes, D., Rosen, S. (2002). Amplitude envelope onsets and developmental dyslexia: A new hypothesis. *Proceedings of the National Academy of Sciences, 99*(16), 10911-10916.

Gregg, N., Hoy, C., Flaherty, D. A., Norris, P., Coleman, C., Davis, M., & Jordan, M.(2005). Decoding and spelling accommodations for postsecondary students with dyslexia--It's more than processing speed. *Learning Disabilities -- A Contemporary Journal, 3*(2), 1-17.

Gregg, N., Coleman, C., Davis, M., Stennet, R., Nielson, K., Knight, D., & Hoy, C. (2002). Lexical and sublexical processing of adults with learning disabilities and attention deficit/hyperactivity disorders. In E.Witruk (Ed.). *Basic Functions of Language and Language Disorders* (pp. 329–358). Dordrecht, Netherlands: Kluwer Academic Press.

Grill-Spector, K., Henson, R. & Martin, A. Repetition and the brain: Neural models of stimulus-specific effects. *Trends in Cognitive Sciences, 10*(1), 14-23.

Gupta, P. (2003). Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *The Quarterly Journal of Experimental Psychology: Section A, 56*(7), 1213-1236.

Gupta, P., & Tisdale, J. (2009). Word learning, phonological short-term memory, phonotactic probability and long-term memory: Towards an integrated framework. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1536), 3755-3771.

Habib, M. (2000). The neurological basis of developmental dyslexia: An overview and working hypothesis. *Brain, 123*(12), 2373-2399.

Hämäläinen, J.A., Salminen, H.K., & Leppänen, P.H.T. (2012). Basic auditory processing deficits in dyslexia: Systematic review of the behavioral and event-related potential/field evidence. *Journal of Learning Disabilities.*

Hämäläinen, J.A., Rupp, A., Soltész, F., Szücs, D., & Goswami, U. (2012). Reduced phase locking to slow amplitude modulation in adults with dyslexia: An MEG study. *Neuroimage, 59*(3), 2952-2961.

Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education. *British Journal of Educational Psychology, 72*, 119–133.

Heibeck, T.H., & Markman, E.M. (1987). Word learning in children: An examination of fast mapping. *Child Development*, 1021-1034.

Heisler, L. (2004). *The Influence of Neighborhood Density and Phonotactic Probability on Representational and Production Factors in Word Learning*. Ph.D. dissertation, Purdue University, Indiana.

Helland, T., & Kaasa, R. (2005). Dyslexia in English as a second language. *Dyslexia, 11*(1), 41-60.

Holmes, V. M., & Castle, A. E. (2001). Unexpectedly poor spelling in university students. *Scientific Studies of Reading, 5,* 319–350.

Hoover, J.R., Storkel, H.L., & Hogan, T.P. (2010). A cross-sectional comparison of the effects of phonotactic probability and neighborhood density on word learning by preschool children. *Journal of Memory and Language, 63*(1), 100-116.

Hosmer, D.W. & Lemeshow, S. & Sturdivant (2013). *Applied Logistic Regression.* Hoboken, New Jersey: John Wiley & Sons, Inc.

Howland, K.A., & Liederman, J. (2013). Beyond decoding: Adults with dyslexia have trouble forming unified lexical representations across pseudoword learning episodes. *Journal of Speech, Language & Hearing Research, 56*(3), 1009-1022.

Jaeger, T.F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59,* 434-446.

Jarrold, C., & Towse, J. N. (2006). Individual differences in working memory. *Neuroscience, 139*(1), 39-50.

Jakoby, H. (2010) *Foreign Language Aptitude and Phonological Processing Abilities: Evidence from Behavioral and Event-Related Potentials (ERP) Measures,* unpublished dissertation, Bar-Ilan University, Ramat-Gan, Israel.

Jakoby, H. (2011) Electrophysiological correlates of speech perception mechanisms and individual differences in second language attainment. *Psychophysiology, 48,* 1517-31.

Jarrold, C., & Towse, J.N. (2006). Individual differences in working memory. *Neuroscience, 139*(1), 39-50.

Joanisse, M. F., Manis, F. R., Keating, P., & Seidenberg, M. S. (2000). Language deficits in dyslexic children: Speech perception, phonology, and morphology. *Journal of Experimental Child Psychology, 77*(1), 30-60.

Jonides, J., & Nee, D. (2006). Brain mechanisms of proactive interference in working memory. *Neuroscience, 139*(1), 181-193.

Jusczyk, P. W., & Luce, P. A. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language, 33*(5), 630-645.

Jusczyk, P. W., Friederici, A. D., Wessels, J. M. I., Svenkerud, V. Y., & Jusczyk, A. M. (1993). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language, 32*(3), 402-420.

Kane, M.J., & Engle, R.W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(2), 336-358.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. *Psychonomic Bulletin Review, 9*(4), 637-671.

Kapnoula, E.C., Packard, S., Apfelbaum, K.S., McMurray, B., & Gupta, P. (2012). The young and the meaningless: Novel-word learning without meaning or sleep. *The Journal of the Acoustical Society of America, 132*(3), 2077.

Kieras, D.E., Meyer, D.E., Mueller, S., & Seymour, T. (1999). Insights into working memory from the perspective of the epic architecture for modeling skilled perceptual-motor and cognitive human performance. In P. Shah & A. Miyake (Eds.), *Models of Working Memory* (pp. 183-223). New York: Cambridge University Press.

Kovács, G., & Racsmány, M. (2008). Handling L2 input in phonological STM: The effect of non-L1 phonetic segments and non-L1 phonotactics on nonword repetition. *Language Learning*, *58*(3), 597-624.

Kovelman, I., Norton, E. S., Christodoulou, J. A., Gaab, N., Lieberman, D. A., Triantafyllou, C., et al. (2012). Brain basis of phonological awareness for spoken language in children and its disruption in dyslexia. *Cerebral Cortex, 22*(4), 754-764.

Krull, V., Choi, S., Kirk, K.I., Prusick, L., & French, B. (2010). Lexical effects on spoken-word recognition in children with normal hearing. *Ear and Hearing, 31*(1), 102-114.

Lewandowsky, S., Oberauer, K., Yang, L., & Ecker, U. (2010). A working memory test battery for MATLAB. *Behavior Research Methods, 42*(2), 571.

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology, 49*(4), 764-766.

Lipinski, J., & Gupta, P. (2005). Does neighborhood density influence repetition latency for nonwords? Separating the effects of density and duration. *Journal of Memory and Language, 52*(2), 171-192.

Luce, P. A., & Large, N. R. (2001). Phonotactics, density, and entropy in spoken word recognition. *Language & Cognitive Processes, 16*(5/6), 565-581.

Luce, P. & Pisoni, D. (1998) Recognizing spoken words: The Neighborhood Activation Model. *Ear & Hearing, 19,* 1-36.

Ludlow, C. L., Cudahy, E. A., Bassich, C. & Brown, G. L. (1983). Auditory processing skills of hyperactive, language impaired and reading disabled boys. In E. Z. Lasky & J. Katz (Eds.), *Central Auditory Processing Disorders* (pp. 163-184). Baltimore: University Park Press.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53,* 1–14.

MacRoy-Higgins, M. (2009). Word learning and phonological representations in children who are late talkers. Ph.D. dissertation. The Graduate Center of the City University of New York, New York.

Maïonchi-Pino, N. (2012). Phonological restriction knowledge in dyslexia: Universal or language-specific? In T. N. Wydell & L. Fern-Pollak (Eds.), *Dyslexia - A Comprehensive and International Approach*. Rijeka: InTech.

Maïonchi-Pino, N., Taki, Y., Yokoyama, S., Magnan, A., Takahashi, K., Hashizume, H. (2013). Is the phonological deficit in developmental dyslexia related to impaired phonological representations and to universal phonological grammar? *Journal of Experimental Child Psychology, 115*(1), 53-73.

Majerus, S., van der Linden, M., Mulder, L., Meulemans, T., & Peters, F. (2004). Verbal short-term memory reflects the sublexical organization of the phonological language network: Evidence from an incidental phonotactic learning paradigm. *Journal of Memory and Language, 51*(2), 297-306.

Marshall, C. R. (2011). Do children with dyslexia and/or specific language impairment compensate for place assimilation? Insight into phonological grammar and representations. *Cognitive Neuropsychology, 27*(7), 563-586.

Martin, N. A., & Brownell, R. (2005). *Test of Auditory Processing Skills - Third Edition*. Novato, CA: Academic Therapy Publications.

Mayringer, H., & Wimmer, H. (2000). Pseudoname learning by German-speaking children with dyslexia: Evidence for a phonological learning deficit. *Journal of Experimental Child Psychology, 75*(2), 116-133.

McMurray, B., Horst, J.S., & Samuelson, L.K. (2012). Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychological Review, 119*(4), 831-877.

Melby-Lervåg, M., & Lervåg, A. (2012). Oral language skills moderate nonword repetition skills in children with dyslexia: A meta-analysis of the role of nonword repetition skills in dyslexia. *Scientific Studies of Reading, 16*(1), 1-34.

Meschyan, G., & Hernandez, A. E. (2002). Is native-language decoding skill related to second-language learning? *Journal of Educational Psychology, 94*(1), 14-22.

Messbauer, V. C. S., & de Jong, P. F. (2003). Word, nonword, and visual paired associate learning in Dutch dyslexic children. *Journal of Experimental Child Psychology, 84*(2), 77-96.

Meyler, A., & Breznitz, Z. (2005). Visual, auditory and cross-modal processing of linguistic and nonlinguistic temporal patterns among adult dyslexic readers. *Dyslexia, 11*(2), 93-115.

Micheyl, C., Xiao, L. & Oxenham, A.J.(2012). Characterizing the dependence of pure-tone frequency difference limens on frequency, duration, and level. *Hearing Research, 292,* 1-13.

Milne, R.D., Nicholson, T. & Corbalis, M.C. (2003). Lexical access and phonological decoding in adult dyslexic subtypes. *Neuropsychology, 17*(3), 362-368.

Miyake A, & Shah, P (1999) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control.* New York: Cambridge University Press.

Mody, M. (2003a). Phonological basis in reading disability: A review and analysis of the evidence. *Reading and Writing: An Interdisciplinary Journal, 16*(1-2), 21-39.

Mody, M., (2003b). Rapid auditory processing deficits in dyslexia: A commentary on two differing views, *Journal of Phonetics, 31,* 529-539.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*(2), 199-231.

Mood, C. (2010). Logistic regression: Why we cannot do what we think we can do, and what we can do about it. *European Sociological Review, 26*(1), 67-82.

Morton, J., Marcus, S. M., & Frankish, C. (1976). P-centres. *Psychological Review, 83,* 405–408.

Munson, B. (2001). Phonological pattern frequency and speech production in adults and children. *Journal of Speech, Language, and Hearing Research, 44*(4), 778-792.

Nagy, W.E., Herman, P.A., & Anderson, R.C. (1985). Learning words from context. *Reading Research Quarterly*, 233-253.

Newman, R., Samuelson, L., & Gupta, P. (2008). *Learning novel neighbors: Distributed mappings help children and connectionist models.* Paper presented at the 30th annual meeting of the cognitive science society.

Nieuwenhuis, R., Pelzer, B., te Grotenhuis, M. (2012) Influence.ME: Tools for detecting influential data in mixed effects models, R Journal, 4(2), 38-47.

Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech Language and Hearing Research, 42,* pp. 925–942.

Oberauer, K. (2009). Design for a working memory. *Psychology of Learning and Motivation, 51,* 45-100.

Oganian, Y., & Ahissar, M. (2012). Poor anchoring limits dyslexics' perceptual, memory, and reading skills. *Neuropsychologia, 50*(8), 1895-1905.

Ortiz, R., Jimenez, J.E., Miranda, E.G., Rosquete, R.G., Hernandez-Valle, I., Rodrigo, M. (2007). Locus and nature of perceptual phonological deficit in Spanish children with reading disabilities. *Journal of Learning Disabilities, 40*(1), 80-92.

Packard, S. & Gupta, P. (2007). Multiple exemplars increase swapping in novel word learning In D. S. McNamara & J. G. Trafton (Eds.), *Proceedings of the 29th Annual Cognitive Science Society* (p. 1831). Austin, TX: Cognitive Science Society.

Page, M. P. A., & Norris, D. (2009). A model linking immediate serial recall, the Hebb repetition effect and the learning of phonological word forms. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1536), 3737-3753.

Papagno, C. & Vallar, G. (1992). Phonological short term memory and the learning of novel words: the effects of phonological similarity and item length. *Quarterly Journal of Experimental Psychology A, 44*, 47-67.

Pasquini, E.S., Carriveau, K.H., & Goswami, U. (2007). Auditory processing of amplitude envelope rise time in adults diagnosed with developmental dyslexia. *Scientific Studies of Reading, 11*(3), 259–286.

Paul, I., Bott, C., Heim, S., Wienbruch, C., & Elbert, T. R. (2006). Phonological but not auditory discrimination is impaired in dyslexia. *European Journal of Neuroscience, 24*(10), 2945-2953.

Perin, D. (1983). Phonemic segmentation in spelling. *British Journal of Psychology, 74*, 129–144.

Perrachione, T.K. (2012). *Impaired Learning of Phonetic Consistency and Generalized Neural Adaptation Deficits in Dyslexia*. (Ph.D.), Massachusetts Institute of Technology.

Poelmans, H., Luts, H., Vandermosten, M., Boets, B., Ghesquière, P., & Wouters, J. (2011). Reduced sensitivity to slow-rate dynamic auditory information in children with dyslexia. *Research in Developmental Disabilities, 32*(6), 2810-2819.

Postman, L., & Keppel, G. (1977). Conditions of cumulative proactive inhibition. *Journal of Experimental Psychology: General, 106*,376 – 403.

Quene, H. & van den Bergh, H, (2008). Examples of mixed-effects modeling with crossed random effects and with binomial data. *Journal of Memory and Language , 59*, 413–425.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL, http://www.R-project.org/.

Ramus, F., & Ahissar, M. (2012). Developmental dyslexia: The difficulties of interpreting poor performance, and the importance of normal performance. *Cognitive Neuropsychology*, 1-19.

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *Quarterly Journal of Experimental Psychology, 61*(1), 129-141.

Ramus, F., Marshall, C.R., Rosen, S., & van der Lely, H.K. (2013). Phonological deficits in specific language impairment and developmental dyslexia: Towards a multidimensional model. *Brain, 136*(2), 630-645.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126*(4), 841-865.

Repovs, G., & Baddeley, A. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience, 139*(1), 5-21.

Rey, A. (1964) L'examen clinique en psychologie. Paris, Presses Universitaire de France.

Rey, V., De Martino, S., Espesser, R., & Habib, M. (2002). Temporal processing and phonological impairment in dyslexia: Effect of phoneme lengthening on order judgment of two consonants. *Brain and Language, 80*(3), 576-591.

Richardson, U., Thomson, J., Scott, S. K., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia: An International Journal of Research & Practice, 10*(3), 215–233.

Rispens, J & Baker, A. (2012) Nonword repetition: The relative contributions of phonological short-term memory and phonological representations in children with language and reading impairment. *Journal of Speech, Language, and Hearing Research, 55*, 683-694.

Rodríguez-Fornells, A., Cunillera, T., Mestres-Missé, A., & de Diego-Balaguer, R. (2009). Neurophysiological mechanisms involved in language learning in adults. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1536), 3711-3735.

Roodenrys, S., & Hinton, M. (2002). Sublexical or lexical effects on serial recall of nonwords? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(1), 29-33.

Roodenrys, S., & Stokes, J. (2001). Serial recall and nonword repetition in reading disabled children. *Reading and Writing, 14*(5), 379-394.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything? *Journal of Phonetics, 31*(3), 509-527.

Schmidt, M. (1996). *Rey Auditory and Verbal Learning Test: A Handbook.* Los Angeles, CA, Western Psychological Services.

Schulte-Körne, G., Deimel, W., Bartling, J., & Remschmidt, H. (1998a). Auditory processing and dyslexia: Evidence for a specific speech processing deficit. *NeuroReport, 9,* 337–340.

Schulte-Korne, G., Deimel, W., Bartling, J., & Remschmidt, H. (1998b). Role of auditory temporal processing for reading and spelling disability. *Perceptual and Motor Skills, 86*(3), 1043-1047.

Scott, S.K. (2005) Auditory processing - speech, space and auditory objects. *Current Opinion in Neurobiology, 15*, 197-201.

Sebastian, C., & Yasin, I. (2008). Speech versus tone processing in compensated dyslexia: Discrimination and lateralization with a dichotic mismatch negativity (MMN) paradigm. *International Journal of Psychophysiology, 70*(2), 115-126.

Serniclaes, W. (2006). Allophonic perception in developmental dyslexia: Origin, reliability and implications of the categorical perception deficit. *Written Language & Literacy, 9*(1), 135-152.

Serniclaes, W., Sprenger-Charolles, L., Carre, R., & Demonet, J.-F. (2001). Perceptual discrimination of speech sounds in developmental dyslexia. *Journal of Speech, Language, and Hearing Research, 44*(2), 384-399.

Share, D.L. & Stanovich, K.E. (1995). Cognitive processes in early reading development: Accommodating individual differences into a model of acquisition, *Issues in Education: Contributions from Educational Psychology*, 1,1-57.

Shaywitz, S., & Fletcher, J. M. (1999). Persistence of dyslexia: The Connecticut longitudinal study at adolescence. *Pediatrics, 104*, 1351–1260.

Shuster, L.I. (2009). The effect of sublexical and lexical frequency on speech production: An FMRI investigation. *Brain and Language, 111*(1), 66-72.

Shtyrov, Y. (2012). Neural bases of rapid word learning. *The Neuroscientist, 18*(4), 312-319.

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory, 15*(1), 34-56.

Snowling, M.J. (2000). *Dyslexia* (2nd ed.). Oxford: Blackwell Publishing.

Snowling, M., Goulandris, N., Bowlby, M., & Howell, P. (1986). Segmentation and speech perception in relation to reading skill: A developmental analysis. *Journal of Experimental Child Psychology, 41*(3), 489-507.

Soroli, E., Szenkovits, G., & Ramus, F. (2010). Exploring dyslexics' phonological deficit III: Foreign speech perception and production. *Dyslexia, 16*(4), 318-340.

Sparks, R. L., Patton, J., Ganschow, L., & Humbach, N. (2006). Native language predictors of foreign language proficiency and foreign language aptitude. *Annals of Dyslexia, 56*(1), 129-160.

Sprenger-Charolles, L., Colé, P., & Serniclaes, W. (2006). *Reading Acquisition and Developmental Dyslexia*. New York: Psychology Press.

Stern, C.E. (1996) The hippocampal formation participates in novel picture encoding: Evidence from functional magnetic resonance imaging. *Proceedings of the National Academy of Sciences, 93*, 8660-8665.

Stanovich, K.E., & Siegel, L.S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86*(1), 24-53.

Stemberger, J.P. (2004). Neighbourhood effects on error rates in speech production. *Brain and Language, 90*(1), 413-422.

Stone, B., & Brady, S. (1995). Evidence for phonological processing deficits in less-skilled readers. *Annals of Dyslexia, 45,* 51–78.

Storkel, H.L. (2001). Learning new words: Phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research, 44*(6), 1321-1337.

Storkel, H.L. (2002). Restructuring of similarity neighbourhoods in the developing mental lexicon. *Journal of Child Language, 29*(2), 251-274.

Storkel, H. L., Armbruster, J., & Hogan, T. P. (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech-Language-Hearing Research, 49*(6), 1175-1192.

Storkel, H.L., & Maekawa, J. (2005). A comparison of homonym and novel word learning: The role of phonotactic probability and word frequency. *Journal of Child Language, 32*(4), 827-853.

Swan D, & Goswami U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology 66,* 18–41.

Swanson, H. L., Zheng, X. H., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: A selective meta-analysis of the literature. *Journal of Learning Disabilities, 42*(3), 260-287.

Szenkovits, G., & Ramus, F. (2005). Exploring dyslexics' phonological deficit I: Lexical vs sub-lexical and input vs output processes. *Dyslexia, 11*(4), 253-268.

Szenkovits, G., Darma, Q., Darcy, I. & Ramus, F. (2008). Exploring dyslexics' phonological deficit II: Phonological grammar. Unpublished manuscript.

Szmalec, A., Loncke, M., Page, M., & Duyck, W. (2011). Order or disorder? Impaired Hebb learning in dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(5), 1270.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and Language, 9,* 182–198.

Thomson, J., & Goswami, U. (2010). Learning novel phonological representations in developmental dyslexia: Associations with basic auditory processing of rise time and phonological awareness. *Reading and Writing, 23*(5), 453-473.

Thomson, J. M., Richardson, U., & Goswami, U. (2005). Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia. *Memory & Cognition, 33*(7), 1210-1219.

Thorn, A. S., & Frankish, C. R. (2005). Long-term knowledge effects on serial recall of nonwords are not exclusively lexical. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(4), 729.

Torgesen, J., Wagner, R. & Rashotte, C. (1999) *Test of Word Reading Efficiency (TOWRE).* Austin, TX: ProEd Publishers.

van Hell, J.G., & Mahn, A.C. (1997). Keyword mnemonics versus rote rehearsal: Learning concrete and abstract foreign words by experienced and inexperienced learners. *Language Learning, 47*(3), 507-546.

van Turennout, M., Bielamowicz , L., & Martin, A. (2003) Modulation of neural activity during object naming: Effects of time and practice. *Cerebral Cortex, 14,* 381-391.

Vandermosten, M., Boets, B., Luts, H., Poelmans, H., Golestani, N., Wouters, J., et al. (2010). Adults with dyslexia are impaired in categorizing speech and nonspeech sounds on the

basis of temporal cues. *Proceedings of the National Academy of Sciences, 107*(23), 10389-10394.

Vellutino, F. R. (1979). *Dyslexia: Theory and Research* (pp. 74-81). Cambridge, MA: MIT press.

Vellutino, F. R., & Scanlon, D. M. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study. *Merrill-Palmer Quarterly (1982),* 321-363.

Vitevitch, M.S. (2003). The influence of sublexical and lexical representations on the processing of spoken words in English. *Clinical Linguistics & Phonetics, 17*(6), 487-499.

Vitevitch, M. S., Armbruster, J., & Chu, S. (2004). Sublexical and lexical representations in speech production: Effects of phonotactic probability and onset density. *Journal of Experimental Psychology: Learning, Memory & Cognition, 30*(2), 514-529.

Vitevitch, M.S., & Luce, P.A. (1998). When words compete: Levels of processing in perception of spoken words. *Psychological Science, 9*(4), 325-329.

Vitevitch, M. S., & Luce, P. A. (2004). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, & Computers, 36*(3), 481-487.

Vitevitch, M.S., Luce, P.A., Pisoni, D.B., & Auer, E.T. (1999). Phonotactics, neighborhood activation, and lexical access for spoken words. *Brain & Language, 68*(1-2), 306-311.

Vitevitch, M.S., & Rodríguez, E. (2005). Neighborhood density effects in spoken word recognition in Spanish. *Journal of Multilingual Communication Disorders, 3*(1), 64-73.

Vitevitch, M.S., & Stamer, M.K. (2006). The curious case of competition in Spanish speech production. *Language and Cognitive Processes, 21*(6), 760-770.

Wagner, R., Torgesen, J., & Rashotte, C. (1999). *Comprehensive Test of Phonological Processing (CTOPP)*: Pro-Ed, Inc.

Wang, N.M., Wu, C.-M., & Kirk, K.I. (2010). Lexical effects on spoken word recognition performance among mandarin-speaking children with normal hearing and cochlear implants. *International Journal of Pediatric Otorhinolaryngology, 74*(8), 883-890.

Warmington, M. (2008). *The Role of Lexical Phonological Representations in New Word Learning: Evidence from Dyslexia and Typical Development.* Ph.D. dissertation, University of York, York.

Werker, J.F., & Curtin, S. (2005). PRIMIR: A developmental framework of infant speech processing. *Language Learning and Development, 1*(2), 197-234.

Wilkinson, G. S. (1993). *Wide Range Achievement Test-Third Edition*. San Antonio, TX: The Psychological Corporation.

Wilson, A. M., & Lesaux, N. K. (2001). Persistence of phonological processing deficits in college students with dyslexia who have age-appropriate reading skills. *Journal of Learning Disabilities, 34*(5), 394-400.

Winkler, I., Lehtokoski, A., Alku, P., Vainio, M., Czigler, I., Csépe, V. (1999). Pre-attentive detection of vowel contrasts utilizes both phonetic and auditory memory representations. *Cognitive Brain Research, 7*(3), 357-369.

Woltman, H., Feldstain, A., MacKay, C. & Rocchi, M, (2012). An introduction to hierarchical linear modeling. *Tutorials in Quantitative Methods for Psychology,8*(1), 52-69.

Woodcock, R.W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities*. Itasca, IL: Riverside.

Wong, P. C., Perrachione, T. K., & Parrish, T. B. (2007). Neural characteristics of successful and less successful speech and word learning in adults. *Human Brain Mapping, 28*(10), 995-1006.

Zamuner, T. S. (2009). Phonotactic probabilities at the onset of language development: Speech production and word position. *Journal of Speech, Language and Hearing Research, 52*(1), 49.

Zhao, L. (2013). *The Effect of Referent Similarity and Phonological Similarity on Concurrent Word Learning.* Ph.D. dissertation, University of Iowa.

Ziegler, J. (2008). Better to lose the anchor than the whole ship. *Cognition, 107,* 151-178.