The Impact of Multisensory Instruction on Learning Letter Names and Sounds, Word Reading and Spelling

by

Nora Wersich Schlesinger

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved May 2016 by the
Graduate Supervisory Committee:

Shelley Gray, Chair
Stephen Graham
Scott Marley

ARIZONA STATE UNIVERSITY

August 2016

ABSTRACT

Children with dyslexia have difficulty learning to read. The purpose of this study was to investigate whether the use of simultaneous multisensory structured language (multisensory) instruction promoted better letter name and sound production, word reading, and word spelling for second grade children with typical development (TD; *N*=6) or with dyslexia (DYS; *N*=5) than structured language instruction alone. The use of non-English graphemes (letters) to represent two pretend languages were used to control for children's lexical knowledge.

A multiple baseline, multiple probe across subjects single-case design, paired with an alternating treatments design, was used to compare the efficacy of multisensory and structure language interventions. Participant's graphed data was visually analyzed and individual Tau-U and weighted Tau-U effect sizes were calculated for the outcome variables: letter name production, letter sound production, word reading, and word spelling.

Both interventions had an overall effect for participants with TD and DYS, though for individual participants intervention effects varied across outcome variables. However, the multisensory intervention did not provide a clear advantage over the structured intervention for participants with TD or DYS.

Much gratitude to my husband, Phil, who makes the best honey and almond butter sandwiches. You supported me every inch of the way, it is because of you that I survived. Your unwavering support and belief in me gave me sustenance. Your love was a gift and genuinely felt throughout my studies. Words are not enough to express my profound appreciation and love.

To my children, Paul, Nora, Cole, and Max. Thank you for your understanding and never making me feel guilty when time was a short commodity. Your calls, text messages, and words of encouragement gave me courage to forge ahead. Thanks for your insight and wisdom…..love you and am so proud of you all.

To my siblings, extended family, and friends who believed in me. Sorry for the missed visits. I look forward to future reunions.

Thank you to my parents, Bill and Rita Wersich, who came from humble beginnings and overcame many hurdles to achieve a college degree. Thank you for stressing the importance of education and instilling a strong work ethic. Mom, I hear your words echo in my head, “Hard work is good for you. You can accomplish anything you set your mind to, girl.”

Last but not least, thank you Snoopy, our beagle, bagel, puppy boy. Your antics over the years will continue to provide us with much laughter. Thank you for literally being beside me the last few months. Your unconditional love and presence was much appreciated.

Knowledge is never wasted.

My mother, Rita Wersich

ACKNOWLEDGMENTS

Thank you to my committee members, Dr. Shelley Gray, Dr. Stephen Graham, and Dr. Scott Marley. Your support and thoughtful insight has been most appreciated. A special note of gratitude to my mentor and dissertation chair, Dr. Shelley Gray. I am grateful for your patience, kindness, and high expectations. Your writing feedback challenged me to become a better writer, your funnel analogy will continue to guide me.

To Dr. Nancy Scherer, Dr. Andrea Pittman, and Dr. Shara Brinkley, thank you for your willingness to serve as masked visual analysts. Your support helped provide additional control to my study. A special thanks to Dr. Shara Brinkley, your friendship and insight throughout my graduate studies has been greatly appreciated.

I would like to thank all the wonderful doctoral students past and present in room 2222 who I have leaned on over the years. Your kindness and encouragement gave me strength. Special thanks to, Hui-Chun, Betsy, Ileana, Carol, Karen, Xuan, Rene, and Michelle.

Many thanks to the research assistants and volunteers whose support and hard work helped complete the study. Sunil for bringing the 3D letters to life. Amy, Diala, and Karisa for your precision in making letter and word cards. Akhila and Farah I am grateful for all your help completing and checking assessment forms. Jeffrey for all your patience making/revising lesson and assessment cards and due diligence analyzing lessons for fidelity. Maria and Angela your attention to detail and ability to transcribe assessments and check for reliability gave me great piece of mind. Yousif you were indispensable. I am forever appreciative for all your hard work on my dissertation. Much gratitude to Kelley for helping me survive the on slot of baseline assessments. Lori, I cannot express my gratitude to you for your willingness to support this study as an interventionist and observer. Amy, Sarah, and Jaclyn, thank you. I was so fortunate to have had such conscientious interventionists. Briana words cannot express my gratitude for your willingness to jump in as a lesson checker, assessment maker, lesson observer, transcriber, the list is endless, thank you.

Much appreciation and gratitude to the participants and their families, the reading centers and schools who supported this study. Without your dedication this study would not have been possible.

This work was funded in part by the Graduate and Professional Student Association at Arizona State University, Graduate Research Support Program grant sponsored by the Office of the Vice-President for Research and Economic Affairs, and by the Graduate College Arizona State University.

Much appreciation courtesy of Lucasfilm Ltd. for the approval to use the Aurebesh letters ***Star Wars*** © & ™ Lucasfim Ltd.

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Children with dyslexia have difficulty learning to read. There is substantial evidence that the primary deficit in dyslexia is phonologically based (Bradley & Bryant, 1983; Liberman, 1973, Liberman, Shankweiler, Fisher, & Carter, 1974; Shaywitz & Shaywitz, 2005; Wagner & Torgesen, 1987). Liberman's seminal work in the 1970's helped lay the foundation for the importance of phonological awareness in reading acquisition and promoted the belief that there is an underlying core phonological deficit in dyslexia (Liberman, 1973; Liberman et al., 1974). Individuals with dyslexia present with intact intelligence (IQ). The adversities they face in accurately and fluently decoding words in print and difficulty with spelling are thought to be due to deficits in the phonological processing of language and are not due to other cognitive impairments (International Dyslexia Association [IDA], 2012; National Institutes of Health [NIH], 2012). For children with dyslexia, it is the reading and decoding skills that are below the population mean on norm-referenced tests (e.g., Berninger, et al., 2006; Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008). Unfortunately for these individuals, reading and spelling impairments are persistent (Shaywitz, 1998), continue into adulthood (Berninger, 2001; Berninger et al., 2008), and may even prevent the attainment of competent literacy skills (e.g., Berninger, Lee, Abbot, & Breznitz., 2013; Berninger et al., 2008; Lyon, Shaywitz, & Shaywitz, 2003; Shaywitz & Shaywitz, 2005; Thambirajah, 2010).

Decades of empirical evidence suggest that to improve overall reading it is important to provide children with training in the alphabetic principle, for example, phonological awareness and letter sound correspondence (e.g., Adams, 1990; Bradley & Byrant, 1983; Velluntino, Fletcher, Snowling, & Scanlon, 2004). In fact, educational policy has been directed over the last few decades by research on reading development (Moats, 2009). An example of a research directed educational policy is the No Child Left Behind (NCLB) Act signed into law by President George W. Bush in 2001.This law ushered in a new era of accountability (Jorgensen & Hoffmann, 2003) and established stringent guidelines for states and public schools (Yell, Shriner, & Katsiyannis, 2006). Under NCLB schools were required to implement evidence-based practices (Yell et al., 2006). The Individuals with Disabilities Education (IDEA) Improvement Act of 2004 also included provisions for the use of evidence-based practices (Etscheidt & Curran, 2010; Yell et al., 2006). Under IDEA a student's individualized education program for special education and related services had to be based on peer-reviewed research to the extent practicable (IDEA, 2004; 20 U.S.C. § 1414 (d)(1)(A)(i)(IV)). The Reading First initiatives of NCLB stipulated that local educational agencies were legally mandated to use funds for "selecting and implementing a learning system or program of reading instruction based on scientifically based reading research" (NCLB, 2002 § 1202(c)(7)(A)). Per NCLB scientifically based reading research meant research that has withstood rigorous, systematic, and objective procedures in reading development, reading instruction, and reading difficulties. This research was to be conducted using systematic, empirical methods with rigorous data analysis to test the stated hypotheses and justify the conclusions drawn. The utilized measurements and methods must provide valid data across evaluators and observers. In addition, the reading research must have been accepted by a peer-review journal or a panel of independent experts via a rigorous, and objective scientific review (NCLB, 2002 § 1208(6)(A)(B)(i-iv). These laws have focused national attention on students' academic performance (Etscheidt & Curran, 2010; Yell et al., 2006).

The need for scientifically-based research has been punctuated by the results of the most recent Nation's Report Card (Institute of Education Sciences [IES], 2015) showing that 64% of fourth-graders and 66% of eighth-grade students are still performing below proficient levels on reading comprehension on the National Assessment of Educational Progress (NAEP). Of those reading below proficient levels, 31% and 24% of fourth- and eighth-grade students, respectively, perform below even a Basic level of reading comprehension. Furthermore, the results of the new computer-based assessment of students' writing skills in the Nation's Report Card Writing 2011 show that only 24% of students in grades 8 and 12 write at the proficient level. However, 54% of grade 8 students and 52% of grade 12 students write only at a basic level, leaving only 3% of grades 8 and 12 students writing at the advanced level (National Center for Education Statistics, 2012). The results from the Nation's Report Cards (IES, 2015) for reading and writing and mandates of NCLB and IDEA stress the need for sound evidence based pedagogical practices for literacy instruction.

To be considered truly literate one must be both a proficient reader and writer. The Carnegie Corporation's 2007 Writing Next Report states that reading comprehension, along with writing skills, predicts academic achievement and that students need to obtain both skills to fully participate in society at local and global levels (Graham & Perin, 2007). To help meet this challenge, a set of rigorous standards known as the Common Core State Standards (CCSS) have been adopted by states across the nation. The CCSS are reported to be evidence-based and align with expectations to ensure students are prepared properly for success in their chosen college and/or career paths (National Governors Association [NGA] Center for Best Practices, Council of Chief State School Officers [CCSSO], 2010). With the inevitability of high stakes assessments, it is critical students, especially students with learning disabilities, are provided with literacy instruction that is evidence-based.

In an alphabetic language such as English, several sub skills are needed to become a skillful reader and writer. Early literacy studies suggest knowledge of letter names is an important fundamental literacy skill that promotes awareness of letter sounds (National Early Reading Panel [NELP], 2008; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). Letter sound correspondence is known as the alphabetic principle (Eden & Moats, 2002) and is a critical foundational literacy skill (Adams, 1990; Bradley & Byrant, 1983). Other important skills include phonological awareness (e.g., Berninger & Richards, 2002; Ehri, 2014; Dixon, Stuart, & Masterson, 2002; Richards, et al., 2006; Velluntino et al., 2004) and automatized access to correct word reading (Gough & Tunmer, 1986) and spelling (Berninger, 1999; Graham & Perrin, 2006). Difficulty acquiring these basic skills, as in dyslexia, adversely impacts reading acquisition (e.g., Bradley & Bryant, 1983; Liberman, 1973, Shaywitz & Shaywitz, 2005).

Dyslexia is a disorder that negatively impacts an individual’s ability to read and spell (Berninger et al., 2013; Berninger et al., 2008; Lyon, Shaywitz, & Shaywitz., 2003; Shaywitz & Shaywitz, 2005). It affects about 80% of individuals identified as learning disabled (Lerner, 1989) and is thought to be the most common neurobehavioral disorder affecting children, with prevalence rates ranging from 5 to 10 percent to upwards of 17.5 percent (Shaywitz, 1998; Shaywitz, Fletcher, & Shaywitz, 1994). For individuals with dyslexia it is critical to provide literacy instruction based on sound empirical evidence so these individuals may become fully literate members of society (e.g., Berninger et al., 2013; Berninger et al., 2000; MacArthur & Graham, 1987; Torgesen, et al., 2001).

An important theoretical model that helps explain reading problems individuals with dyslexia face is the *simple view of reading*. According to this model, reading comprehension results when an individual has both skillful word decoding and quality listening comprehension (Gough & Tunmer, 1986). Decoding, per the simple view of reading, is defined as efficient word recognition in which mental representations are accessed rapidly and accurately (Hoover & Gough, 1990).

For English, automatized word decoding results when an individual internalizes the orthographic code, which is dependent on the knowledge of the rules that govern letter sound correspondences (Gough & Hillinger, 1980). Deficiencies associated with dyslexia negatively impact the acquisition of letter knowledge (Ehri, 2014; Gallagher, Frith, & Snowling, 2000; Snowling & Hulme, 2012) and the ability to decipher the alphabetic code (Shaywitz, Morris, & Shaywitz, 2008). According to the simple view of reading, the reason individuals with dyslexia do not read well is poor word decoding (Gough & Tunmer, 1986). The current study focused on foundational literacy skills as applicable to basic word decoding and encoding in young children with typical development and dyslexia.

Reading Decoding Instruction

Empirical data supports the use of explicit, systematic, and sequential word instruction along with instruction in phonological awareness to teach reading and spelling to elementary age children (e.g., Adams, 1990; Berninger & Amtmann, 2003; Moats, 2006; National Reading Panel [NRP], 2006). Systematic phonics instruction introduces phonic elements, e.g., letter-sound correspondence, in a planned and sequential manner (NRP, 2000). This approach appears to be especially important for teaching literacy skills to students with learning disabilities, such as dyslexia, because it addresses core phonological deficits (Berninger & Amtmann, 2003; Gabrieli, 2009; Graham, Harris, & Chorzempa, 2002; Moats, 2006; NRP, 2000, 2006; Snowling & Hulme, 2011).

Multisensory instruction. Multisensory structured language programs utilize systematic phonics and are popularly used as reading interventions for individuals with dyslexia (McIntyre & Pickering, 2001). In multisensory programs, as one type of a structured language program, direct and explicit instruction based on the structures of English is used to teach reading and writing (Birsh, 2006; Cox, 1992; Neuhaus Education Center, 2008), which is supported by research (e.g., Berninger & Amtmann, 2003; Gabrieli, 2009; NRP, 2006). In addition to structured language principles, these programs utilize multisensory techniques and are therefore called multisensory structured language programs (McIntyre & Pickering, 2001). Multisensory programs present direct and explicit instruction while simultaneously engaging at least two sensory modalities: visual, auditory, or kinesthetic/tactile (Birsh, 2006; Cox, 1992; McIntyre & Pickering, 2001). Advocates believe multisensory input strengthens memory through conscious awareness of mechanisms such as articulation and focuses attention on distinguishing features by providing multiple representations in memory (Moats & Farrell, 2002). For example, the use of mirrors during multisensory instruction helps develop oral-motor awareness (Lindamood & Lindamood, 1998) and emphasizes correct speech sound production (Cox, 1992). Multisensory input, such as letter tracing, helps individuals with dyslexia enhance visual memory by directing attention to the letter form and increasing the information stored in memory (Hulme, 1981).

Multisensory English instruction teaches language structure through phonological and phonemic awareness, sound-symbol association, syllable instruction, morphology, syntax, and semantics (Cox, 1992; McIntyre & Pickering, 2001) and utilizes the following principles: (a) simultaneous multisensory engagement, (b) diagnostic teaching, (c) systematic, cumulative, and direct instruction, and (d) synthetic and analytic instruction (Cox, 1992; McIntyre & Pickering, 2001).

The simultaneous engagement of sensory modalities during lesson activities is believed to enhance learning (Birsh, 2006; Cox, 1992; McIntyre & Pickering, 2001; Neuhaus Education Center, 2008). In kinesthetic activities a wide range of manipulatives are used to facilitate tactile and kinesthetic engagement. For example, students might trace letters on textured surfaces with their fingers while naming the letter or select a three-dimensional letter from a bag based on a target phoneme (Birsh, 2006; Cox, 1992; McIntyre & Pickering, 2001; Neuhaus Education Center, 2008).

Diagnostic teaching is utilized in multisensory programs to promote mastery of concepts through continuous assessment of student outcomes (McIntyre & Pickering, 2001). New letters and reading concepts are not introduced until a child is able to demonstrate her understanding of the previously learned material. Therefore, the rate of progression is individualized. In addition, students are not required to read a word with letters that have not been introduced, nor spell a word they have not first practiced reading (Cox, 1992). Formative assessments are embedded within lessons to guide practitioners in preparing diagnostic and prescriptive lessons. Summative assessments are given at the end of each level to ensure mastery of level material. The use of continuous assessments ensures each lesson is prescriptive and individualized to promote students' automaticity of learned material (Cox, 1992; Wilson, 2002).

Multisensory programs use systematic, direct, and cumulative instruction (McIntyre & Pickering, 2001). New concepts (e.g., introduction of sound-symbol association and syllable types) are taught systematically in that concepts follow the logical order of the English language, beginning with the easiest concepts (e.g., individual letters and sounds) and progressing to more difficult material (e.g., morphemes, parts of speech, and composition). New learning is direct and cumulative; it is explicitly taught and scaffolds onto previously learned concepts (Cox, 1992; McIntyre & Pickering, 2001). The cumulative nature of multisensory instruction is enhanced by having students activate prior knowledge by reviewing previously learned material before the introduction of new material (Cox, 1992). In this format, introduction of new information is limited to what the child is able to absorb (Cox, 1992; McIntyre & Pickering, 2001). Therefore, new learning makes up a critical, but small percentage of the overall lesson.

Both synthetic and analytic instruction are provided in multisensory programs (McIntyre & Pickering, 2001). Synthetic instruction involves teaching the parts of language, for example sound-symbol correspondences, then providing instruction on how the parts come together to form a whole, such as blending phonemes to form a word (McIntyre & Pickering, 2001; NRP, 2000). Analytic instruction involves the presentation of the whole (e.g., the whole word) then teaching students to break the whole down to component parts (McIntyre & Pickering, 2001; NRP, 2000). An example of synthetic instruction (or synthetic phonics) occurs in multisensory programs when a new letter's name is tied to a key word that anchors the letter name and grapheme sound (e.g., a, apple, /æ/) via synthetic phonics instruction. Spelling activities in which students spell the word by isolating the individual phonemes is an example of analytic instruction utilized in multisensory instruction.

History of multisensory instruction for remediation. Hinshelwood (1896) suggested that poor visual memory for words and letters was the root cause of dyslexia (Hallahan & Mercer, 2007). He was the first to recommend instructional intervention for children with written language disorders (Henry & Hook, 2006). McGuffy's Eclectic Readers introduced the concept of integrating multiple methods for reading instruction in the 1880s (Henry & Hook, 2006). Later, in the early 1920s, Fernald and Keller (1921) presented a series of individualized case studies of students with impaired reading and the methods of intervention they applied, all of which had a multisensory component (Fernald & Keller, 1921). The interventions included a series of five multisensory phases that have become known as the VAKT (visual-auditory-kinesthetic/tactual) method (Hallahan & Mercer, 2007).

Samuel Orton, a neurologist, began to study reading disabilities and noted, using newly designed intelligence quotient tests, that many of the children he studied had average to above average intelligence (Hallahan & Mercer, 2007; Pennington, 2003). In January of 1925 Dr. Orton established a mobile mental clinic in Greene County, Iowa (Orton, 1925). Two 16-year-old boys were referred with severe reading impairments. Orton began to call the boys' condition "strephosymbolia" (Orton, 1925). Orton (1925) concluded that remediation required repetitive drills using phonic associations with letters, both in printed form and requiring reproduction in writing. Marion Monroe began to work with Orton and designed methods based on Orton's theory of repetitive and phonetic practice along with Fernald and Keller's approach. Students in the mobile lab were exposed to kinesthetic tracing techniques along with sound blending (Henry & Hook, 2006). After leaving Iowa, Orton worked with Anna Gillingham in New York and asked her to organize instruction for individuals impaired in reading and writing based on his theories. Orton wanted a structured program that was adaptable to suit individual needs (Henry & Hook, 2006). In the manuals Gillingham and Besse Stillman wrote teachers were directed to help students make connections using visual, auditory, and kinesthetic/tactile linkages, which subsequently became known as the Orton-Gillingham method (Henry & Hook, 2006). After the 1960s other programs such as Spalding, Alphabetic Phonics, and the Wilson Reading Program were developed that utilized simultaneous, systematic, and structured multisensory instruction (Henry & Hook, 2006; McIntyre & Pickering, 2001). Lessons using multisensory instruction follow a daily sequence and tend to be variations of the original Orton-Gillingham methods and are referred to as Orton-Gillingham programs (Birch, 2006; Hallahan & Mercer, 2007; Henry & Hook, 2006; McIntyre & Pickering, 2001; Pennington, 2003). Orton-Gillingham-based programs are considered multisensory structured language programs (McIntyre & Pickering, 2001). The term *multisensory* used in this study refers to programs that are Orton-Gillingham based or use Orton-Gillingham tenets.

Dual Coding Theory

A well-established theory of reading that focuses on multimodal encoding is the dual coding theoretical model of reading (Paivio, 1991; Sadoski & Paivio, 2001, 2013).

Multisensory approaches to reading instruction have their basis in dual coding theory (Paivio, 1991; Sadoski & Paivio, 2001, 2013). In dual coding theory there are two separate coding systems of mental representations, which are the internal forms of information used in memory. The two systems include a verbal system for coding linguistic information and a nonverbal system for coding nonverbal mental images (Sadoski & Paivio, 2001). Verbal and nonverbal systems are represented symbolically by the structural and functional properties of linguistic and nonlinguistic entities referred to as logogen and imagen, respectively (Paivio, 1991). Logogens are organized in a sequential and hierarchical arrangement. Imagens are nested and overlap in hierarchical arrangements. The two systems are influenced by sensory modalities; and it is presumed these systems retain their distinct modalities (Paivio, 1991). The environmental stimuli enter from input through the sensory systems and are processed at three levels, representational connections, referential connections, or associative connections (Sadoski & Paivio, 2001). Representational connections detect environmental stimuli and as they are processed activate logogens and imagens, which then may process between themselves via referential connections. If additional processing is needed, associative connections within the logogens or imagens are activated. Output in the form of verbal or nonverbal responses are the result of the three levels of processing within the dual coding theory general model (Sadoski & Paivio, 2001). The encoding of mental representations is the basis of all cognition in dual coding theory (Sadoski & Paivio, 2001).

Experiments within the dual coding theory framework of multimodal instruction have been shown to enhance learning and empirical results provide a theoretical explanation as to the possible pedagogical benefits of multisensory reading instruction.

Mayer and Anderson (1991) conducted a series of empirical experiments that varied presentation of information to four groups of participants. Participants were randomly assigned to receive information on a computer screen on how a bicycle pump works in words only, pictures only, or words with pictures. A control group received no information. The group receiving the simultaneous instructions with words and pictures outperformed the other groups on their ability to problem solve. In line with the dual coding theory, the words with pictures scenario provided more opportunity to build representational connections for both visual and verbal information. The ability to build referential connections between logogens and imagens was enhanced by the multimodal presentations (Mayer & Anderson, 1991).

Research on reading comprehension has shown significantly better effects when both linguistic and nonlinguistic inputs are presented in a multisensory manner. Using comprehension process motions, a study was conducted with two U.S. underperforming elementary schools in kindergarten through fifth grade. The teaching procedures involved the use of kinesthetic hand movements and placements to portray visual and physical representations of abstract comprehension processes (Block, Parris, & Whiteley, 2008). Students were randomly assigned to the experimental group that implemented comprehension process motions or the control group, who were taught the same comprehension processes as the experimental group but did not receive kinesthetic teaching procedures. Pretests showed no statistically significant pretest population variance. Posttests showed the experimental groups significantly outperformed the control groups on five explicit comprehension processes: drawing conclusions, clarifying and identifying problems, following a fictional plot, identifying nonfiction writing patterns, and finding main ideas (Block et al., 2008). The comprehension process motions made abstract, metacognitive aspects of comprehension visible and understandable. Following the tenets of dual coding theory, the use of a variety of pathways allowed the students to comprehend and express their comprehension (Block et al., 2008). These experiments lend support to why multisensory reading instruction may be pedagogically efficacious in the development of reading processes.

Multisensory Instruction Research

Multisensory structured language programs are widely used for reading remediation (Clark & Uhry, 1995; Moats & Farrell, 2002). There is empirical evidence to support the structured systematic phonics instruction common to the programs (Clark & Uhry, 1995, NRP 2000), however, there is a lack of scientific evidence indicating the addition of multisensory input makes a significant difference (Clark & Uhry, 1995). In addition, the body of research supporting multisensory structured language as efficacious for reading intervention is limited and often inconclusive (Bhat, Rapport, & Griffin, 2000; Clark & Uhry, 1995; Ritchey & Goeke, 2006; Rose & Zirkel, 2007). This is due, in part, to the lack of well controlled studies comparing multisensory instruction to an alternative remedial approach (Clark & Uhry, 1995; Moats & Farrell, 2002; Ritchey & Goeke, 2006; Rose & Zirkel, 2007; Snowling & Hulme, 2011). However, the available research suggests multisensory instruction is advantageous (e.g., Hulme, 1981, Hulme, Monk, & Ives, 1987; Joshi, Dahlgren, & Boulware-Gooden, 2002; Post & Carreker, 2002; Torgesen et al., 2001). As a consequence, parents and advocacy groups often request multisensory instruction as a preferred form of reading intervention. This has led to an increase in litigation requesting multisensory instruction under the IDEA act (Bhat et al., 2000; Ritchey & Goeke, 2006; Rose & Zirkel, 2007). Therefore, it is important to empirically evaluate the efficacy of multisensory instruction in the acquisition of basic literacy skills, especially for children who have significant reading and spelling impairments.

Efficacy of Multisensory Programs for Teaching Decoding

To locate multisensory studies a multiple database search was conducted for topics related to multisensory reading and spelling instruction. Of interest were studies evaluating basic decoding and encoding skills for early elementary-age children with typical development and dyslexia. Although multisensory instruction is primarily utilized as a form of reading remediation, it was important to include multisensory studies with children with typical development as a gauge to judge its effectiveness as a method of reading instruction. Articles from the 1990s and later were included if they contained a treatment condition that utilized multisensory reading or spelling instruction with at least one measure assessing word reading. In addition, only studies from peer reviewed journals were included. Furthermore, articles had to contain enough information to ascertain whether the method of instruction was based on a tenet of Orton-Gillingham. Lastly, only articles written in English pertaining to an alphabetic language system were included. Four studies were found that compared the efficacy of multisensory instruction and non-explicit systematic phonics instruction for elementary-age children with typical development or dyslexia. Three studies were found that compared the effects of multisensory instruction with other structured systematic phonics based reading programs for children with dyslexia.

Multisensory instruction versus non-explicit and systematic phonics instruction. Four studies comparing the efficacy of multisensory instruction and nonsystematic instruction in elementary age children with typical development (TD) and with dyslexia (DYS) showed multisensory instruction provided better outcomes for word decoding (Joshi et al., 2002; Oakland, Black, Stanford, Nussbaum, & Balise, 1998; Uhry & Shepherd, 1993) and spelling (Post & Carreker, 2002; Uhry & Shepherd, 1993). However, of the available studies only one used an experimental group design; the other three studies used a quasi-experimental group design. Of the four studies only one, a quasi-experimental group study, evaluated the effects of multisensory instruction on children with DYS. In addition, fidelity of implementation scores was not directly reported in the studies. Fidelity of implementation, the extent to which an intervention was enacted as prescribed (Century, Rudnick, & Freeman, 2010; Schoenwald, et al., 2011), provides important accountability outcomes for evidence-based treatments (Schoenwald, et al., 2011).

Experimental TD group study. Uhry and Shepherd (1993) used an experimental design to conduct a study with first grade children in typical classroom settings using multisensory techniques to teach spelling and its effects on reading. The aim of the study was not to evaluate multisensory instruction, however the spelling method used was an Orton-Gillingham based program, Alphabetic Phonics (Cox, 1992). Stratified random assignment was used to form two treatment groups with strata (low, medium, or high) based on kindergarten teachers' estimates of reading ability. The study included an experiment group who received multisensory spelling instruction (11 children) and a control group (11 children). Children in the experimental and control groups received instruction administered by the first author and a trained graduate student. Instruction was given each week in two 20-minute sessions with equal time between groups. The interventions for the two groups started at the beginning of first grade with assessments given four times in the course of the study. Pre and post assessments spanned six and a half months. The children who received multisensory instruction made significant gains reading real and nonsense words whereas the control group did not. The multisensory group also had significantly higher passage reading. The children who received multisensory instruction were significantly better at spelling words containing short vowels with consonant clusters and spelling words with letter units (i.e., analogy spelling such as cube or throw).

This was a carefully controlled study with randomization of participants to groups. The results provided evidence that multisensory spelling procedures may be an effective teaching strategy.

Quasi-experimental TD group studies. Two of the three quasi-experimental studies found multisensory instruction significantly improved phonological awareness, word decoding (Joshi et al., 2002) and, spelling (Post & Carreker, 2002) within typical classrooms.

Joshi et al. (2002) compared the use of a nonsystematic phonics district-approved curriculum (32 children) and multisensory instruction (24 children) in first grade classrooms. Students received 50 minutes of literacy instruction daily. The teachers implementing the multisensory program had certifications as Academic Language Therapists and received 42 additional hours of training in multisensory techniques. Assessments were given at the beginning of the year and included decoding related assessments in phonological awareness and word attack. The multisensory group had significant gains in phonological awareness and decoding. Results suggested the gain scores of the treatment group were significantly higher than the control group.

This study provided insight into the efficacy of implementing multisensory instruction at the classroom level. However, there were several implementation concerns. The participants in this study were not randomly assigned to groups and multisensory interventionists appeared to have extensive language training compared to the teachers in the control group. Controls for fidelity of implementation were in place, but specific scores for fidelity were not reported.

Post and Carreker (2002) studied second through fourth grade students from two neighborhood elementary schools who received either explicit multisensory spelling (70 children) or implicit spelling (70 children) instruction for words ending in *–ion,* spelled with *tion* or *sion* spelling pattern. Both spelling interventions were taught by the same teacher. Each intervention took 20 minutes per day, four days a week for two weeks. To measure change, students were assessed on: (a) vowel and consonant discrimination by comparing embedded vowels or consonants in nonsense words, (b) vowel and word ending requiring reading of words ending in either *tion* or *sion*, (c) vowel and word ending letter insertion in which a word lacked either a vowel in the stressed syllable or a word ending following the stressed syllable, and (d) dictation requiring students to spell words ending in *tion* or *sion*. Students receiving the explicit multisensory instruction made significantly fewer errors than students receiving implicit spelling instruction for consonant discrimination, letter insertion of word ending, and on a spelling generalization task.

This study presented many positive and potentially efficacious practices for teaching spelling. However, there were several concerns with the study methodology. Importantly, participants were not randomly assigned to treatment groups and this may have inadvertently biased results in favor of the explicit instruction. Also, intervention implementation fidelity scores were not provided.

Quasi-experimental DYS group study. The third quasi-experimental study, which included children with DYS, found multisensory instruction improved word reading (Oakland et al., 1998). In this longitudinal study children received as their primary reading instruction either multisensory instruction in a clinical setting (22 children) or a control reading instruction provided by their local school (26 children). Children in the clinical setting received multisensory instruction five days per week, 10 months per year, for two years. The amount of reading instruction varied among the participants in the control group, with modified basal reading programs as the predominant lesson format. Some participants from both groups received additional ancillary services (e.g., Chapter 1 and resource room) through their schools. Participants received assessments prior to intervention and at the end of years one and two. Analysis of variance was conducted for each group by time on the following measures: reading comprehension, word recognition, mono- and polysyllabic nonsense word decoding, and spelling. Two groups by time interactions; reached significance. Analysis showed the control group made little word reading progress; while the multisensory group, which initially performed lower, had better performance than the control group after two years. In polysyllabic nonsense word decoding the multisensory group, which initially performed lower, performed significantly higher at the end of two years. It is important to note in this study, neither the instructional time between groups nor the ancillary services individual participants received were controlled. Furthermore, the reading instruction for participants in the control group varied.

Multisensory instruction versus structured systematic instruction. Three studies evaluated the effects of multisensory instruction and other phonics based reading programs with elementary age children with DYS. Results suggested multisensory instruction was advantageous for phonological gains and word decoding (Campbell, Helf, & Cooke, 2008; Foorman et al., 1997; Torgesen et al., 2001). Two were comparison studies, one in which children with comorbid DYS and ADHD were included, and one was a single case design study.

Experimental DYS group design. In an experimental longitudinal study Torgesen et al. (2001) evaluated intensive remedial instruction for children with DYS, including children with comorbid DYS and ADHD, and found multisensory instruction provided better outcomes for word attack and spelling. Children between 8-10 years of age participated in either a multisensory program (26 children) or an embedded phonics program (24 children) developed by the authors. Participants individually received two 50-minute intervention sessions each week day, for up to 67.5 hours, in lieu of resource room instruction. Reading assessments were given prior to the intervention, post intervention, and again at one and two year intervals following post assessments. The assessments included several measures each of phonological processing, word reading skills, and spelling. In order to isolate treatment effects, analysis of variance was conducted for treatment interventions separately from growth during follow-up periods. The only significant group differences found during the span of time children received interventions, were the rates of growth from pre- to post-test in word attack, reading rate, and accuracy, with the multisensory group showing an advantage. However, growth at follow-up assessments (posttest, one and two years later) showed standard scores for the groups did not maintain normal growth in word attack. Though a control group was not used, researchers had the children's resource room instruction pre-intervention rates of growth, which were utilized to determine children's broad reading growth. Effect sizes of standard scores using pre-intervention resource instruction were 4.4 for the multisensory group and 3.9 for the embedded phonics group. For spelling skills, the embedded phonics group significantly improved their spelling scores during intervention, but had a marked decline in growth rate at the two-year follow-up. Both treatments had significant effects for phonological spelling (writing letters to represent sounds). However, the rate of growth at follow-up was strongest for the multisensory group. Overall the children continued to have deficiencies and group differences were not present at the end of two years. This well controlled longitudinal study provided additional support for the use of structured systematic instruction for children with DYS. In addition, the study addressed issues regarding treatment resisters and the significant hours of intervention individuals with DYS require.

Quasi-experimental DYS group design. Using a quasi-experimental design, Foorman et al. (1997) evaluated the effects of three reading treatments with second and third grade children: a synthetic multisensory phonics program (28 children), a sight-word program (39 children), and an analytic phonics program based on rime patterns versus phonic rules (47 children). Reading treatments were 60 minutes per day over six months with an average of eight students per treatment session. The multisensory and analytic phonics were taught as a whole group and the sight-word program was delivered in centers. Individual growth curve analyses were conducted in-year (October, December, February, and April) on measures for: phonological analysis, orthographic processing, and word reading. The only significant difference in outcomes was the synthetic multisensory group outperformed the sight-word group but not the analytic phonics group in phonological gains, with verbal intelligence quotient (IQ) being a significant covariate (Foorman, et al., 1997). This study presented important data comparing two phonics based reading practices. However, because participants were not randomly assigned to treatment groups results may have been biased towards the synthetic multisensory instruction.

Single case design with DYS. The last study, a multiple baseline across subjects single-case design, showed that multisensory instruction improved children's nonsense word and passage reading (Campbell et al., 2008). Campbell et al. (2008) evaluated the impact of simultaneous multisensory instruction added to a supplemental reading program for six young second grade students who were considered treatment resisters. Participants were seven and eight years of age and identified as treatment resisters because they failed to reach grade level benchmarks per the Dynamic Indicators of Basic Early Literacy Skills (DIBELS, Good and Kaminiski, 2014) in which fewer than 18 nonsense words were correctly read per minute. The children in this experiment had received more than two years of instruction in an evidence-based reading program and 20 lessons in an explicit, systematic supplemental reading program. The study assessed: (a) correct number of whole words read per minute in phonetically regular vowel-consonant (vc) and consonant-vowel-consonant (cvc) nonsense words, (b) the number of sounds pronounced correctly per minute within the nonsense words, (c) words read correctly per minute on a first-grade passage, and (d) average words read correctly on second-grade passages.

During baseline the participants received 20 supplemental lessons in an explicit, systematic reading program in addition to their evidence-based school reading program. When stable baseline was evident by lack of an ascending trend, one student from each group began the intervention phase and received multisensory techniques as an additional component to the supplemental reading program. When the newly introduced participants' level or trend increased, using at least five data points, the next participant from that group received multisensory instruction. Upon reading correctly 25 nonsense words per minute, participants began the maintenance phase, which meant deletion of multisensory techniques to the supplemental program. However, none of the children met this criterion.

The baseline data suggested there were two distinct patterns of performance. One group of children showed Low Words/Low Sounds read nonsense words below ceiling (i.e., 18 per minute) and below DIBELS benchmark for sounds within nonsense word (i.e., 50 per minute). The other group, Low Words/High Sounds, met benchmarks but continued to read nonsense words below ceiling. Results indicated that vc and cvc nonsense word decoding improved for all students when the multisensory components were added and fluency for correct sound recognition within vc and cvc words increased from baseline for the Low Words/Low Sounds group. However, for the Low Words/High Sounds group sound recognition within vc and cvc words decreased because students segmented sounds then read the entire word before going onto the next word. This process slowed participants down compared to baseline when words were segmented into phonemes only. Four participants met or exceeded the DIBELS benchmark of 50 correct sounds per minute during the intervention. Five of the six participants modestly improved the number of words read correctly per minute for each first grade passage probe, the reading of one first-grade passage. All six participants improved with the addition of the multisensory intervention on the second-grade passages. The discrepancy between the first and second grade passages may reflect different collection procedures for second-grade passages in which three different passages are read and the median score of the three are taken versus one passage read for first grade passage probes. This well controlled study provided support for the use of structured systematic instruction to differentiate instruction for children who resist treatment. Both inter-rater assessment reliability and fidelity of treatment implementation were directly reported.

Current Study

The current study used a unique integrated single-case design (Shadish & Sullivan, 2011) to improve upon the research designs of previous studies of multisensory instruction. A multiple baseline, multiple probe, single-case design with alternating treatments was used that met the What Works Clearinghouse criteria for *Meets Evidence Standards without Reservations* (What Works Clearinghouse [WWC], 2013). To meet this criteria: (a) methodically manipulate the independent variable, (b) measure outcome variables over time by more than one assessor, (c) collect inter-assessor agreement on twenty percent of the data points across phases for each condition (exceptions noted below) with inter-assessor agreements averaging at least 80 to 90 percent, (d) include a minimum of three baseline conditions, (e) compare two alternating treatments with each other, and (f) collect at least five data points per phase and five alternating repetitions of the interventions. Due to logistics inter-assessor agreement was collected for 14% of baseline, 33% of treatment, and 10% of follow-up sessions for participants with TD for both interventions. For participants with DYS inter-assessor agreement was collected for 10% of baseline, 43% of treatment, and 30% of follow-up sessions. In addition, inter-observer agreement was calculated by individuals not directly involved in data collection as per recommendations (Richards, Taylor, & Ramasamy, 2014), with the exception of the first author. Although the first author was involved in data collection and calculating inter-observer agreement, scores were validated by another trained rater. Furthermore, specific measurements for fidelity of implementation were reported, which has been lacking in past multisensory research.

To help control for Type I error, data analysis tasks related to introduction of participants to treatments were performed by individuals who were not involved in presenting the intervention. The interventionists had direct contact with participants and sent collected data to data analysts who were not privy to treatment and participant group affiliation (Ferron & Jones, 2006).

In this study interventionists implemented two interventions, a structured language and a multisensory structured language treatment. The interventionists included a doctoral student and speech-language pathology assistants, who received equivalent training for each treatment. Furthermore, internal validity was strengthened by controlling for investigator and interventionists' bias (Barlow & Hersen, 1973). To control for bias, interventionists other than the first author were naive to research hypotheses (Barlow & Hersen, 1984; Richards et al., 2014), and group affiliation of participants (TD or DYS). The first author served as an interventionist only when logistics prevented the availability of another interventionist.

Purpose, Hypotheses, and Research Questions

The purpose of this study was to determine whether simultaneous multisensory input, in addition to structured language instruction, would promote better letter name, sound production, word decoding, and encoding in young children with TD and DYS than structured language instruction alone. Letter name, letter sound, word reading, and word spelling were selected as dependent variables because knowledge of letter names is an important fundamental literacy skill that promotes awareness of letter sounds (NELP, 2008; Treiman, et al., 1998). In turn knowledge of the alphabetic code, grapheme-phoneme, allows children to shift from reliance on visual cues to phonetic processing (Ehri & Wilce, 1985). Utilization of grapheme-phoneme correspondences allows for the formation of orthographic mapping for sight word reading and spelling from memory (Ehri, 2014). Collectively, these dependent variables give a range of early literacy skills to assess the impact of multisensory instruction.

The inclusion of children with TD was advantageous on three levels. First, it provided an evaluation of whether multisensory instruction was effective for teaching foundational literacy skills for children with TD. Second, it allowed for an evaluation of whether lesson factors, such as number of letters or words taught per session, were reasonable. Third, it helped evaluate that the level of learning for participants with dyslexia was not due to the interventions taught, but rather reflective of their disability.

Based on a visual inspection of slope, level, immediacy of effects, and the Tau-U nonoverlap index of effect the specific research questions and hypotheses were:

1. Will the multisensory intervention be more effective than the structured language intervention for learning letter names, letter sounds, word reading, and spelling for participants with TD? We hypothesized that there would be a multisensory intervention advantage for learning among all participants with TD.
2. Will the multisensory intervention be more effective than the structured language intervention for learning letter names, letter sounds, word reading, and spelling for participants with DYS? We hypothesized that there would be a multisensory intervention advantage for learning among participants with DYS.
3. Will the multisensory intervention be more effective than the structured language intervention for maintenance of letter names, letter sounds, word reading, and spelling for participants with TD? We hypothesized that there would be a multisensory intervention advantage for maintenance among all participants with TD.
4. Will the multisensory intervention be more effective than the structured language intervention for maintenance of letter names, letter sounds, word reading, and spelling for participants with DYS? We hypothesized that there would be a multisensory intervention advantage for maintenance among all participants with DYS.

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The Impact of Multisensory Instruction on Learning
Letter Names and Sounds, Word Reading and Spelling

Nora W Schlesinger

Arizona State University

Author Note

Nora W. Schlesinger, Department of Speech and Hearing Science, Arizona State University.

Acknowledgements. This work was funded in part by the Graduate Research Support Program grant by the Graduate College at Arizona State University. Much appreciation courtesy of Lucasfilm Ltd. for the approval to use the Aurebesh letters ***Star Wars*** © & ™ Lucasfim Ltd. Many thanks to the participants and their families, the reading centers and schools who supported this study, and the visual analysts, research assistants, and volunteers whose support and hard work helped completed the study. Much gratitude to the interventionists who went above and beyond to ensure a quality study.

Correspondence concerning the article should be addressed to Nora W. Schlesinger, Department of Speech and Hearing Science, Arizona State University, PO Box 870102, Coor Hall 2222, Tempe, AZ 85287-0102. Email: Nora.Schlesinger@asu.edu.

Abstract

Purpose: Children with dyslexia have difficulty learning to read. The purpose of this study was to investigate whether the use of simultaneous multisensory structured language instruction promoted better letter name and sound production, word reading, and word spelling for second grade children with typical development (TD; *N*=6) or with dyslexia (DYS; *N*=5) than structured language instruction alone. The use of non-English graphemes (letters) to represent two pretend languages were used to control for children's lexical knowledge.

Method: An integrated multiple baseline, multiple probe across subjects single-case design, with an embedded alternating treatments design, was used to compare the efficacy of multisensory and structure language interventions. Both interventions provided explicit systematic phonics instruction; however, the multisensory intervention utilized simultaneous engagement of at least two sensory modalities (visual, auditory, and kinesthetic/tactile). Participant's graphed data was visually analyzed and individual Tau-U and weighted Tau-U effect sizes were calculated for the outcome variables: letter name production, letter sound production, word reading, and word spelling.

Results: The multisensory intervention did not provide a clear advantage over the structured intervention for participants with TD or DYS. However, both interventions had an overall treatment effect for participants with TD and DYS, though for individual participants, intervention effects varied across outcome variables.

Children with dyslexia have difficulty learning to decode. There is substantial evidence the primary deficit in dyslexia is phonologically based (Liberman, Shankweiler, Fisher, & Carter, 1974; Wagner & Torgesen, 1987). Knowledge of letter names is an important fundamental literacy skill that promotes awareness of letter sounds (National Early Reading Panel [NELP], 2008; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). Learning to read and spell in an alphabetic language like English requires understanding of the alphabetic principle (letters-sound correspondences) and phonological awareness (e.g., Ehri, 2014; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Deficiencies in these areas, as found in dyslexia, negatively impact the acquisition of letter knowledge (Ehri, 2014; Snowling & Hulme, 2012) and the ability to decipher the alphabetic code (Shaywitz, Morris, & Shaywitz, 2008), which leads to word decoding problems (e.g., Berninger, 2001; Ehri, 2014; Vellutino et al., 2004). For individuals with dyslexia, reading and spelling impairments are persistent (Shaywitz, 1998) and may hinder the development of competent literacy skills (e.g., Berninger, Lee, Abbott, & Breznitz, 2013; Berninger et al., 2008).

Research suggests phonics instruction is effective for teaching word decoding and spelling to young children (e.g., Adams, 1990; National Reading Panel [NRP], 2000; Snowling & Hulme, 2012). Systematic phonics instruction introduces phonics elements such as letter sound correspondence and spelling patterns in a planned, sequential manner (NRP, 2000). Reading interventions that utilize systematic phonics have been shown to address core phonological deficits found in dyslexia (e.g., Berninger & Amtmann, 2003; NRP, 2006).

Multisensory structured language is a reading method that incorporates systematic phonics and is popularly used in reading remediation for individuals with dyslexia (Clark & Uhry, 1995; Moats & Farrell, 2002). Multisensory programs have become known as Orton-Gillingham programs (Henry & Hook, 2006; McIntyre & Pickering, 2001). In addition to direct, explicit, and systematic phonics instruction, lesson activities incorporate the simultaneous engagement of at least two sensory modalities (visual, auditory, or kinesthetic/tactile) (Birsh, 2006; McIntyre & Pickering, 2001). In this study, multisensory instruction refers to the simultaneous engagement of sensory modalities.

Multisensory approaches to reading instruction have their basis in dual coding theory (Paivio, 1991; Sadoski & Paivio, 2001, 2013) that proposes there are two separate coding systems for the internal forms of mental representations used in memory. These include a verbal system for coding linguistic information and a nonverbal system for coding nonverbal mental images (Sadoski & Paivio, 2001). Based on this theory, teaching that engages a child's sensory modalities (e.g., visual, auditory, and tactile), as well as their linguistic system, may enhance learning. Experiments within the dual-coding theory framework of multimodal instruction have been shown to enhance learning (Bell, 1991) and empirical results provide a theoretical explanation as to the possible pedagogical benefits of multisensory reading instruction (e.g., Block, Parris, & Whiteley, 2008; Mayer & Anderson, 1991).

Empirical evidence supports the structured systematic phonics element common to multisensory structured language instruction (Clark & Uhry, 1995, NRP 2000), however, scientific evidence is lacking that indicates the addition of multisensory input makes a significant difference (Clark & Uhry, 1995). Therefore, the body of research supporting multisensory structured language as efficacious for reading intervention is limited (Alexander & Slinger-Constant, 2004; Rose & Zirkel, 2007) and often inconclusive (Rose & Zirkel, 2007). Yet parents often request it as a preferred form of reading intervention (Rose & Zirkel, 2007) and this has led to an increase in litigation requesting multisensory instruction under the Individuals with Disabilities Education Act (Bhat, Rapport, & Griffin, 2000; Rose & Zirkel, 2007).

Efficacy of Multisensory Programs for Teaching Decoding

Multisensory instruction versus non-explicit and nonsystematic phonics instruction. Four studies have compared the efficacy of multisensory instruction and non-explicit and systematic phonics instruction in typical classrooms and a clinical setting for elementary-age children with typical development (TD) and with dyslexia (DYS). Results showed that multisensory instruction provided the best outcome for word decoding (Joshi, Dahlgren, Boulware-Gooden, 2002; Oakland, Black, Stanford, Nussbaum, & Balise, 1998; Uhry & Sheperd, 1993) and spelling (Post & Carreker, 2002; Uhry & Sheperd, 1993). One study used an experimental group design; the other three studies were quasi-experimental group designs. Of the four studies, only one specifically evaluated the impact of multisensory instruction on children with DYS.

Experimental and quasi-experimental TD group studies. In the study by Uhry and Sheperd (1993) multisensory segmenting and spelling techniques were used. Eleven first grade children received multisensory spelling instruction and made significantly greater gains in decoding nonsense words, reading sight words, passage reading, and word spelling than their 11 counterparts receiving whole language. In the quasi-experimental studies Joshi et al. (2002) found first grade children who received multisensory instruction (24) made greater end of the year gains in phonological awareness and decoding compared to the control group (32) who received nonsystematic phonics instruction. Post and Carreker (2002) compared explicit multisensory spelling instruction (70 children) to implicit spelling instruction (70 children) with second through fourth grade students. Students who received explicit multisensory instruction had fewer errors in consonant sound discrimination tasks and spelling generalization tasks.

Quasi-experimental DYS group study. One quasi-experimental study of children with DYS took place in a clinical setting. The results of this study showed improved word reading (Oakland et al., 1998). In this longitudinal study children received either multisensory instruction in a clinical setting (22) or reading instruction provided at their local school (26). The multisensory group, which initially preformed lower, had significantly better word reading and polysyllabic nonsense word decoding after two years than students receiving instruction from the local school (Oakland et al., 1998).

Multisensory instruction versus structured systematic instruction. Three studies compared the effects of multisensory instruction with other systematic phonics based reading programs for children with DYS. Results suggest multisensory instruction was advantageous for phonological gains and word decoding (Campbell, Helf, & Cooke, 2008; Foorman et al., 1997; Torgesen et al., 2001). The studies included a quasi-experimental group design, an experimental group design, and a single-case design.

Experimental DYS group design. Torgesen et al. (2001) evaluated intensive remedial instruction for children with DYS, including children with comorbid DYS and ADHD and found multisensory instruction provided better outcomes for word attack and spelling. The results were not segregated for children with comorbid diagnoses.

Participants were between 8-10 years of age and participated in either a multisensory program (26 children) or an embedded phonics program (24 children). The multisensory group showed significant gains on the rates of growth from pre to posttest in word attack, reading rate, and accuracy, but group differences were not present at the end of two years.

Quasi-experimental DYS group design. An advantage for multisensory instruction was found in a three- treatment study of children with DYS (Foorman et al., 1997). The effects of the reading treatments were evaluated with second and third grade children: a synthetic multisensory phonics program (28 children), a sight-word program (39 children), and an analytic phonics program based on rime patterns versus phonic rules (47 children). The multisensory group significantly outperformed the sight-word group, but not the analytic phonics group, in phonological gains.

Single case design with DYS. The last study, a multiple baseline across subjects single-case design, showed that multisensory instruction input improved children with DYS's nonsense word and passage reading. Campbell et al. (2008) evaluated the effect of simultaneous multisensory input added to an evidence based reading program for six second grade students with DYS. Results indicated vowel-consonant and consonant-vowel-consonant nonsense word decoding and second-grade passage reading improved for all students when simultaneous multisensory components were added.

Limitations of Current Research

Of the studies that have evaluated multisensory instruction there are have been fundamental flaws limiting the generalization of results. This is due, in part, to the lack of well controlled studies comparing multisensory instruction to an alternative remedial systematic approach (e.g., Uhry & Shepherd, 1993; Joshi et al., 2002; Post & Carreker;

2002). Only one study found, Campbell et al. (2008), specifically evaluated the impact of *simultaneous* multisensory input as a variable. In addition, lack of randomization of participants (e.g., Foorman et al., 1997; Joshi et al., 2002; Post & Carreker; 2002), unequal instructional time between interventions (e.g, Oakland et al., 1998), and level of instructor training or knowledge (e.g., Joshi et al., 2002; Oakland et al., 1998) may have inadvertently biased results in favor of multisensory instruction. Furthermore, specific scores of intervention fidelity were not reported (e.g., Joshi et al., 2002).

Purpose, Hypotheses, and Research Questions

The purpose of this study was to determine whether simultaneous multisensory input, in addition to structured language instruction, would promote better letter name, sound production, word decoding, and encoding in young children with TD and DYS than structured language instruction alone. Letter name, letter sound, word reading, and word spelling were selected as dependent variables because knowledge of letter names is an important fundamental literacy skill that promotes awareness of letter sounds (NELP, 2008; Treiman, et al., 1998). In turn, grapheme-phoneme correspondence allows children to shift from reliance on visual cues to phonetic processing (Ehri & Wilce, 1985). Utilization of grapheme-phoneme correspondences allows for the formation of orthographic mapping for sight word reading and spelling from memory (Ehri, 2014). Collectively, these dependent variables give a range of early literacy skills to assess the impact of multisensory instruction.

The inclusion of children with TD was advantageous on three levels. First, it provided an evaluation of whether multisensory instruction was effective for teaching foundational literacy skills for children with TD. Second, it allowed for an evaluation of whether lesson factors, such as number of letters or words taught per session, were reasonable. Third, it helped evaluate that the level of learning for participants with dyslexia was not due to the interventions taught, but rather reflective of their disability.

Based on a visual inspection of slope, level, immediacy of effects, and the Tau-U nonoverlap index of effect the specific research questions and hypotheses were:

1. Will the multisensory intervention be more effective than the structured language intervention for learning letter names, letter sounds, word reading, and spelling for participants with TD? We hypothesized that there would be a multisensory intervention advantage for learning among all participants with TD.
2. Will the multisensory intervention be more effective than the structured language intervention for learning letter names, letter sounds, word reading, and spelling for participants with DYS? We hypothesized that there would be a multisensory intervention advantage for learning among participants with DYS.
3. Will the multisensory intervention be more effective than the structured language intervention for maintenance of letter names, letter sounds, word reading, and spelling for participants with TD? We hypothesized that there would be a multisensory intervention advantage for maintenance among all participants with TD.
4. Will the multisensory intervention be more effective than the structured language intervention for maintenance of letter names, letter sounds, word reading, and spelling for participants with DYS? We hypothesized that there would be a multisensory intervention advantage for maintenance among all participants with DYS.

Method

Participant Recruitment and Selection

To qualify for inclusion all children were required to pass a bilateral hearing screening at 20dB HL at 500, 1K, 2K, and 4K Hz (ASHA, 1997), a near vision acuity screening (20/32) in both eyes with glasses, and to be monolingual English speakers with no history of a neurologically-based disorder other than dyslexia per parent report. Participants were required to demonstrate nonverbal intelligence within the average range as indicated by a standard score of 75 or higher (70 + 1 SEM) on the nonverbal portion of the Kaufman Assessment Battery for Children - Second Edition (KABC-2; Kaufman & Kaufman, 2004) and were required to demonstrate adequate language performance as specified by a standard score of 88 or higher on the Core Language of the Clinical Evaluations of Language Fundamentals, Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003). In addition, participants were required to demonstrate intelligible speech, with a score higher than the 31st percentile on the Goldman-Fristoe Test of Articulation-Second Edition (GFTA-2; Goldman & Fristoe, 2000).

Children were recruited from public, private, and charter schools and organizations in the Phoenix metropolitan area. The parents of 30 children consented to participation per university institutional review board requirements for human subjects and each child assented to participation. Participants received an incentive of up to 50 dollars for participating. Of the 30 children 19 were excluded for one or more of the following reasons: Spanish was the predominate language, standardized language scores were too low, unintelligible speech, diagnosis of ADHD, or the parents withdrew prior to data collection because of schedule restrictions or illness. Eleven second-graders met inclusionary criteria and participated in the study — six with TD (4 girls) and five with DYS (2 girls). Children ranged in age from 7; 8 to 8; 8 (years; months). One consented participant with typical development began the study but was not able to complete the study. The partial data for this participant is included in the analysis and displayed as indicated in the results section. The participant sample was predominately White (7) but also included one African American and three children identifying as more than one race. Eleven children were non-Hispanic and one was Hispanic.

Participants with TD in this study were required to show adequate word reading with a standard score of 96 or higher on the Test of Word Reading Efficiency (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012). Participants with DYS were required to score 88 or lower on the TOWRE-2 (see Table 1 for test scores). For descriptive purposes each participant also completed the following subtests from the Readiness cluster of the Woodcock Reading Mastery Test-Third Edition (WRMT-III; Woodcock, 2011): Letter Identification, Phonological Awareness, and Rapid Automatic Number and Letter Naming.

Study Design

This study used a multiple baseline multiple probe single-case design with alternating treatments structured language and multisensory intervention. Two groups of children completed treatment – one with TD and one with DYS. The DYS group began one week before the TD group. The independent variable was the type of treatment. This study consisted of three phases: baseline, intervention, and follow-up, which are explained below. Performance on the multisensory letter name production was used as the mastery criterion variable to determine when participants moved from the baseline to intervention phase of the study; however, letter sound production, word reading, and spelling variables were also assessed. Each of the phases are shown in Figure 1 and explained below. To improve upon previous studies of multisensory instruction, this study met the What Works Clearinghouse criteria for Meets Evidence Standards without Reservations (What Works Clearinghouse [WWC], 2013). To meet this criteria researchers must: (a) methodically manipulate the independent variable, (b) measure outcome variables over time by more than one assessor, (c) collect inter-assessor agreement on twenty percent of the data points across phases for each condition (exceptions noted below) with inter-assessor agreements averaging at least 80 to 90 percent, (d) include a minimum of three baseline conditions, (e) compare two alternating treatments with each other, and (f) collect at least five data points per phase and five alternating repetitions of the interventions. Furthermore, specific measurements for fidelity of implementation were reported. Due to logistics inter-assessor agreement was collected for 14% of baseline, 33% of treatment, and 10% of follow-up sessions for participants with TD for both interventions. For participants with DYS inter-assessor agreement was collected for 10% of baseline, 43% of treatment, and 30% of follow-up sessions.

Baseline phase. All participants within a group entered baseline simultaneously, with three baseline data points taken over the same week for each participant. One randomly selected participant within each group then completed two additional baseline data points. After the fifth baseline probe the randomly selected participant proceeded to the treatment phase if a stable baseline pattern was evident for letter name production in the multisensory treatment condition. Baseline stability was determined by data analysts who evaluated data separately and were not privy to the study's purpose. A stable baseline pattern was required to demonstrate: (a) a consistent level, (b) little variability (e.g., consistent data range), and (c) lack of a positive trend using a minimum of three consecutive data points (Barlow & Hersen, 1984; WWC, 2013). All participants, other than the first participant from each group, received six baseline probes to ensure stable baselines. Once the first randomly selected participant in a group entered the treatment phase the next randomly selected participant completed three more baseline probes prior to moving into the treatment phase. Per WWC pilot standards for multiple baseline multiple probes, at least one baseline data point from the second randomly selected participant was taken within the same session time frame, one week, in which the preceding participant first received intervention (WWC, 2013).

Treatment phase. Participants could not enter the treatment phase until the participant ahead of them in the treatment phase demonstrated stable letter name production in the multisensory treatment based on the following criteria: (a) data mean was above that of baseline mean using a minimum of three data points and (b) there were at least three consecutive data points trending in the same direction (Barlow & Hersen, 1984). This introduction format continued for all remaining participants from both groups. Once they entered the treatment phase all participants completed six treatment sessions during which the structured and multisensory interventions were presented in each session in randomized order to control for sequencing effects (Barlow & Hayes, 1979). To progress forward and learn additional letters in the structured language or the multisensory intervention, participants had to meet the mastery criteria. The mastery criteria required participants to correctly name the newly taught letters in an intervention session two times in a row during assessments (explained below). Therefore, a participant could meet the mastery criteria for one intervention and move on, but not meet mastery and repeat lessons in the other.

Follow-up phase. There were two assessment sessions in the follow-up phase. The first was conducted one week after intervention ended and the second two weeks after intervention ended.

Intervention Overview

During the study children attended baseline and follow-up sessions that were 30 minutes and intervention sessions that were approximately one-hour in length, one to three times per week. Sessions were completed over a six to seven-week period. Participants were taught non-English grapheme names and their associated English phonemes (sounds). Two intervention treatments were delivered in random order within each treatment session - structured language and multisensory. The interventions were adapted from Orton-Gillingham-based programs and followed a systematic sequential structured language approach. Structured language activities did not include simultaneous sensory engagement, but the multisensory intervention used simultaneous engagement of at least two of the three sensory modalities (visual, auditory, and kinesthetic/tactile) during each lesson.

Intervention Materials

Graphemes and grapheme names. A total of 18 non-English graphemes were used (see Appendix E for grapheme list). The graphemes were symbols drawn from ancient alphabets, letter forms developed by Gibson (Gibson, Gibson, Pick, & Osser, 1962), and Aurebesh letters from ***Star Wars*** © & ™ Lucasfim Ltd. The names for graphemes were randomly assigned from the set of phonemes (see below) that was in turned randomly assigned to either the structured or multisensory intervention. Graphemes and their names were unique for each participant.

Phonemes. Eighteen English phonemes were used and divided into two sets of seven consonants and two lax vowels per set (see Appendix F for phoneme list). Research shows a grapheme's sound is easier to learn if the grapheme name contains the phoneme (Treiman, et al., 1998). Therefore, one third of grapheme names contained the phoneme at the beginning (e.g, /n/ beginning the grapheme name /nɛ/), one third at the end (e.g., /p/ ending the grapheme name /ɪp/), and one third did not contain the phoneme (e.g., /k/ for a grapheme named /Λz/). For each child the sets were randomly assigned to one intervention or the other and within each set the grapheme-phoneme pairings were randomized. The only exceptions were graphemes representing /b/and /d/ phonemes, which were assigned mirror image forms so that they were visually similar as they are in English.

Words. Children were asked to decode and spell 12 words in each intervention. They included vowel-consonant (vc), consonant-vowel (cv), consonant-vowel-consonant (cvc), and vowel-consonant-vowel (vcv) constructions.

Teaching Cards. Four sets of color coded cards were used for the interventions (see Appendix G). White grapheme cards and word cards were used for teaching and assessing letter names and words. Green phoneme cards and spelling cards were used for teaching and assessing phonemes and word spelling.

Spelling Matrix. A six-inch bingo-like spelling matrix with three columns and three rows was used for spelling activities and assessments (see Appendix H). Graphemes were placed on the matrix and participants placed selected graphemes onto a line below the matrix during spelling practice and assessment activities. For the structured language intervention each grapheme was written on a white, two-inch square piece of cardstock. For the multisensory intervention three-dimensional plastic graphemes were placed in each of the squares. The plastic 3D shapes were approximately 1 to 1 ¼ inches high by 1-inch-wide and ¼ inch thick (see Appendix I).

Teaching Procedures

Interventions took place at the university lab, a local library or center, or the participant's home. All sessions were audio recorded and implemented by trained interventionists. Children received instruction from at least two different interventionists who provided no fewer than two intervention sessions. Interventionists were naive to the research hypotheses (Barlow & Hersen, 1984) and completed an implementation checklist each session.

Within each research session children completed two teaching sessions with assessments given after each teaching session. During teaching, interventionists highlighted the scripted text as it was read. The order of intervention types was randomized with the caveat that no intervention may be presented in the same order more than two consecutive times. During the first intervention session children were informed they would be learning two pretend languages (Hulme, Monk, &Ives., 1987). The structured language was called *Saraf* and multisensory was called *Rasaf*. Each teaching session followed the same lesson schedule, however activities varied between interventions.

The first lesson began with *New learning*. In this activity two graphemes were taught. Using a grapheme card the first grapheme was presented and the letter name and sound were taught, followed by the second new grapheme. For the multisensory lessons, but not the structured lessons, participants utilized mirrors to see how their mouths looked and felt when saying letter names and sounds. Participants were also taught how to write the letter. In structured language lessons, participants traced over the letter twice, after tracing it the first time the participant named the letter and after the second trace participants gave the letter's sound. In contrast, during multisensory lessons participants were guided to skywrite the letter using gross motor movements while simultaneously looking at the letter and saying the letter's name. Then participants traced over the letter while simultaneously saying the letter's sound. In the second activity, *Word reading,* participants practiced reading words. In the structured lessons participants sounded out each phoneme then read the word. During multisensory lessons, participants looked at the word and simultaneously tapped and sounded out each phoneme by sequentially tapping their index, middle, and ring fingers to their thumb. Participants then looked at the word and read it by scooping their finger under it while simultaneously blending the phonemes. *Spelling practiced* was then introduced which consisted of two activities. In the first activity, *sound dictation,* participants repeated a given letter sound then selected the correct grapheme from the spelling matrix. For structured language, participants selected the grapheme tile, then named it. In contrast, for multisensory, 3D plastic letters were selected then traced over by participants while simultaneously saying the letter's name. For the second activity, *word spelling,* participants were required to repeat the word given then selected the word's graphemes from the matrix and placed them on the line from left to right. During structured language lessons participants sounded out each phoneme, next they said the letter names, then selected the letter tiles, after which they named them, and lastly read the word. During multisensory participants simultaneously tapped and sounded out each phoneme, next simultaneously tapped and named each letter, then selected 3D letters while simultaneously naming them, then scooped under the word and read it.

The same lesson schedule was followed for all subsequent lessons, except three review activities were presented before new learning. In order of presentation the activities were: *alphabet review*, *grapheme practice*, and *sound dictation*. In alphabet review, all previously learned letter names or sounds were reviewed through various activities. Structured lesson activities used grapheme cards to elicit letter names or sounds. Activities included turning cards print side up, selecting cards from the interventionist's hand, or touching a card print side up. Multisensory lessons incorporated 3D letters to prompt letter names or sounds and included tossing then turning 3D letters face side up, holding and feeling each letter with eyes closed, or tracing over each letter while simultaneously responding. The second review activity, grapheme practice, was the same for both interventions. In this activity grapheme cards were presented one at a time and the participant recited the letter name and sound. In the last review activity, sound dictation, previously learned letter sounds were presented using phoneme cards. In the structured lesson participants wrote the letter for each sound on the table top with their index finger, then named the letter. Multisensory lessons required the participant to look in their mirror while repeating the letter sound, then wrote the letter with their index finger while simultaneously naming it. Different materials were used for writing the letter on and included, a small carpet square, tray of sand, or a wipe-off board. After these three review activities new learning was introduced. Following this, assessments were administered (see below).

Treatment integrity. To ensure treatment integrity, direct observation of twenty percent of intervention lessons were observed by another interventionist or trained observer who also completed an implementation checklist (Fiske, 2008; Schoenwald, et al., 2011). The two intervention checklists were evaluated for adherence using point-by-point agreement. The average percent of agreement (Kershener, et al., 2014) indicated structured language interventions were implemented for participants with typical development with 99% (range 94 – 100%) fidelity and the multisensory with 98% (range 96 – 100%) fidelity. The structured language fidelity for participants with dyslexia was 96% (range 83 - 99) and the multisensory fidelity was 96% (87 - 99).

Assessments. Assessments were administered during each phase of the study. Within all phases the order of assessment presentation and the items within each assessment measure were randomly determined. During the treatment phase interventions assessments were conducted immediately after the teaching session for each intervention. At follow-up, assessment measures were given at minimum one and two weeks after the participant's last teaching session.

For each assessment participants were asked to produce letter names and letter sounds, to read words, and to spell words. A score of zero was given for incorrect responses and one point for correct responses. To assess letter name and letter sounds participants were shown nine grapheme cards, one at a time, and asked to give the letter name or sound. Nine points were possible for letter names and nine for letter sounds.

Responses were written phonetically by the interventionist. For word reading 12 word cards were presented, one at a time. Children's responses were recorded phonetically by the interventionist, with 12 points possible. To assess word spelling participants used the spelling matrix to select letter tiles or 3D letters for structured language and multisensory, respectively. Interventionist marked participant's grapheme selections in numerical order on spelling boxes containing all available graphemes to the right of each spelling word. Word spelling had 12 points possible.

Reliability. Twenty percent of assessments in the study including baseline, treatment, and follow-up phases, were double scored by a trained observer who attended the research sessions and wrote and scored participant responses. Inter-rater agreement was calculated using point-by-point agreement between interventionists and observers' records. Inter-observer agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100 (Caro, Roper, Young, & Dank, 1979). The average agreement for participants with TD in the structured language intervention was 99% (range 88% - 100%) and for multisensory was 98% (range 83% - 100%). The average agreement for participants with DYS in the structured language intervention was 99% (range 87% - 100%) and for multisensory was 98% (range 78% - 100%).

Analytic Approach

Each participant's data was evaluated using visual analysis to compare the effects of structured language and multisensory interventions on letter name, letter sound, word reading, and spelling. *Tau-U* and *weighted Tau-U* effect sizes were also calculated for each dependent variable to permit comparison of the effects for both interventions.

Visual Inspection. Within- and between-phase data patterns were examined for each dependent variable in each condition to address the research questions. The visual analyses included the projected data, which refers to the hypothetical continuation of a data pattern from the previous phase, and the observed data within each phase evaluated based on data features for (a) level (mean), (b) trend (slope of the best-fitting line), and (c) variability (range of the data about the best-fitting line). In addition, data patterns across phases were examined for (a) immediacy of effect, (visible distinction between the data features of the last three baseline data points and the first three treatment data points), (b) the proportion of data points overlapping between baseline and treatment with low overlap suggesting larger treatment effects (Horner, Swaminathan, & Smolkowski, 2012), and (c) inter-case (across participants) replication of data patterns. In this study, three inter-case replications indicated an experimental effect (Horner, et al., 2005; WWC, 2013).

To address Research Questions 1 and 2, regarding whether the multisensory intervention would be more effective than the structured language intervention for learning letter names, letter sounds, word reading, and spelling for participants with TD and DYS, the slope, level, immediacy of effects, and Tau-U effect sizes of each participant's data from baseline to intervention was subjected to visual inspection. For Research Questions 3 and 4, regarding whether the multisensory intervention would be more effective than the structured language intervention for maintenance of letter names, letter sounds, word reading, and spelling for participants with TD and DYS, the data in each participant's follow-up phase was visually inspected. Figure 2 provides examples for level, trend, immediacy of effect, and maintenance at follow-up.

Tau-U Effect Size

Tau-U effect size, a nonoverlap index of effect, was used to determine whether individual participants had a statistically significant treatment effect across the dependent variables for each intervention. Tau-U is distribution free, utilizes trend and level, and can control for baseline trends (Brossart, Vannest, Davis, & Patience., 2014). Rather than measurements of central tendency, Tau-U takes into account the individual values of all data points in pairwise comparisons across phases. Conceptually it is the percentage of data showing improvement from the baseline and treatment phases for each participant (Parker, Vannest, & Davis, 2011). The *individual* Tau-U contrast was calculated for each dependent variable for each participant.

A *weighted* Tau-U effect also was calculated for both interventions for each of the dependent variables. Weighted Tau-U is all of the individual participants' phase contrasts between baseline and treatment, for a specific dependent variable and intervention, combined to reflect the overall effect for each intervention resulting in a combined weighted average for each dependent variable (Vannest., Parker, & Gonen, 2011). The tentative benchmarks for the individual and weighted Tau-U range are in percentages from 0-100, with a weak to small effect size indicated by results of 65% or less, moderate to high effect sizes range from 66 to 92%, and large effect sizes of 93% or greater. Both the individual Tau-U and the weighted Tau-U effect sizes were calculated using the Single Case Research™ web-based calculator (Parker & Vannest, 2009). The statistical power for Tau-U ranges from 91% to 95% (Parker, et al., 2011; Vannest et al., 2011).

Results

Results were analyzed using visual analysis, individual Tau-U, and weighted Tau-U effect sizes. A summary of observed means, range, overlap, and the individual Tau-U effect sizes for the dependent variables for both interventions for participants with TD are presented in Tables 2 and 3 and a summary for participants with DYS are presented in Tables 4 and 5. Baseline data were stable for all participants for both interventions and observed treatment levels were above projected levels based on baseline scores. In addition, visual analyses of data features indicated both interventions had a positive effect as indicated by slope, level, linear trends, and immediacy of effect. Exceptions are presented below.

Letter Name Production

Participants with TD. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 3 and 4. The positive response data patterns and the inter-case treatment replications indicated a positive experimental effect for both interventions, which is supported by the individual Tau-U effect sizes. Thus overall, both interventions had a positive treatment effect. In addition, the weighted Tau-U for letter names showed statistically significant, moderate effect sizes for both interventions (structured language *Tau-U* = 82, multisensory *Tau-U* = 83). However, multisensory did not appear to have an overall greater effect than structured language.

Follow-up data showed that all participants demonstrated maintenance for letter names in each treatment condition, with somewhat higher maintenance in structured language intervention for all participants except 3TD. Participant 3TD showed a higher maintenance in multisensory intervention.

Participants with DYS. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 5 and 6. Participant 9DYS remained at baseline levels across all three phases of the study. Visual analyses of data features indicated structured language intervention had a small overall effect, but multisensory did not have an effect as demonstrated by slope, level, linear trends, or immediacy of effect. For all participants neither intervention showed a clear advantage, which is supported by individual Tau-U effect sizes. However, for 10DYS the structured language intervention appeared more effective. The three inter-case replications for 7DYS, 8DYS, and 10DYS, indicated structured language intervention showed an experimental effect, but the lack of three inter-case replications indicated there was not an experimental treatment effect for multisensory intervention. The inter-case replications for structured language suggested a structured language advantage over multisensory intervention. However, the less conservative weighted Tau-U indicated statistically significant, small effect sizes for both interventions (structured language *Tau-U* = 53, multisensory *Tau-U* = 43).

Follow-up data showed 7DYS, 8DYS, and 11DYS demonstrated maintenance for letter names in each intervention, with higher maintenance for structured language compared to multisensory for 7DYS and 8DYS. Participant 11DYS had higher maintenance in multisensory intervention. Data for 10DYS did not demonstrate maintenance in either intervention.

Letter Sound Production

Participants with typical development. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 7 and 8. Neither treatment appeared to be more effective except for 2TD who showed a multisensory advantage and 4TD who showed a structured advantage. The positive response data patterns and inter-case treatment replications indicated a positive experimental effect for both interventions, which is supported by individual Tau-U effect sizes. This positive effects of both interventions are supported by the weighted Tau-U, which indicated statistically significant, moderate effect sizes for both interventions (structured language *Tau-U* = 80, multisensory *Tau-U* = 77).

Follow-up data showed all participants demonstrated maintenance for letter sounds in each treatment condition. Participants 3TD, 4TD, and 5TD had higher maintenance in the structured language intervention. Participants 1TD and 6TD had higher maintenance in the multisensory intervention.

Participants with dyslexia. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 9 and 10. Visual analyses of data features indicated the multisensory intervention had a small overall effect as demonstrated by slope, level, linear trends, and immediacy of effect, but the structured language did not have an effect. There were only two structured inter-case replications, 7DYS and 8DYS, which indicated structured language did not have an experimental effect. For multisensory, 7DYS, 8DYS, and 9DYS demonstrated inter-case replications. Only one participant, 8DYS, had individual statistically significant Tau-U effect sizes, for this participant both structured language and multisensory were significant. The response patterns and inter-case replications indicated an experimental effect for multisensory, but not for structured language interventions. However, the less conservative weighted Tau-U for letter sounds showed small, statistically significant effect sizes for both interventions (structured *Tau-U* = 55, multisensory *Tau-U* = 58).

Follow-up data showed 7DYS, 8DYS, 9DYS, and 11DYS demonstrated maintenance of letter sounds. Participants 7DYS, 8DYS, and 11DYS had higher maintenance in structured language than multisensory. Participant 11DYS did not demonstrate maintenance in multisensory intervention but did in structured language. Participant 9DYS had higher maintenance in multisensory than structured intervention.

Words Read Correctly

Participants with typical development. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 11 and 12. Positive response data patterns and inter-case treatment replications indicated a positive experimental effect for both interventions, which was supported by individual Tau-U effect sizes. However, visual analyses indicated a structured language intervention advantage. This was supported by the weighted Tau-U for words read correctly which indicated there was a statistically significant, large effect size for structured intervention (*Tau-U* = 95), and a significant, moderate effect size for multisensory (*Tau-U* = 78).

Follow-up data showed all participants demonstrated maintenance for words read correct in each treatment condition, with somewhat higher maintenance in structured language intervention for 3TD, 4TD, and 5TD. Participants 1TD and 6TD had higher maintenance in multisensory intervention; follow-up data was not available for 2TD.

Participants with dyslexia. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 13 and 14. Observed treatment levels were greater than projected levels at baseline for all participants except for 9DYS and 10DYS. Participant 9DYS remained at baseline levels for both interventions throughout the three phases and 10DYS remained at baseline levels for multisensory throughout the three phases. For the remaining participants neither structured language nor multisensory appeared effective, which was supported by individual Tau-U effect sizes. Only participants 7DYS and 8DYS had inter-case replications. Thus per visual inspection neither intervention appeared to have had an experimental effect for words read correctly since three inter-case replications were not evident. However, the weighted Tau-U indicated significant, small effect sizes for both interventions (structured language and multisensory *Tau-U* = 46).

Follow-up data showed 7DYS, 8DYS, 10DYS, and 11DYS demonstrated structured language maintenance for words read correctly. Participants 7DYS, 8DYS, and 11DYS demonstrated maintenance in multisensory intervention. Participants 8DYS and 10DYS demonstrated higher structured language maintenance and 7DYS and 11DYS had higher multisensory maintenance. Participant 9DYS remained at baseline for each intervention.

Words Spelled Correctly

Participants with typical development. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 15 and 16. For participant 4TD multisensory intervention had lower scores and more variable data patterns, which indicated structured intervention was more effective than multisensory. For the remaining participants neither intervention showed a clear advantage. The positive response data patterns and inter-case treatment replications indicated a positive treatment effect for both interventions, which was supported by individual Tau-U effect sizes. Based on visual analyses, both interventions had a positive overall experimental effect. The weighted Tau-U for words spelled correctly indicated statistically significant, moderate effect sizes for both interventions (structured language *Tau-U* = 85, multisensory *Tau-U* = 86).

Follow-up data showed all participants demonstrated maintenance for words spelled correctly in each treatment condition. For 1TD multisensory had a higher follow-up level and for 4TD structured language had a higher follow-up level. For the remaining participants structured language and multisensory follow-up levels were similar.

Participants with dyslexia. Graphs of visual analyses and Tau-U effect sizes are presented in Figures 17 and 18. For both interventions the observed treatment levels were above projected levels based on baseline scores, except for 10DYS who did not respond to multisensory treatment and remained at baseline levels. Visual analyses of data features indicated both interventions had a small effect as demonstrated by slope, level, linear trends, and immediacy of effect. There were three structured language inter-case treatment replications for 7DYS, 8DYS, and 11DYS compared to two multisensory inter-case replications for 7DYS and 8DYS. Therefore, structured language had an experimental effect, but the multisensory intervention did not. The individual Tau-U effect sizes supported the structured language experimental effect for 7DYS, 8DYS, and 11DYS. Based on visual analyses and inter-case replications, the structured language intervention showed an advantage over multisensory. The weighted Tau-U for words spelled correctly showed a statistically significant, moderate effect size for structured (*Tau-U* = 69) and a significant, small effect size for multisensory (*Tau-U* = 60).

Follow-up data showed that 7DYS, 8DYS, and 11DYS demonstrated maintenance for words spelled correctly in each treatment condition. Structured language had higher maintenance for 8DYS and 11DYS, and 7DYS had higher maintenance for multisensory. Participants 9DYS and 10DYS did not demonstrate maintenance for either intervention.

Discussion

This study investigated the efficacy of two reading interventions for teaching letter name, sound production, word reading, and word spelling for 11 second grade students, six with TD and five with DYS. The first intervention was a structured language program with restricted use of simultaneous multisensory input; the second intervention was a multisensory structured language program that included simultaneous multisensory input. Due to the lack of experimental control in previous multisensory intervention studies (Ritchey & Goeke, 2006; Rose & Zirkel, 2007), this empirical study was designed to add to the limited scientific evidence testing the efficacy of simultaneous multisensory instruction for improving reading skills.

Based on research that has shown simultaneous multisensory instruction to be effective for teaching foundational reading skills to children with TD (Joshi et al., 2002; Uhry & Shepherd, 1993) and DYS (Campbell et al., 2008; Hulme, 1981; Torgesen et al., 2001), the hypotheses were that multisensory intervention would provide an advantage over structured instruction for the learning and maintenance of letter names, letter sounds, word reading, and spelling. Hypotheses were in line with the principles of dual coding theory and supported by research that multimodal instruction has been shown to provide more opportunity to build representational connections for both visual and verbal information and enhanced referential connections between logogens and imagens (Mayer & Anderson, 1991).

Visual analysis and Tau-U effect sizes indicated that both structured language and multisensory instruction had a positive treatment effect for participants. However, there did not appear to be a clear overall advantage for one type of instruction. Visual analyses indicated that maintenance was apparent for both interventions, but there did not appear to be an overall advantage for either intervention.

Effectiveness of Multisensory Compared to Structured Language Intervention for Letter Names and Sounds, Words Read, and Words Spelled for Participants with TD

Letter names for participants with TD. Visual analyses and Tau-U effect sizes indicated both structured language and multisensory instructions had an overall treatment effect. Though there appeared to be a multisensory intervention advantage in some cases for letter name, the multisensory intervention was not more effective for all participants than structured language. Therefore, the hypothesis that multisensory would be more efficacious than the structured language for all participants for letter name with TD per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

The results of this study were consistent with findings in the extant literature that explicit, structured, and systematic instruction is effective for teaching basic literacy skills (e.g., Adams, 1990; Ehri, 2014; NRP, 2006). However, it did not appear that the addition of simultaneous multisensory input provided an overall advantage. During auditory learning of words for objects, such as in learning letter names in this study, phonological representations are cognitively processed (Gupta & Tisdale, 2009). For participants with TD, with intact phonological processing abilities, it appeared they learned grapheme names because they were able to effectively build, for each grapheme in each intervention, a phonological representation, a semantic representation, as well as links between the representations (Gupta & Tisdale, 2009).

Although participants with TD did well learning letter names, during structured language letter name assessments error responses of participants 1TD, 2TD, 3TD, and 4TD frequently were due to responding with the correct letter sound instead of the letter name. These errors changed the level and trend in structured language for participants' letter names. This type of incorrect response did not result in changes in the data trajectory for multisensory intervention letter name. In a series of experiments with similar aged children Hulme (1987) found simultaneous tracing and naming of letter-like forms resulted in improved visual recognition as well as significantly more correct letter form names. Results were interpreted to imply that simultaneous multisensory tracing and naming improved the recognition phase of paired-associate learning. Perhaps the simultaneous multisensory tracing activities resulted in better visual-verbal paired-associate learning for the multisensory letter name and therefore participants did not incorrectly give multisensory letter sounds during assessments as in structured language.

Letter sounds for participants with TD. Visual analyses and Tau-U effect sizes indicated both structured language and multisensory instructions were similarly advantageous for letter sound. Therefore, the hypothesis that multisensory would be more efficacious than structured language for all participants for letter name and sound with TD per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

Participants with TD were able to learn letter sounds equally well for both structured language and multisensory interventions, likely due to the evidence based practice found in both interventions. Furthermore, as indicated by research, children utilize phonological skills to learn grapheme sounds. Sounds are learned easiest if the name contains the phoneme represented by the grapheme (Treiman, et al., 1998). Participants with TD frequently appeared to be vocalizing sounds before responding to assessment prompts. Because of intact phonological processing it is possible that participants were able to use sub vocalization, to rehearse letter sounds (Baddeley, Gathercole, & Papagno, 1998). In addition, because a majority of the grapheme names contained the grapheme's sound, either at the beginning or the end of the letter name, interventions further promoted letter sound learning.

The lower multisensory data features for letter sounds for 4TD's was likely was due to the grapheme to phoneme randomization process; a grapheme with a similar shape to the English uppercase letter *A* was paired with a lax vowel for this participant in the multisensory intervention. Participant 4TD associated the incorrect vowel sound, /æ/, to the grapheme during baseline assessments. Due to continued practice associating the incorrect sound, it appeared that participant 4TD was unable to inhibit interference for the /æ/ sound during the treatment phase, despite being taught the correct sound. This lack of interference control influenced multisensory assessment responses for letter name until the third teaching session, when the /æ/ sound was taught in structured language. However, letter sounds and words read continued to be affected throughout the treatment phase. As a result, the multisensory data had lower levels and trends in letter sound and words read. For words read this is because multiple words contained the grapheme 4TD consistently and incorrectly encoded as /æ/.

Words read correct for TD. Per visual analysis and individual Tau-U effect sizes, structured language showed an advantage. However, upon closer inspection of the data the advantage appeared to be related to data patterns for two participants, 2TD and 4TD. Participant 2TD only attended four teaching sessions and 4TD's lower multisensory data patterns were due to the interference of the /æ/ sound in word reading. This calls into question the structured language advantage. However, the hypothesis that multisensory would be more efficacious than the structured language for words read for all participants with TD per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

In this paper orthographic knowledge includes mental representations of written words stored in memory and how speech is represented in writing, including the alphabetic principle (Apel, 2011). To learn words participants utilized phonological awareness and newly developed orthographic knowledge for both interventions to effectively read words. Participants demonstrated phonological awareness in their ability to decode words by segmenting then blending sounds during reading activities and assessments. Orthographic knowledge was evident by participants' ability to correctly read newly taught words and utilize analogy to read unknown words. For example, participants were able to use a previously taught rime /ɛz/ and correctly insert an untaught phoneme for a word containing the rime (e.g., the /k/ in /kɛz/). For participants with TD their proficiency in phonological awareness, phonological recoding, and phonetic recoding allowed them to learn to read words fluently (Wagner & Torgesen, 1987) in both interventions.

Words spelled correct for TD. Visual analyses and Tau-U effect sizes indicated both structured language and multisensory instructions had an overall treatment effect for all participants. Consequently, the hypothesis that multisensory would be more efficacious than structured language for word spelling for all participants with TD per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

Much of the same underlying knowledge used for reading is also used in spelling (Moats, 2006). Orthographic processing is the ability to acquire, store, and use orthographic knowledge (Apel, 2011). For both interventions participants' well developed phonological awareness and orthographic processing were able to be employed to spell words. During session activities participants with TD segmented spelling words into phonemes, correctly selected graphemes, then checked spelling accuracy by decoding the word. Furthermore, via a process of elimination, participants appeared to use orthographic processing to help spell words. For example, participants would spell a three phoneme word containing two letters in which letter-sound correspondence had been taught, and correctly guess about another sound in which the letter-sound had not been directly taught. Participants were able to map phonological and orthographic connections between words and develop orthographic word forms (Berninger et al., 2006).

Effectiveness of Multisensory Compared to Structured Language Intervention for Maintenance of Letter Names and Sounds, Words Read, and Words Spelled for Participants with TD

Letter names for TD. For participants with TD it was hypothesized there would be a multisensory intervention advantage for maintenance of letter names. Both interventions proved to be effective for the retention of letter names, however the multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. All participants demonstrated maintenance for letter names for both interventions, although follow-up levels were not available for participant 2TD. Participants with TD, because of their ability to efficiently learn letter names, were able to meet the mastery criteria (correctly name new letters twice in assessments) and learn new letter names in subsequent sessions. All material previously taught was reviewed at the beginning of each teaching session. The repeated exposure and practice of previously taught information likely strengthened participants' mental and semantic representations and links for letter names in both interventions. The results were well retained letter names.

Letter sounds for TD. For participants with TD it was hypothesized there would be a multisensory intervention advantage for maintenance of letter sounds. Both interventions proved to be effective for the maintenance of letter sounds, however the multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. All participants demonstrated maintenance for letter sounds for both interventions. However, for 4TD the incorrect /æ/ sound continued to be given during multisensory assessments and as a consequence multisensory letter sound level was lower than structured level. Research has shown knowledge of letter names promotes awareness of letter sounds (NELP, 2008; Treiman, et al., 1998). Participants overall were successful at maintaining letter sounds, in part due to their ability to successfully utilize existing phonological skills and strategies for learning letter-sound correspondence, such as letter name and phonemic awareness, which they appeared to apply equally well to both interventions. Because of intact phonological processing it is probable that participants utilized articulatory rehearsal to recover auditory memory (Baddeley, 2000; Berninger et al., 2006). This would explain the consistent maintenance results found across interventions for letter sound.

Words read correct for TD. For participants with TD it was hypothesized there would be a multisensory intervention advantage for maintenance of words read. Both interventions proved to be effective for maintenance of word reading, however the multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. The available follow-up data showed all participants demonstrated maintenance for words read correct for both interventions. For participants with TD word reading was fluent and accurate for both interventions. Repeated word reading practice during teaching sessions gave participants the opportunity to develop strong phonological and orthographic connections for words. Participants' initial and repeated practice using decoding and analogy word reading strategies lead to maintenance, as demonstrated by their fluent word reading (Ehri & McCormick, 1998) at follow-up.

Words spelled correct for TD. It was hypothesized for participants with TD there would be a multisensory intervention advantage for maintenance of words read. Although, both interventions were effective for maintenance of word spelling, multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. Follow-up data showed all participants demonstrated maintenance for words spelled similarly for both interventions. For both interventions participants utilized their phonological awareness and orthographic processing abilities to spell words forms. This allowed participants to map phonological and orthographic connections between words and allowed participants to not only develop, but maintain orthographic word forms (Berninger et al., 2006).

Summary for Participants with TD

Research supports use of structured, systematic instruction for teaching basic reading skills (e.g., Adams, 1990; Ehri, 2014; NRP, 2006). For participants with TD, the explicit and systematic instruction common to both interventions provided a possible explanation for the positive overall intervention effects found across dependent variables and interventions. The results of this study reinforce extant literature that evidence-based reading instruction should incorporate structured, systematic instruction (NRP, 2006). Results extends the literature by demonstrating structured language and multisensory interventions were efficacious for teaching foundational literacy skills. Lack of overall multisensory advantage suggested overall positive effects for both interventions were likely not due to the simultaneous multisensory input, but to the embedded Orton-Gillingham structured language components common to both reading interventions.

Effectiveness of Multisensory Compared to Structured Language Intervention for Letter Names and Sounds, Words Read, and Words Spelled for Participants with DYS

Letter names for participants with DYS. Visual analyses and Tau-U effect sizes indicated structured language appeared to be more advantageous than multisensory instruction. Therefore, the hypothesis that multisensory would be more efficacious than structured language for letter name for all participants with DYS per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

It is unclear why structured language was more advantageous. Although interventions were based on best practices, participants had considerable difficultly learning letter names for both interventions. Learning letter names for the graphemes required participants to cognitively process an internal phonological representation of the word (Gupta & Tisdale, 2009). In order to learn the letter name participants had to store both a phonological and a semantic representation of the word. In addition, participants had to develop strong phonological-semantic links, to produce the letter name during assessments (Gray, 2005). Participants with DYS, who by definition have difficulty with phonological processing, appeared to have difficulty encoding phonological information and developing phonological and semantic representations and links (Gray, Pittman, & Weinhold, 2014; Gupta & Tisdale, 2009). This was evident by the difficulty all participants had meeting mastery criteria. Participants frequently required three or more re-introductions of a letter name before meeting the mastery criteria. Participants with DYS needed repetitive practice to allow them to develop sufficient phonological and semantic representations and links in order to recall the novel letter names during assessments (Gray, 2005).

Furthermore, participants 9DYS, 10DYS, and 11DYS did not respond in the same manner as 7DYS and 8DYS to either intervention. It appears these three participants were *treatment resisters,* which meant they did not respond or were slower to respond to interventions (Alexander & Slinger-Constant, 2004; Berninger et al., 2000; Shaywitz et al., 2008), based on their lower levels and trends for letter name and sound, words read and spelled. Empirical evidence suggests treatment resisters require differentiated instruction that meet their individual needs (Berninger et al., 2000; Alexander & Slinger-Constant, 2004). The multiple re-introduction of letter names in order to meet the mastery criteria suggested the need for differentiated instruction. Perhaps the presentation of only one intervention per session, or the introduction of only one letter per intervention may have improved data response patterns for these three participants.

Letter sounds for participants with DYS. Visual analyses indicated multisensory intervention was more effective for letter sound based on three inter-case replications. However, the weighted Tau-U effect sizes indicated both interventions were similarly advantageous. The hypothesis that multisensory would be more efficacious than structured language for letter name for all participants with DYS per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

Deficiencies associated with dyslexia have been known to affect the ability of individuals to develop the alphabetic principle (Shaywitz et al., 2008). Research has indicated that children do not memorize letter-sound correspondences as rote pairs; rather they evaluate and utilize their knowledge of the letter's name to develop an understanding of the letter's sound. Therefore, both letter knowledge and phonological awareness are utilized in learning letter sounds (Treiman, et al., 1998). Because of poor phonological awareness and difficulty establishing letter knowledge, participants exhibited a difficult time making necessary links between a letter's name and sound. Due to their difficulty encoding phonological information participants were not able to effectively utilize the phonological loop as a resource for learning and later recovering stimuli via auditory rehearsal (Baddeley, 2000; Berninger et al., 2006).

Words read correct for DYS. Visual analysis and individual Tau-U effect sizes indicated that both interventions were effective for two participants only, therefore, due to the lack of three inter-class replications, neither intervention appeared to be effective. Thus the hypothesis that multisensory would be more effective than structured language for words read for all participants with DYS per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

Only participants 7DYs and 8DYS appeared to learn in both interventions for word reading. The remaining participants, 9DYS, 10DYS, and 11DYS, did not learn well in either intervention, per their levels and trends for words read. These participants appeared to struggle with letter sound decoding as evident by their difficulty segmenting words during teaching sessions and their inability to demonstrate one to one letter sound correspondence for two and three phoneme words. Participants also required frequent redirection to maintain focus.

Participant 10DYS presented additional concerns. Participant 10DYS had trouble accurately repeating spelling words two to three phonemes long. An inspection of 10DYS's inclusionary phonemic decoding assessment revealed it was in the 1st percentile, indicating a possible issue with phonological recoding. Additional examination of descriptive assessments indicated phonological awareness was in the 5th percentile and rapid automatic was naming in the 25th percentile. Poor phonological awareness and rapid automatic naming may indicate a possible double deficit. The double deficit hypothesis suggests children who have deficits in both phonological awareness and rapid automatic naming are the most severely impaired readers (Norton & Wolf, 2012). A double deficit profile would provide a hypothesis for 10DYS's lack of response to either intervention.

Participants 9DYS, 10DYS, and 11DYS difficulties with phonological awareness, poor attention, and the possible double deficit for 10DYS are indicative of the heterogeneous nature of DYS (Tobia & Marzocchi, 2014; Ramus, 2004). Alexander and Slinger-Constant (2004) suggests reading requires attention to sensory input to map representations, such as phonological and orthographic representations, to neural substrates (Alexander & Slinger-Constant, 2004). It appears the lack of attention to incoming stimuli for 9DYS, 10DYS, and 11DYS made it difficult for them to map phonological and orthographic representations. The lack of or poorly developed representations resulted in deficit input from phonological and orthographic components, and affected the holding and manipulation of information for processing in working memory (Alexander & Slinger-Constant, 2004). This further may help explain the response patterns for these three participants.

Words spelled correct for DYS. Visual analyses and Tau-U effect sizes indicated structured language instruction had an overall treatment effect for participants, but multisensory intervention did not. Therefore, the hypothesis multisensory would be more efficacious than structured language for words spelled for all participants with DYS per visual inspection of slope, level, immediacy of effects, and Tau-U effect sizes was not supported.

It appeared participants with DYS had difficulty mapping phonological and orthographic relationships and therefore were not able build orthographic word forms (Berninger et al. 2006). For participants with DYS their poorly developed phonological awareness made it difficult to acquire, store, and use orthographic knowledge. For example, participants with DYS would select three or more graphemes for a two phoneme spelling word or select a grapheme they had been taught, but place it the incorrect position. In addition, participants with DYS often would not attempt to spell a three phoneme word containing an untaught phoneme, even though they had demonstrated correct spelling of a word containing the two taught phonemes.

Multisensory Effectiveness Compared to Structured Language for Maintenance of Letter Names and Sounds, Words Read and Spelled for Participants with DYS

Letter name for DYS. For participants with DYS it was hypothesized there would be a multisensory intervention advantage for maintenance of letter names. Only three participants demonstrated maintenance for letter names. Therefore, the hypothesis was not supported. Participants 7DYS, 8DYS, and 11DYS had follow-up levels higher than treatment phase levels in structured language. The remaining participants did not demonstrate maintenance of information. Due to the inability of participants with DYS to meet the mastery criteria their exposure to new letter names was limited. However, in spite of repeated exposures and practice on a limited number of letter names, some participants with DYS had difficulty maintaining letter names. It appeared, for both interventions, the phonological and semantic representations and links for letter names were tenuously established and subject to decay without the repeated practice of treatment sessions. Despite the implementation of evidence based practices the instruction was not differentiated based on individual needs, which further may explain the poor retention for participants with DYS.

Letter sound for DYS. For participants with DYS it was hypothesized there would be a multisensory intervention advantage for maintenance of letter sounds. Only four participants had maintenance of letter sounds. Three, 7DYS, 8DYS, and 11DYS, demonstrated higher structured language maintenance. Though, only 11DYS had higher follow-up levels than treatment phase levels in structured language. The multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. Poor maintenance by participants with DYS for letter sounds was in part due to their difficulty establishing secure phonological and semantic representations and links for letter names. Their poorly developed letter name representations made linking a sound to the letter difficult, which resulted in poor retrieval and production. It required multiple repetitions for participants with DYS before information about the letter sound was able to activate a short term trace in the phonological store that was able to influence long term retention (Baddeley, 2000; Baddeley et al., 1998).

Words read correct for DYS. For participants with DYS it was hypothesized there would be a multisensory intervention advantage for maintenance of words read. Three participants, 7DYS, 8DYS, and 11DYS, demonstrated maintenance for letter names in both interventions. Participant 10DYS only demonstrated maintenance for the structured language. However, follow-up levels for 10DYS and 11DYS were quite low due to lack of maintenance at follow-up two. The multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. The low follow-up levels for both interventions by participants with DYS may reflect their poor phonological awareness and orthographic knowledge (Lyon, Shaywitz, & Shaywitz, 2003; Richards, et al., 2006). For participants with DYS few words were read fluently in either intervention, despite repeated exposures to a limited set of reading words. Participants were unable to develop strong phonological and orthographic connections to words. Also, participants were not able to efficiently store phonological representations (Gupta & Tisdale, 2009) and therefore were not able to maintain words during follow-up.

Importantly, the short duration of the study may not have provided enough instructional time for either intervention to effectively address the participants' learning differences. Research suggests for individuals with DYS to demonstrate overall gains in reading requires time-intensive intervention (Torgesen, et al., 2001). Neuroimaging studies of individuals with DYS have shown normalization of activity in left temporo-parietal and frontal regions with intensive differentiated remediation, (Gabrieli, 2009).

Words spelled correct for DYS. For participants with DYS it was hypothesized there would be a multisensory intervention advantage for maintenance of words spelled. Only 7DYS, 8DYS, and 11DYS appeared to retain information of words spelled, with follow-up levels higher than treatment levels for structured language. Only 7DYS had follow-up levels higher than treatment levels in multisensory. The multisensory intervention did not provide an overall advantage. Therefore, the hypothesis was not supported. Maintenance of spelling words was only evident for three participants with DYS despite repeated practice with limited spelling words and one to one correspondence for each grapheme with an English phoneme. Participants with DYS were not able to utilize orthographic knowledge (e.g., NRP, 2000, Snowling & Hulme, 2011) to correctly spell words containing two to three phonemes and therefore were not able to maintain the phonological and orthographic connections they had developed. Poor maintenance by participants with DYS for either intervention may be reflective of the short duration of the treatment phase. Research has shown intensive reading remediation, 100 minutes per day for eight weeks, in small groups with explicit systematic instruction improves reading outcomes and promotes maintenance (Gabrieli, 2009).

Summary for Participants with DYS

Participants with DYS demonstrated varied data patterns for both interventions. For participants with DYS the multisensory instruction did not provide an overall advantage. It appeared neither intervention adequately overcame all participants' poor orthographic knowledge, phonological awareness, or phonological recoding to help them learn the targeted literacy skills. Though both interventions were evidence based, 9DYS, 10DYS, and 11DYS did not appear to respond in the same manner as 7DYS and 8DYS. The response patterns for 9DYS, 10DYS, and 11DYS highlighted the concern for treatment resisters (Alexander & Slinger-Constant, 2004; Berninger et al., 2000; Shaywitz et al., 2008). For these participants the lack of differentiated instruction, which is shown to be important in current research (Berninger et al., 2000; Alexander & Slinger-Constant, 2004), may have been a factor in poor learning. Furthermore, the individual profile characteristics for participants 9DYS, 10DYS, and 11DYS showed the multifactorial nature of DYS (Ramus, 2004; Tobia & Marzocchi, 2014).

Educational Implications and Future Research

This study evaluated the impact of simultaneous multisensory input on developing basic reading skills within an Orton-Gillingham based structured language frame work. It is one of the first studies to evaluate simultaneous multisensory input in a well-controlled study. This scientific study supported structured language instruction, within Orton-Gillingham based programs, as efficacious in promoting basic decoding and encoding skills for children with TD and DYS. However, this study did not show that simultaneous multisensory input improved learning over structured language intervention alone. In fact, results suggested that possibly other components within the Orton-Gillingham frame work may play critical roles in the effectiveness of structured language programs. It is important to empirically study other elements of Orton-Gillingham multisensory structured language programs, for example the diagnostic teaching to mastery, embedded phonological awareness activities, and reciprocal teaching of reading and spelling, to determine which components promote learning.

The divergent characteristics profiled by inclusionary and descriptive assessments and session observations for participants with DYS support research demonstrating dyslexia is a multifactorial deficit (e.g., Berninger, 2008; Berninger et al., 2013; Shaywitz et al., 2008; Norton & Wolf, 2012) and provided insight as to the impact individual profiles have on learning basic literacy skills. There is a worthwhile opportunity to extend this research by using diagnostic and prescriptive protocol to determine how best to meet the needs of treatment resister. Evaluating the impact of differentiated instruction in longitudinal studies for individuals with DYS would develop a clearer picture of how to best support treatment resisters across the continuum.

Strengths and Limitations

Strengths. This empirical study was highly controlled, ensuring scientifically valid results. First, non-English graphemes were used to better target simultaneous multisensory input as a variable and provided control for participants' prior letter and lexical knowledge. Second, outside of the first author, interventionist received the same amount of training. Third, percentages for fidelity of implementation and reliability were high and directly reported. Fourth, the use of visual analysts naïve to the study's purpose helped control for Type I errors. Fifth, the integrated design followed WWC (2013) established criteria. Lastly, the more stringent experimental effect of three inter-case replications was used versus the minimally accepted two inter-case replications (Horner et al., 2012).

Limitations. In both interventions participants were introduced to reading and spelling practices not commonly utilized in classrooms (Berninger et al., 2000), for example spelling isolated phonemes. Dual coding research has shown the lack of experience with a task can increase demands on the central executive and in turn hinder working memory (Constantinidou, Danos, Nelson, & Baker, 2011). Practice with strategies prior to beginning the study could have helped control for new learning techniques and strategies and their undue influence on outcomes. Furthermore, poor response by participants with DYS to either intervention may have been due to the short duration of the treatment phase. A more pronounced advantage for one intervention over the other may have become more evident had the study included a longer treatment phase. Research suggests intensive intervention is needed for individuals with DYS to demonstrate reading gains (Gabrieli, 2009; Torgesen, et al., 2001).

Conclusions

This well-controlled study provided important missing information regarding simultaneous multisensory input as efficacious reading intervention. Results supported structured language instruction within an Orton-Gillingham based program as effective in promoting basic literacy skills. However, simultaneous multisensory input did not provide a treatment effect above and beyond the structured language effect. Other components inherent to structured language may have directly impacted treatment effects. This study supported extant literature that explicit systematic language instruction is important for developing foundational decoding and encoding skills for both children with TD and DYS. Importantly, the multifactorial nature of dyslexia was amplified in this study. The critical need for individuals with dyslexia, especially treatment resisters, to be provided with differentiated instruction that is diagnostic, prescriptive, and empirically based was accentuated.

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APPENDIX A

TABLES

Table 1

Participant Description Information Including Age, Mother's Years of Education, Mean Standard Scores, and Standard Deviations on Norm-Referenced Tests

Measure	TD Mean (SD) (n=6)	Dyslexia Mean (SD) (n=5)
Age in Months	99 (3.9)	94 (6.6)
Mother's Ed	15 (3.5)	15 (1.1)
Attention	20* (3.8)	30* (6.7)
CELF-4	114.5** (8.6)	96.6** (9.6)
KABC-2[a]	112.8 (19)	112 (11.50)
GFTA-2[b]	51 (6.2)	40 (20)
WRMT-III LID[c]	100 (0)	100 (0)
WRMT-III PA	111* (12.7)	91* (16.30)
WRMT-III RAN	100* (6.7)	92* (3.10)
TOWRE-2	108** (6.0)	78.4** (3.6)

Note. TD = Typical Development; Attention Questionnaire = Attention; Clinical Evaluations of Language Fundamentals, Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003); KABC-2 = Nonverbal Scale of the *Kaufman Assessment Battery for Children-Second Edition* (KABC-2; Kaufman & Kaufman, 2004); GFTA-2 = *Goldman-Fristoe Test of Articulation-Second Edition* (GFTA-2; Goldman & Fristoe, 2000); WRMT-III = *Woodcock Reading Mastery Test-Third Edition* (WRMT-III; Woodcock, 2011); WRMT- III LID = Letter Identification Subtest; WRMT-III PA = Phonological Awareness Subtest; WRMT-III RAN Rapid Automatic Naming Subtest; TOWRE-2 = *Total Word Reading Efficiency of the Test of Word Reading Efficiency-Second Edition* (TOWRE-2; Torgesen et al., 2012). [a]KABC-2 scores for one participant with TD were unavailable, per parents and from observations cognition was not a concern. [b]Less than 31% allowed if treatment phonemes were articulated consistently. [c]Standard scores for subtest were unavailable for age of participants, scores reflect percent correct.
$^{*}p \leq .05$. $^{**}p \leq .01$.

Table 2

Letter Name and Sound Production Outcome Variables for Children with Typical Reading across Interventions and Phases

DV	Structured Language Intervention					Multisensory Intervention				
	BL	TX	FU			BL	TX	FU		
	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES
Letter Name Production										
1 TD[a]	0(0)	1.3(0-3)	1.5(1-2)	17	83*	0(0)	2.5(2-4)	1(0-2)	0	100**
2 TD	0(0)	1.3(0-3)	–	50	50	0.3(0-1)	2(0-4)	–	25	42
3 TD	0(0)	3.7(0-7)	6(5-7)	17	83*	0(0)	3.7(0-7)	6(5-7)	17	83**
4 TD	0(0)	2.5(0-5)	3.5(3-4)	33	67	0(0)	2(0-4)	2.5(2-3)	33	67
5 TD	0(0)	5(2-9)	8(NR)	0	100**	0(0)	5.7(2-9)	8(NR)	0	100**
6 TD	0(0)	4.7(1-8)	8(7-9)	0	100**	0(0)	5.2(2-8)	7(NR)	0	100**
Letter Sound Production										
1 TD[a]	0.6(0-2)	2.5(0-5)	1.5(0-3)	50	53	0.8(0-1)	2.2(0-5)	2(0-4)	50	13
2 TD	0(0)	2.3(0-4)	–	17	75	0.2(0-1)	3.3(2-4)	–	0	100**
3 TD	0(0)	6(2-9)	9(NR)	0	100**	1(NR)	5.7(3-8)	8(7-9)	0	100**
4 TD	0.7(0-1)	4.2(0-8)	7(6-8)	17	56	0.2(0-1)	1.5(0-3)	1.5(0-3)	67	64
5 TD	0.8(0-2)	6.2(3-9)	9(NR)	0	92**	0.2(0-1)	6(2-9)	8.5(8-9)	0	86
6 TD	0(0)	5.5(2-9)	8(NR)	0	100**	1(0-1)	6.2(3-9)	9(NR)	0	100**

Note. Overlap is expressed in percent data overlap between baseline and treatment. DV = Dependent Variables; BL = Baseline mean; TX = Treatment mean; FU = Follow-up mean; Tau-U ES = Individual Tau-U effect size expressed in percentage. [a]Participant 1TD inadvertently received six less review activities for the multisensory intervention. $^{*}p \leq .05$. $^{**}p \leq .01$.

Table 3

Word Reading and Spelling Outcome Variables for Children with Typical Reading across Interventions and Phases

DV	Structured Language Intervention					Multisensory Intervention				
	BL	TX	FU			BL	TX	FU		
	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES
Word Reading										
1 TD[a]	0(0)	2.3(0-7)	1(NR)	17	83*	0.4(0-1)	3.2(0-6)	2.5(2-3)	50	57
2 TD	0(0)	3.8(2-5)	-	0	100**	0(0)	3.5(2-6)	-	0	25
3 TD	0(0)	8(1-12)	12(NR)	0	100**	0(0)	6.7(2-12)	10(NR)	0	100**
4 TD	0(0)	6.3(3-10)	11(10-12)	0	100**	0(0)	3.7(1-9)	7.5(6-9)	0	100**
5 TD	0.2(0-1)	9(4-12)	12(NR)	0	86**	0(0)	8(2-12)	11.5(11-12)	0	100**
6 TD	0(0)	6.5(3-12)	11(11-12)	0	100**	0.3(0-1)	6.7(3-10)	12(NR)	0	78*
Word Spelling										
1 TD[a]	0(0)	2(0-9)	2(NR)	50	50	0(0)	2.5(0-6)	3.5(2-5)	50	50
2 TD	0(0)	4(2-6)	-	0	100**	0(0)	6.5(4-9)	-	0	100**
3 TD	0.3(0-1)	8.5(2-12)	11.5(11-12)	0	78*	0(0)	7.3(2-12)	11.5(11-12)	0	100**
4 TD	0(0)	6.2(1-10)	10(8-12)	0	100**	0.5(0-1)	5.2(2-10)	5.5(5-6)	0	81*
5 TD	0(0)	8.2(5-12)	11.5(11-12)	0	100**	0(0)	8.2(5-12)	11.5(11-12)	0	100**
6 TD	0(0)	6.2(0-12)	12(NR)	17	83*	0(0)	6.2(0-12)	12(NR)	17	83*

Note. Overlap is expressed in percent data overlap between baseline and treatment. DV = Dependent Variables; BL = Baseline mean; TX = Treatment mean; FU = Follow-up mean; Tau-U ES = Individual Tau-U effect size expressed in percentage. [a]Participant 1TD inadvertently received six less review activities for the multisensory intervention.
$^{*}p \leq .05$. $^{**}p \leq .01$.

Table 4

Letter Name and Sound Production Outcome Variables for Children with Dyslexia across Interventions and Phases

DV	Structured Language Intervention					Multisensory Intervention				
	BL	TX	FU			BL	TX	FU		
	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES	M (Range)	M (Range)	M (Range)	Overlap	Tau-U ES
Letter Name Production										
7 DYS	0(0)	1.8(0-4)	3.5(3-4)	33	67	0(0)	1.8(0-4)	1(0-2)	33	67
8 DYS	0(0)	2.5(0-5)	4(NR)	17	83*	0(0)	2.2(0-4)	1(NR)	17	83*
9 DYS	0(0)	0(NR)	0(NR)	100	0	0(0)	0(NR)	0(NR)	100	0
10 DYS	0(0)	1(0-2)	0(NR)	17	83*	0(0)	0.3(0-2)	0(NR)	83	17
11 DYS	0(0)	0.5(0-2)	1(0-2)	67	33	0(0)	0.5(0-1)	1(0-2)	50	50
Letter Sound Production										
7 DYS	0.6(0-1)	3(0-5)	3(2-4)	17	67	0.2(0-1)	3(0-6)	2.5(0-5)	17	67
8 DYS	0(0)	3.7(2-5)	3.5(3-4)	0	100**	0.2(0-1)	2.8(0-6)	2.5(2-3)	17	78*
9 DYS	0.2(0-1)	0.3(0-1)	0.5(0-1)	100	8	0.8(0-2)	1.7(0-4)	2(1-3)	17	40
10 DYS	0(0)	0.7(0-2)	0(NR)	50	50	0(0)	0.7(0-1)	0(NR)	33	67
11 DYS	0(0)	1.3(0-3)	2(0-4)	50	50	0.2(0-1)	1.2(0-3)	0(NR)	50	42

Note. Overlap is expressed in percent data overlap between baseline and treatment. DV = Dependent Variables; BL = Baseline mean; TX = Treatment mean; FU = Follow-up mean; Tau-U ES = Tau-U effect size expressed in percentage.
$^{*}p \leq .05$. $^{**}p \leq .01$.

Table 5

Word Reading and Spelling Outcome Variables for Children with Dyslexia across Interventions and Phases

DV	Structured Language Intervention					Multisensory Intervention				
	BL M (Range)	TX M (Range)	FU M (Range)	Overlap	Tau-U ES	BL M (Range)	TX M (Range)	FU M (Range)	Overlap	Tau-U ES
Word Reading										
7 DYS	0(0)	3.2(1-5)	4(NR)	0	100**	0(0)	3.5(1-7)	8(NR)	0	100**
8 DYS	0(0)	2(0-5)	3.5(3-4)	50	50	0(0)	2.3(0-4)	3(2-4)	17	83*
9 DYS	0(0)	0(NR)	0(NR)	100	0	0(0)	0(NR)	0(NR)	100	0
10 DYS	0(0)	0.3(0-1)	0.5(0-1)	67	33	0(0)	0(NR)	0(NR)	100	0
11 DYS	0(0)	0.8(0-3)	1(0-2)	50	50	0(0)	0.8(0-2)	1.5(1-2)	33	50
Word Spelling										
7 DYS	0(0)	2.8(1-4)	4(NR)	0	100**	0(0)	4.8(1-9)	8(NR)	0	100**
8 DYS	0.2(0-1)	3.5(0-7)	6(4-8)	33	78*	0(0)	1.5(0-4)	1(0-2)	33	67
9 DYS	0(0)	0.3(0-1)	0(NR)	67	33	0(0)	0.8(0-1)	0(NR)	17	83*
10 DYS	0(0)	0.7(0-2)	0(NR)	50	50	0.2(0-1)	0(NR)	0(NR)	100	-31
11 DYS	0(0)	2.2(0-4)	3.5(3-4)	17	83*	0(0)	1.5(0-3)	2(NR)	17	83*

Note. Overlap is expressed in percent data overlap between baseline and treatment. DV = Dependent Variables; BL = Baseline mean; TX = Treatment mean; FU = Follow-up mean; Tau-U ES = Tau-U effect size expressed in percentage.
$^{*}p \leq .05$. $^{**}p \leq .01$.

APPENDIX B

FIGURES

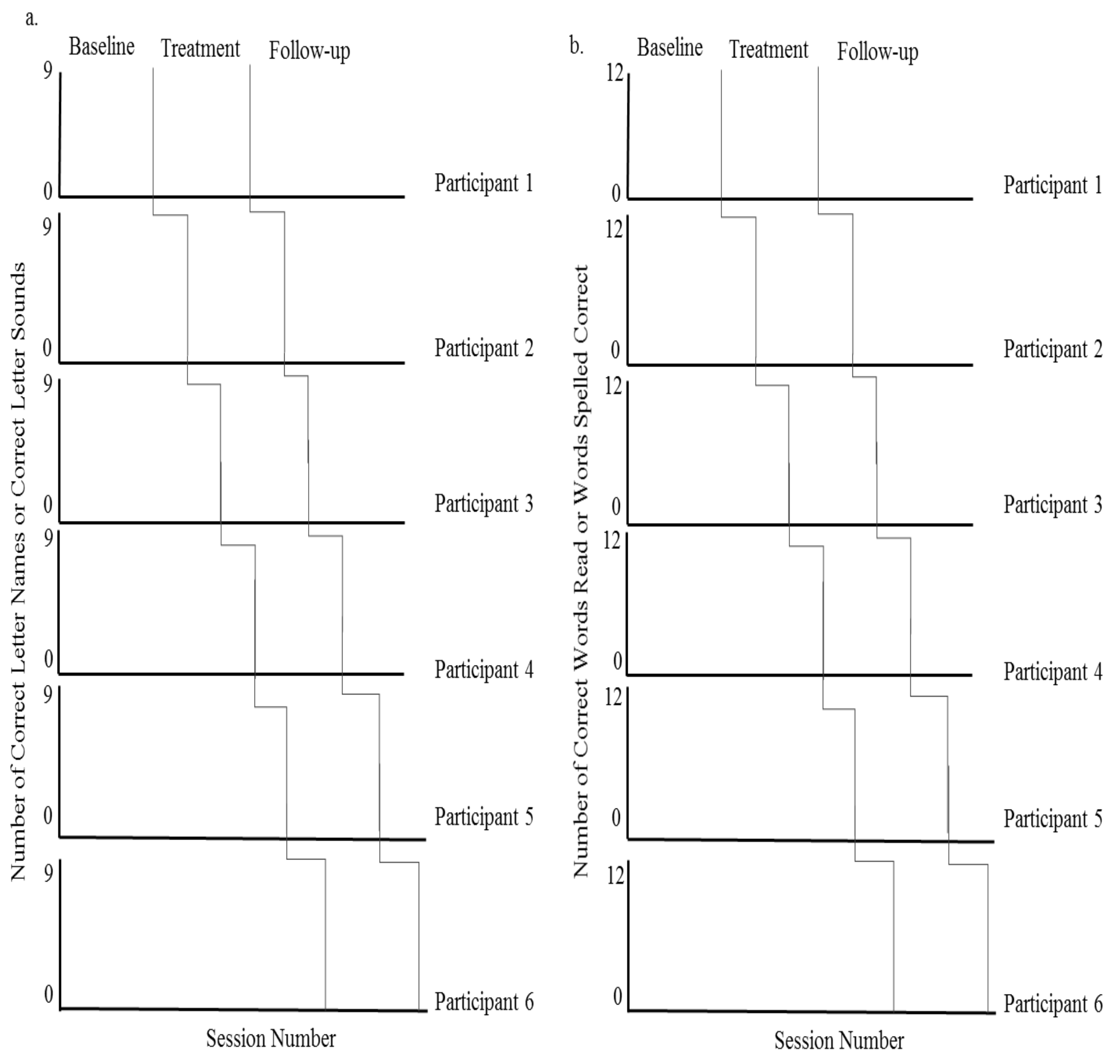


Figure 1. Example of participant graphs across dependent variables and phases. Number of correct letters names or correct letter sounds (a), number of words read correct or words spelled correct (b).

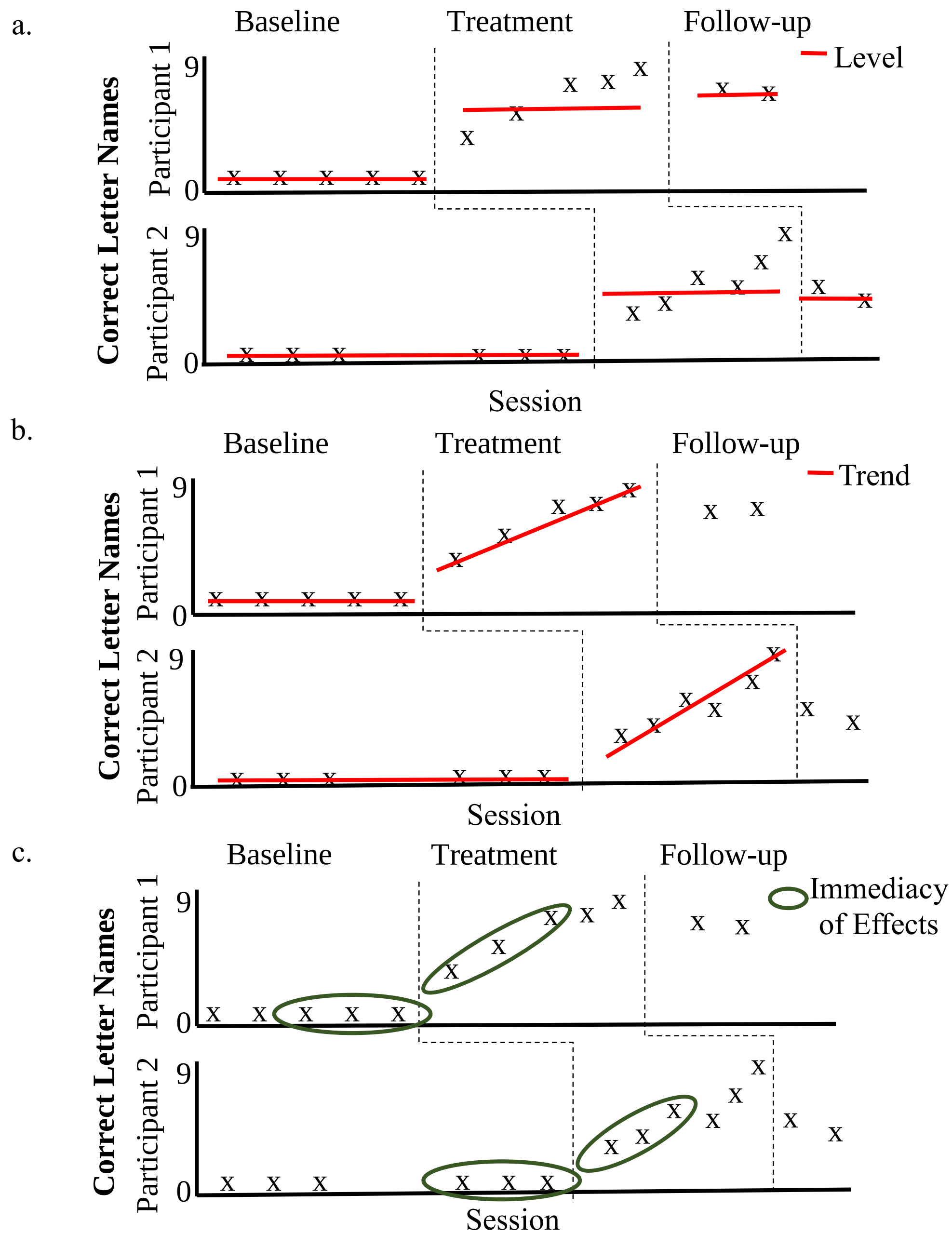


Figure 2. Example of visual inspection of data for level (a), trend (b), and immediacy of effects (c).

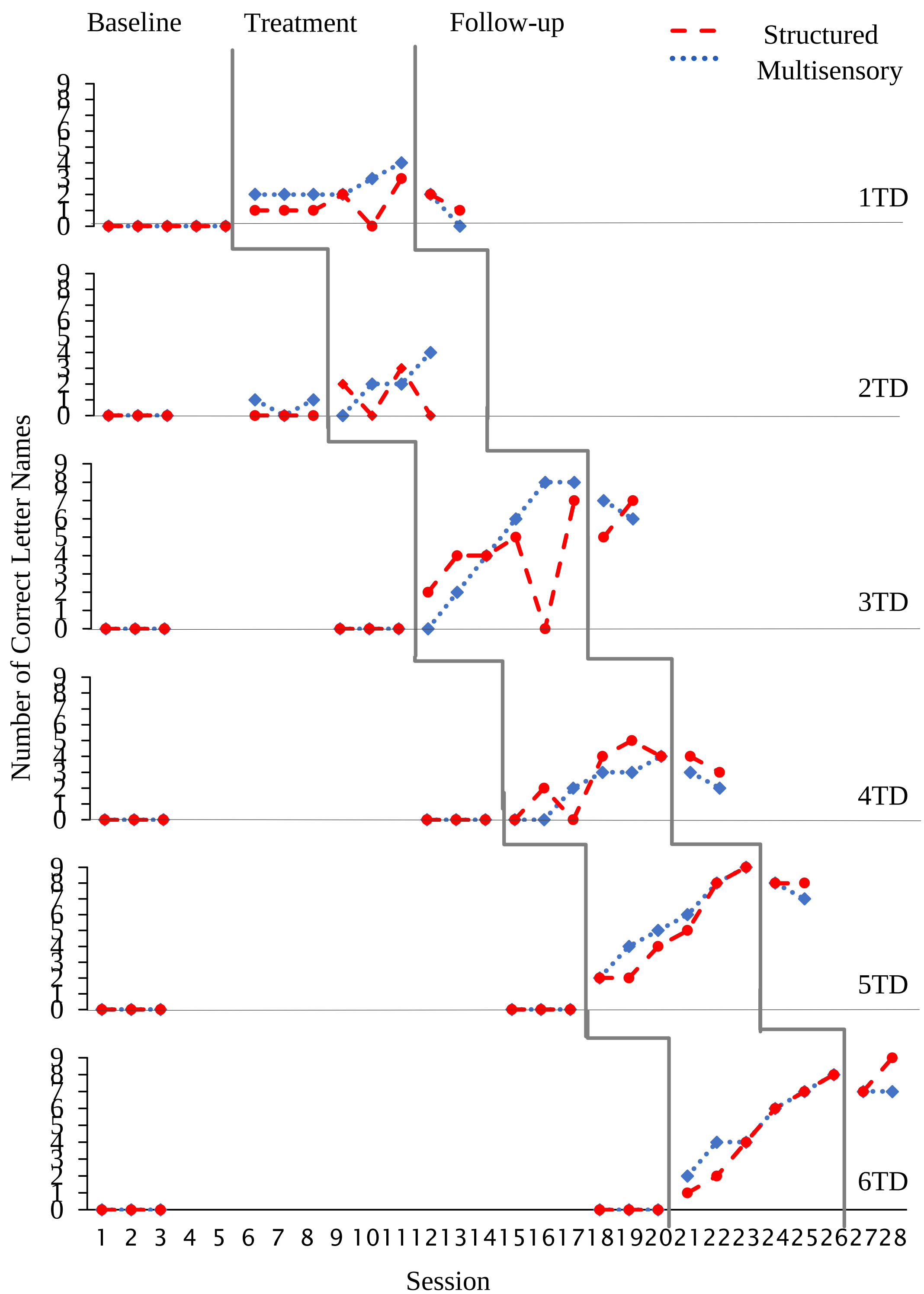


Figure 3. Accuracy of the number of letter names produced for each participant with typical development across three phases. TD = Typical development.

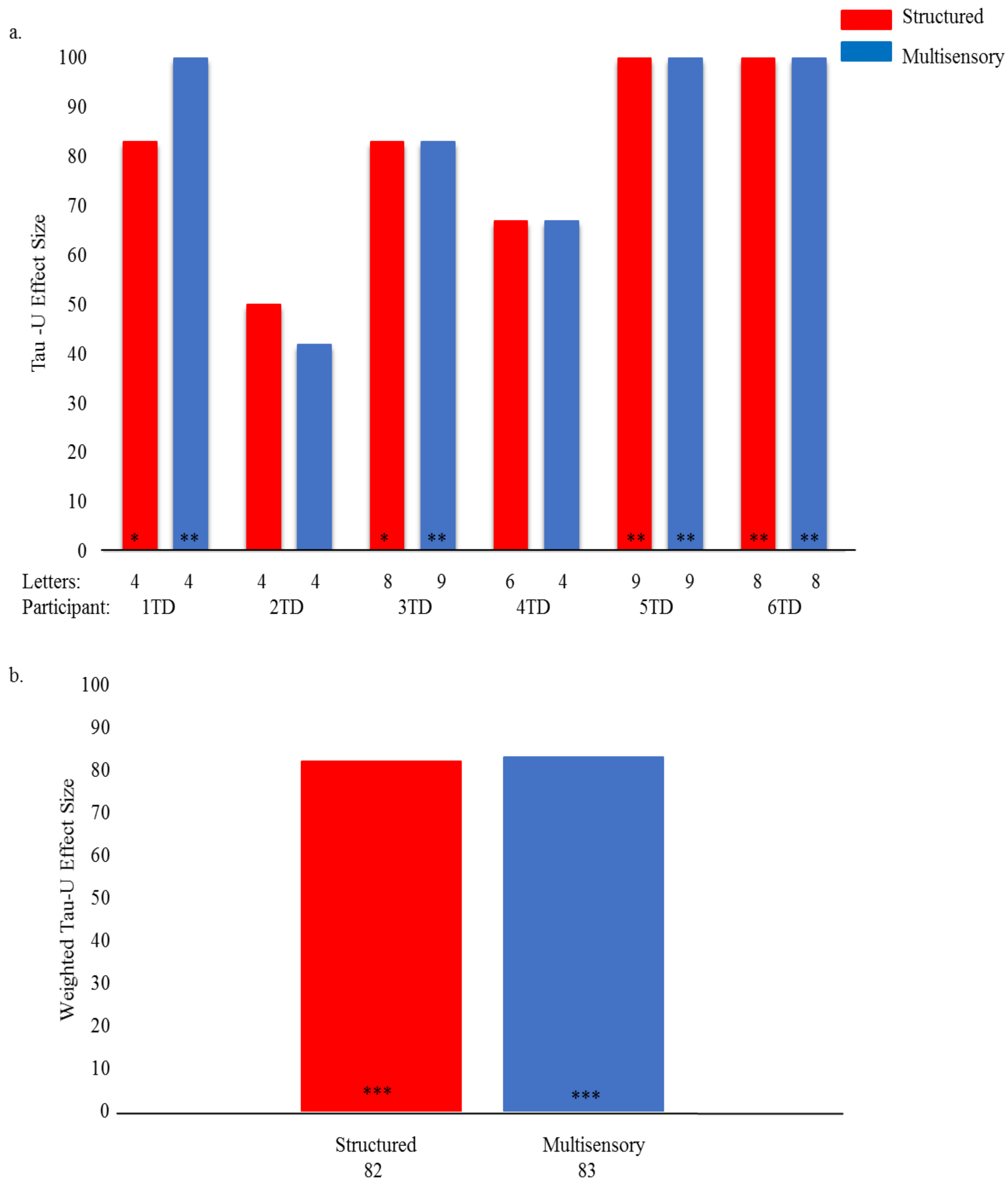


Figure 4. Number of correct letter names Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with typical development. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; TD = Typical development.
* $p \leq .05$. ** $p \leq .01$. ***$p = .001$.

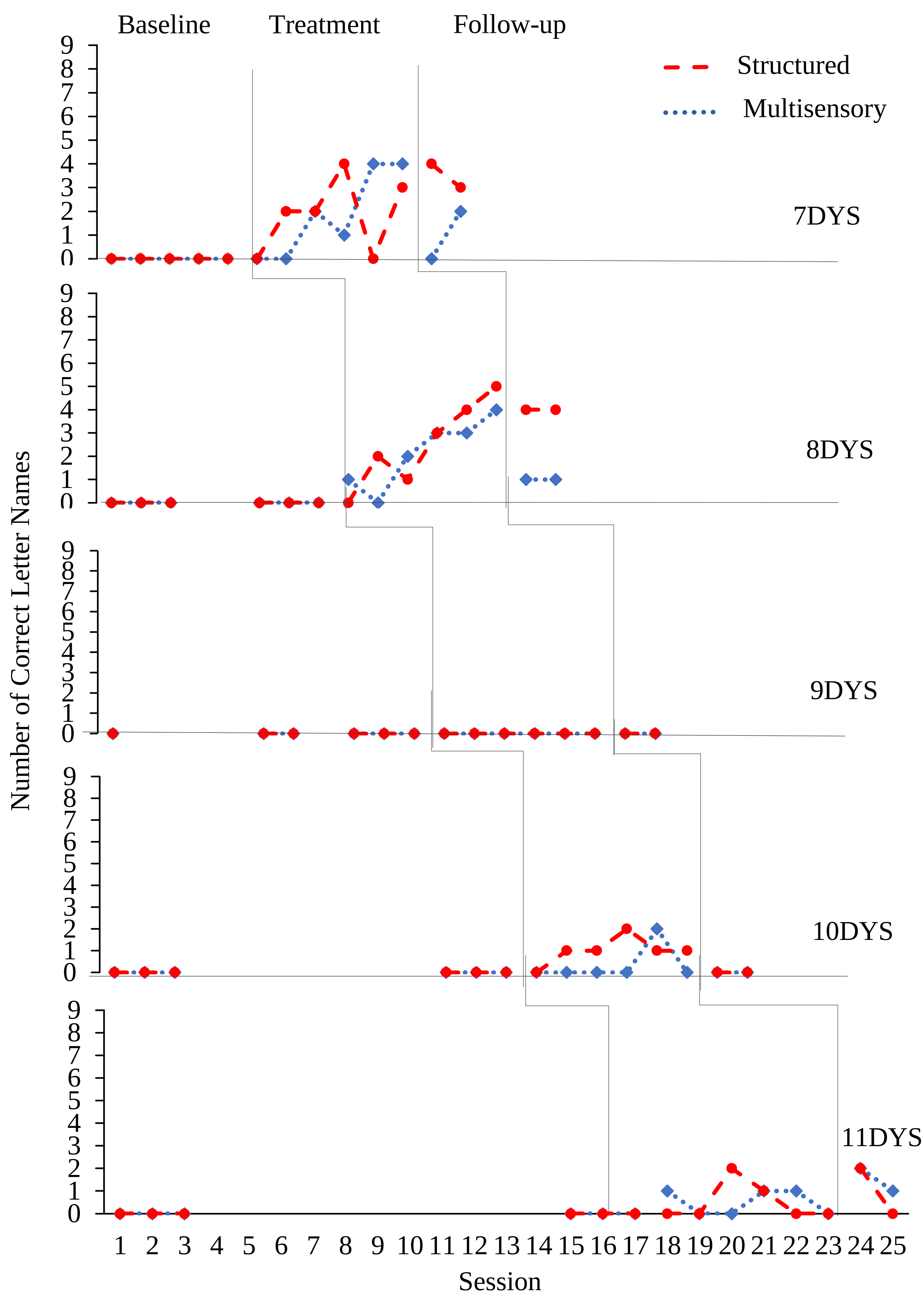


Figure 5 Accuracy of the number of letter names produced for each participant with dyslexia across three phases. DYS = Dyslexia.

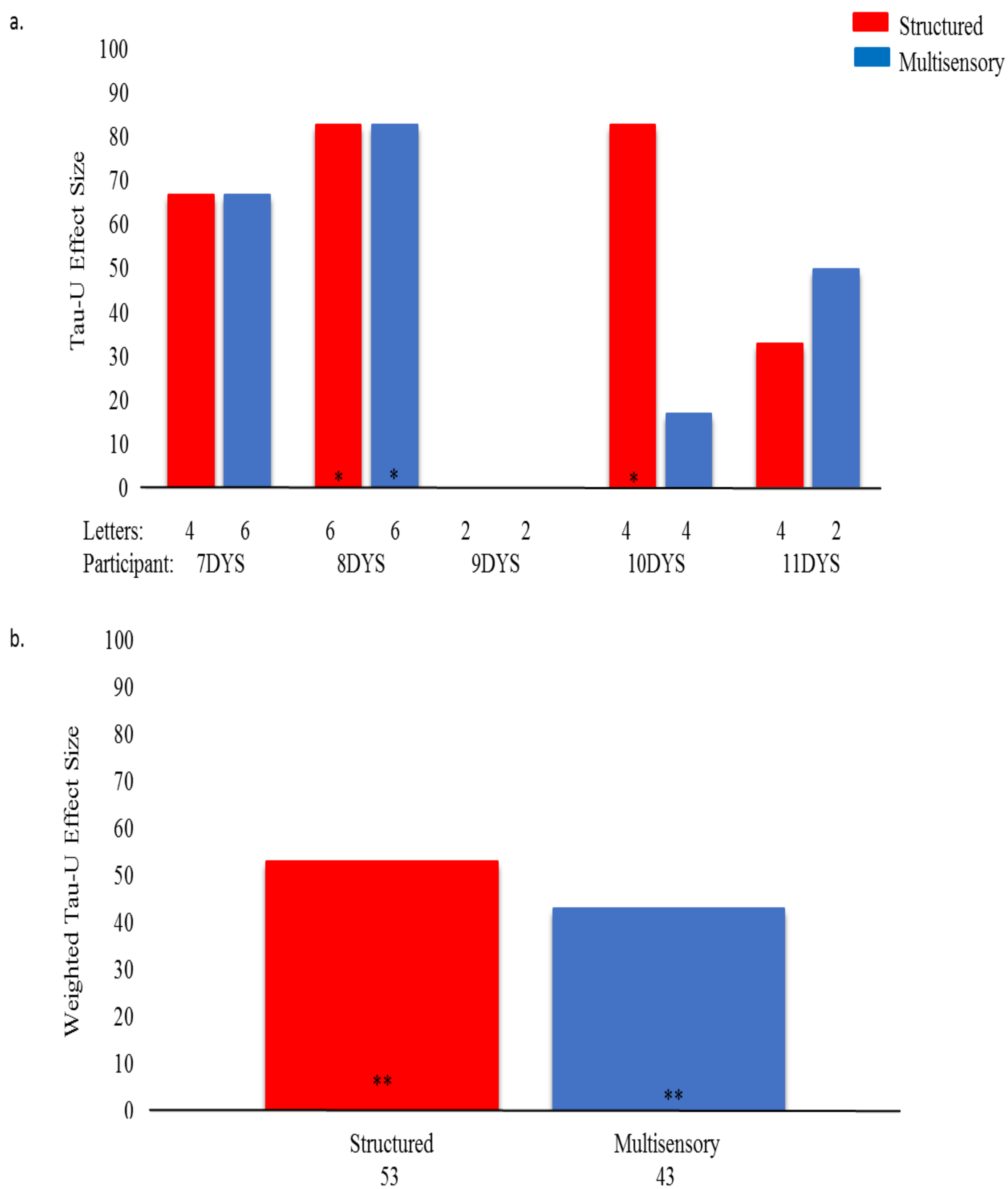


Figure 6. Number of correct letter names Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with dyslexia. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; DYS = Dyslexia. * $p \leq .05$. ** $p \leq .01$.

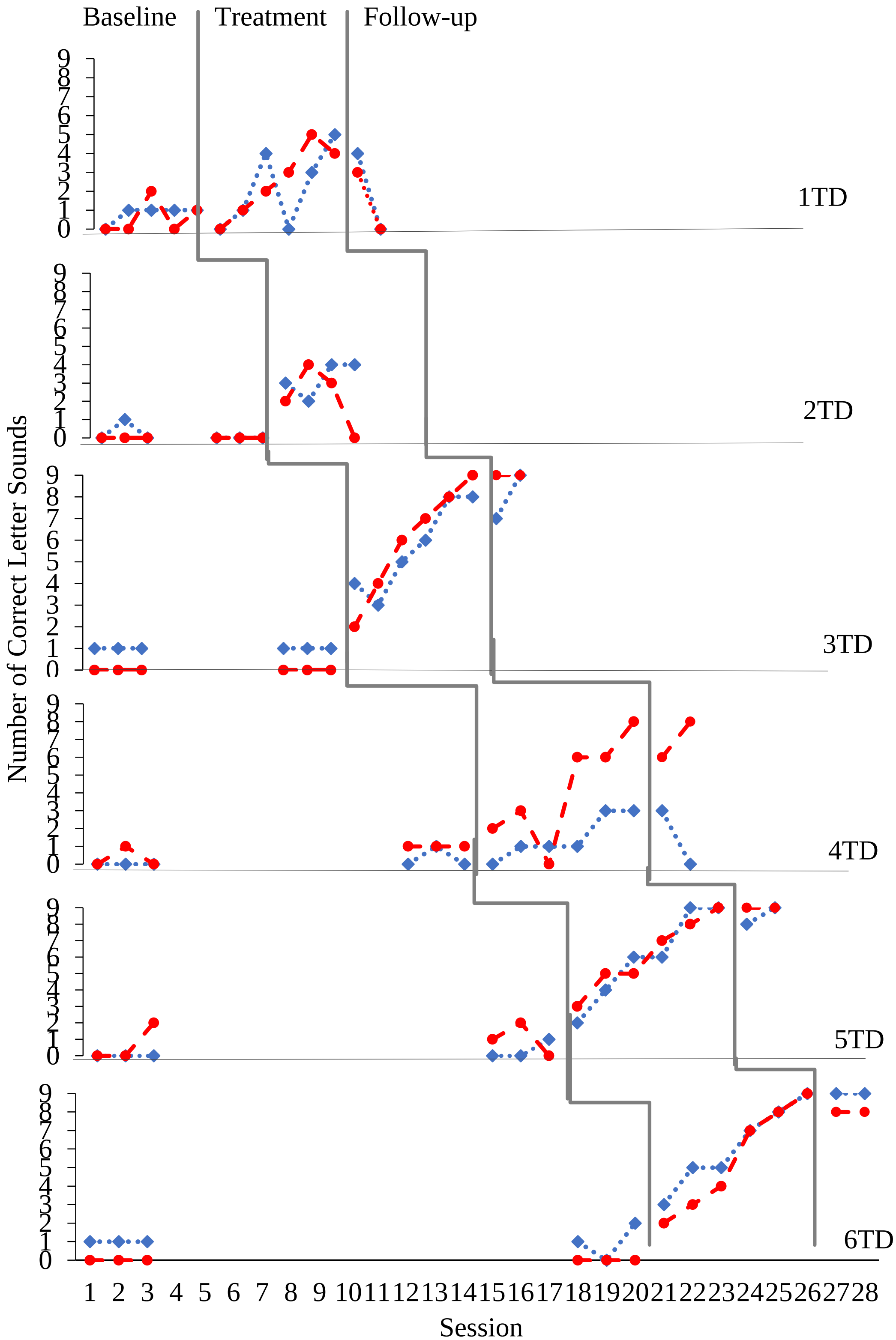


Figure 7. Accuracy of the number of letter sounds produced for each participant with typical development across three phases. TD = Typical development.

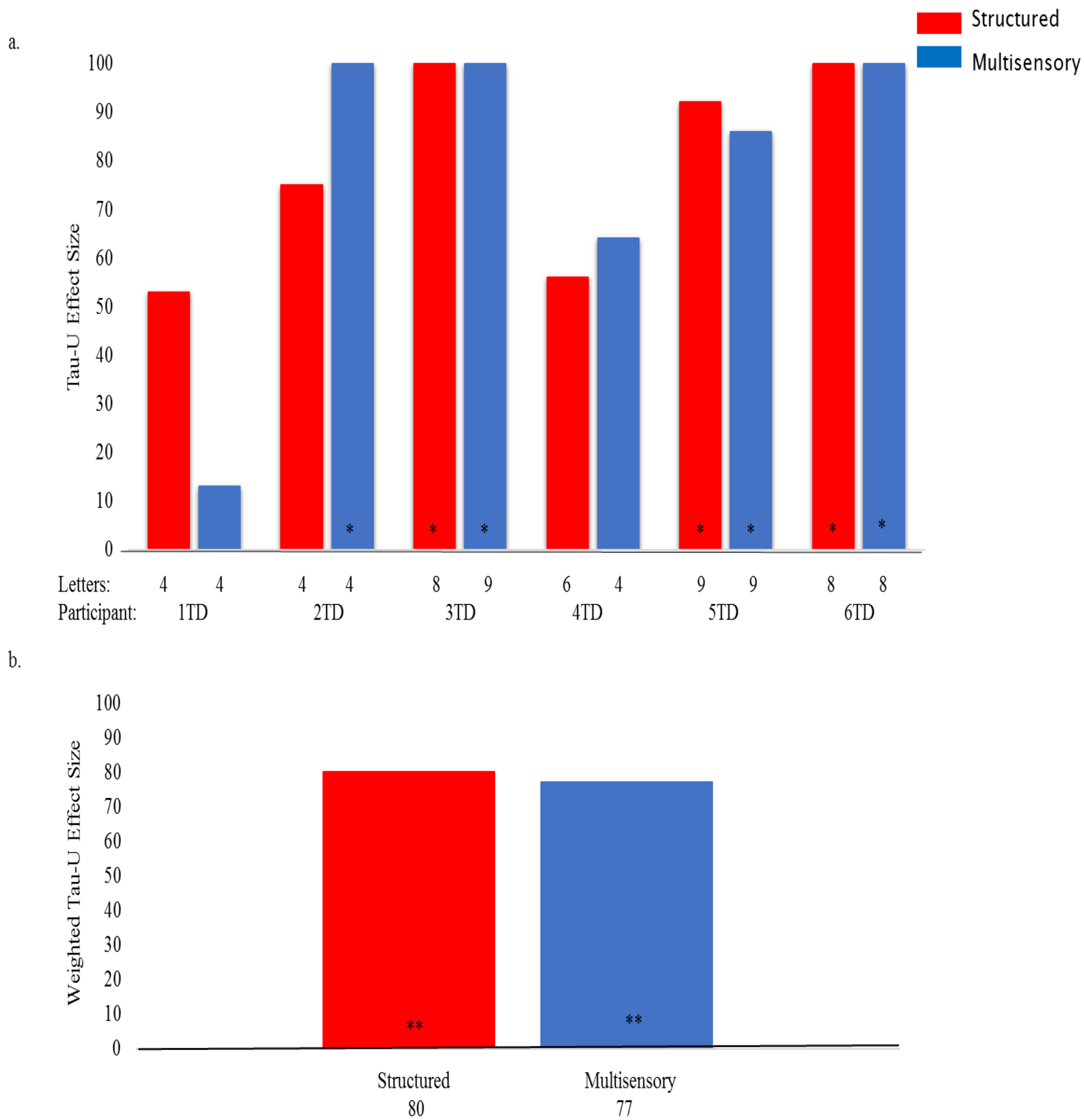


Figure 8. Number of correct letter sounds Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with typical development. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; TD = Typical development.
* $p \leq .01$. **$p = .001$.

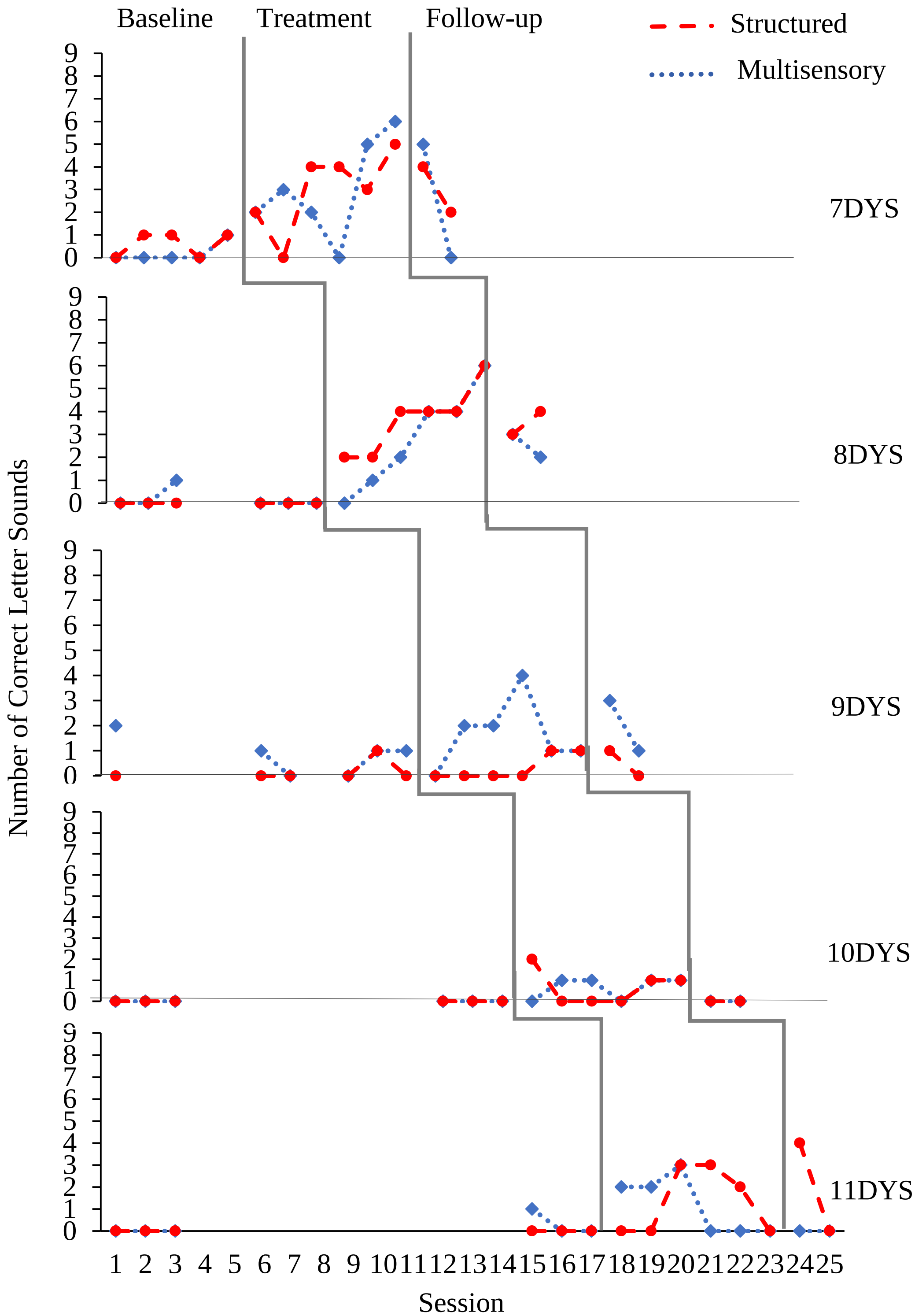


Figure 9. Accuracy of the number of letter sounds produced for each participant with dyslexia across three phases. DYS = Dyslexia.

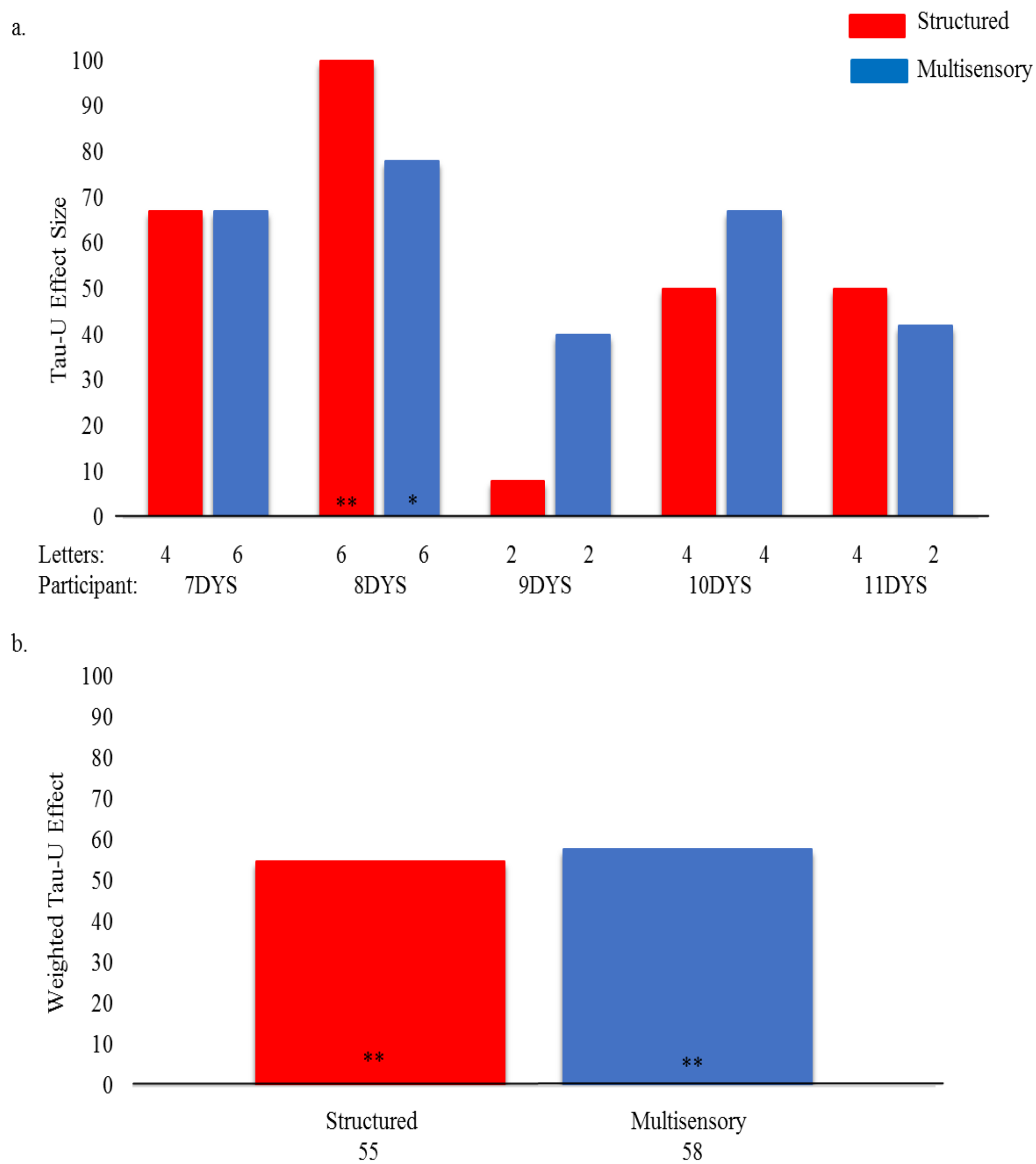


Figure 10. Number of correct letter sounds Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with dyslexia. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; DYS = Dyslexia. * $p \leq .05$. ** $p \leq .01$.

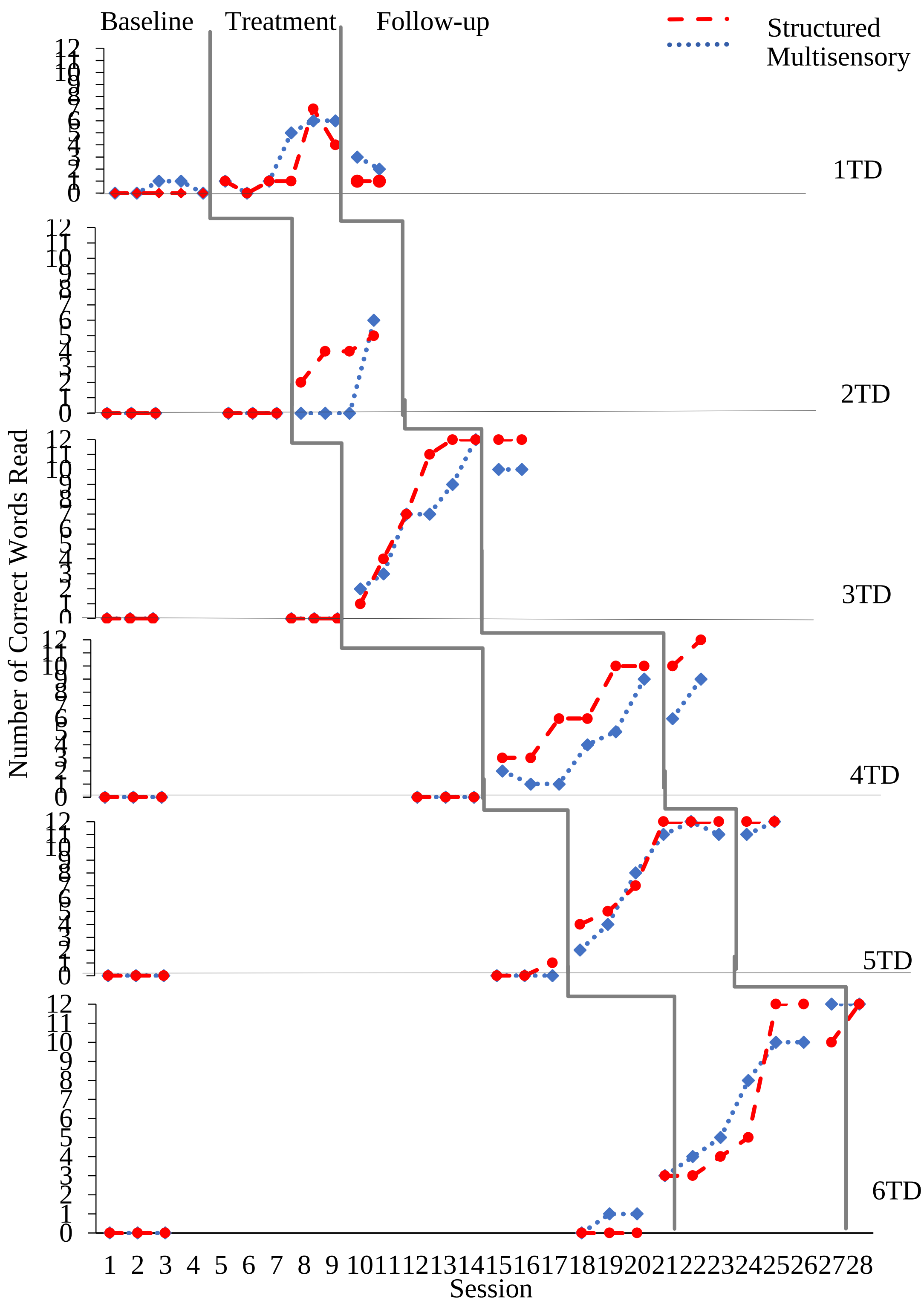
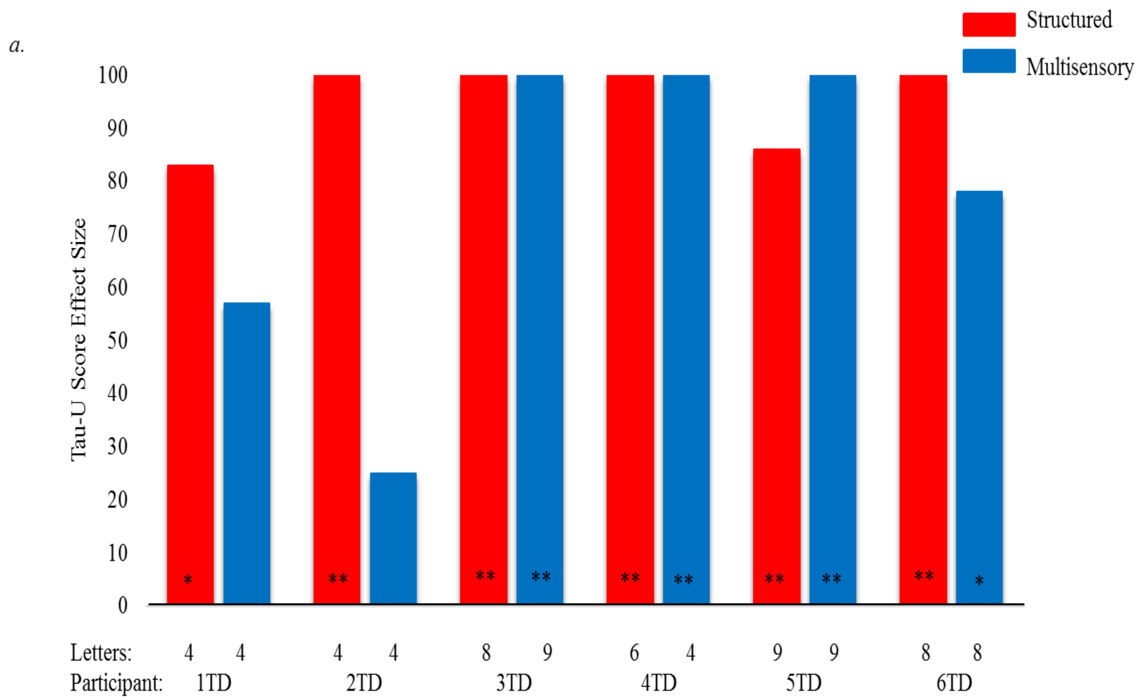


Figure 11. Accuracy of words read correct for each participant with typical development across three phases. TD = Typical Development.



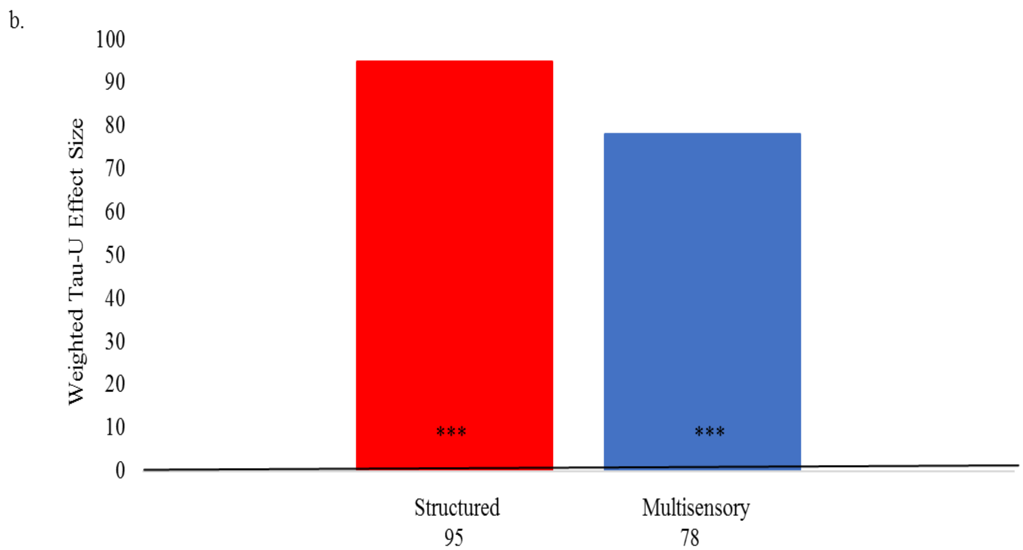


Figure 12. Number of words read correct Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with typical development. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; TD = Typical development.

* $p \leq .05$. ** $p \leq .01$. *** $p = .001$.

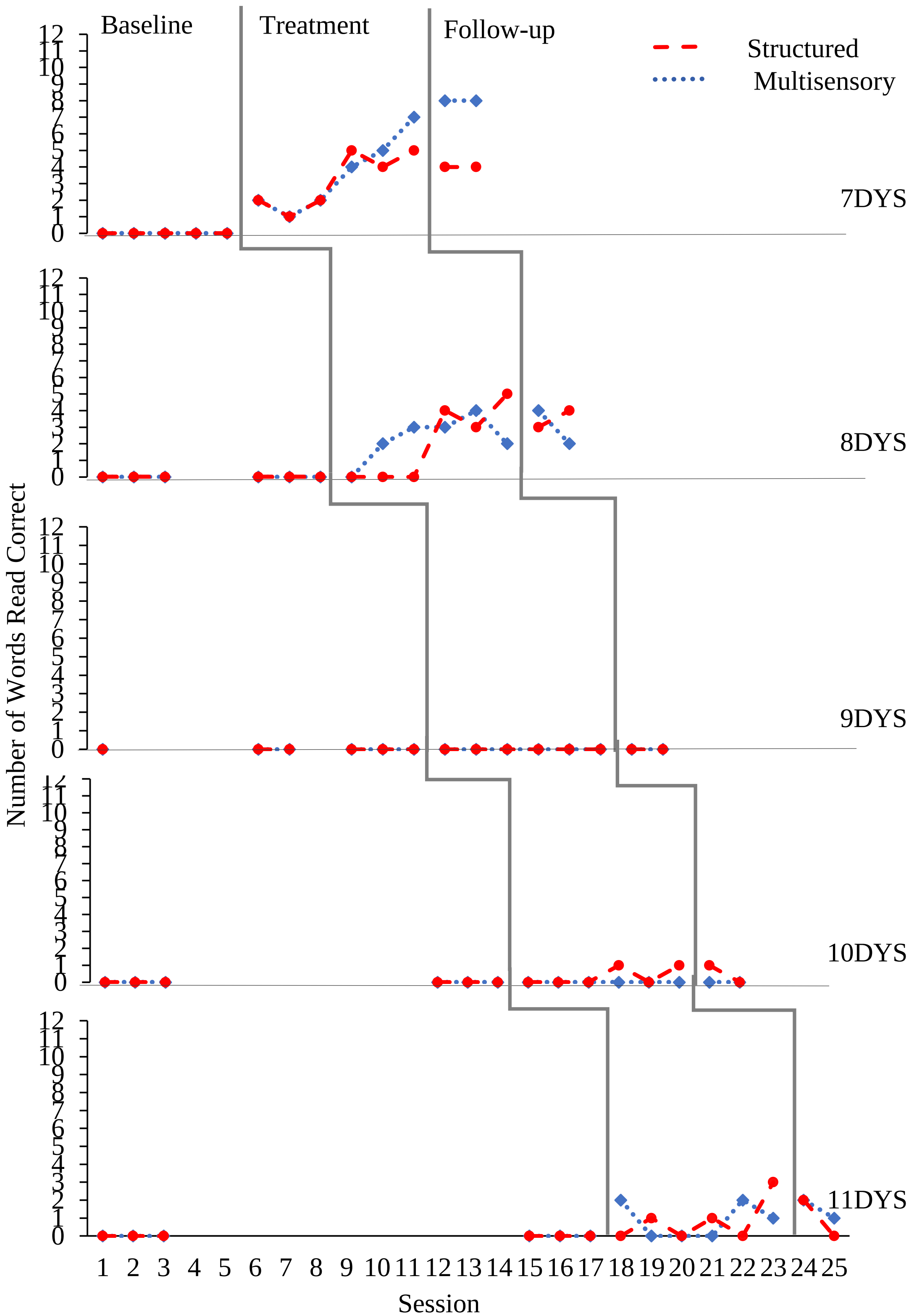


Figure 13. Accuracy of words read correct for each participant with dyslexia across three phases. DYS = Dyslexia.

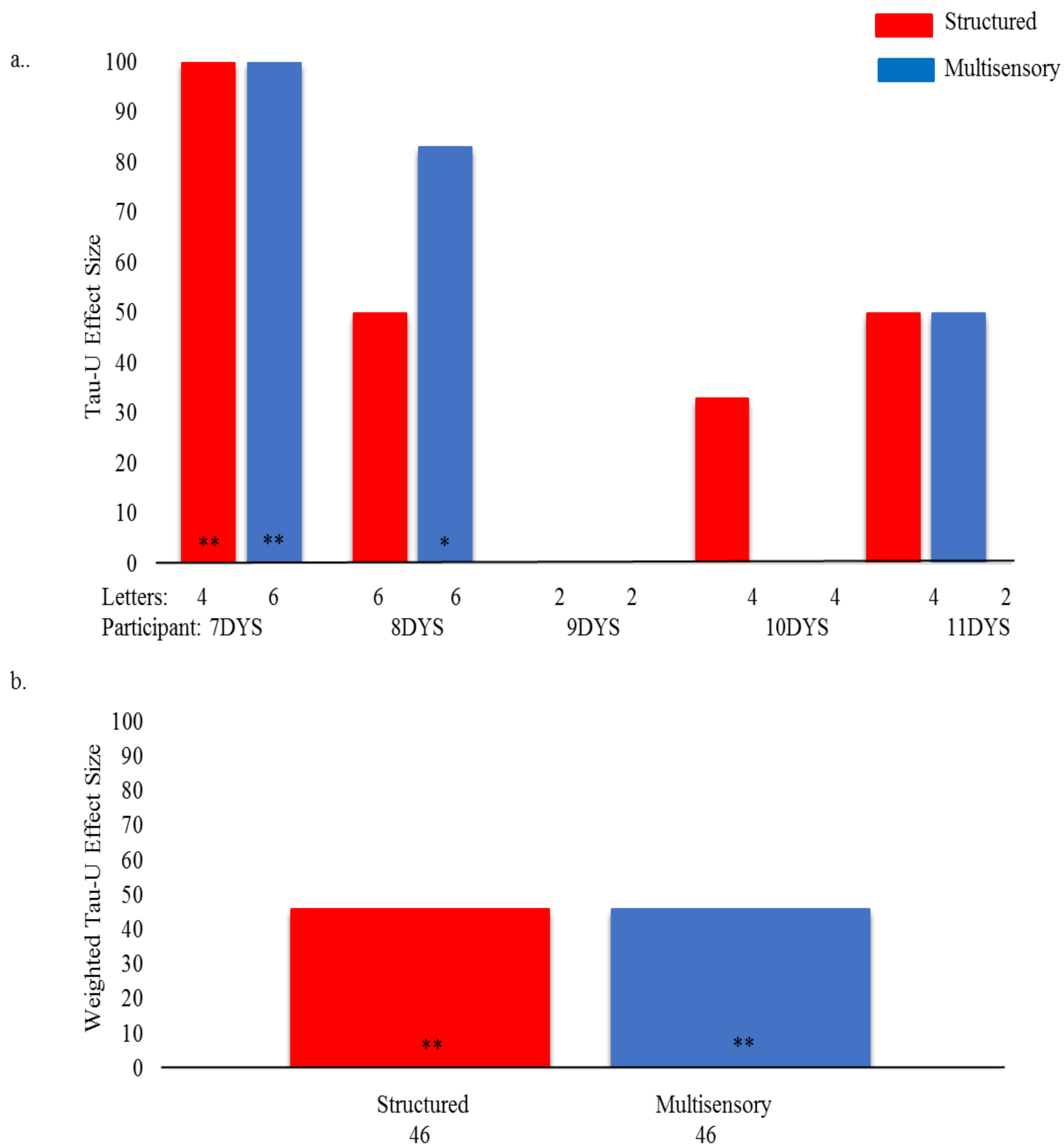


Figure 14. Number of words read correct Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with dyslexia. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; DYS = Dyslexia. * $p \leq .05$. ** $p \leq .01$.

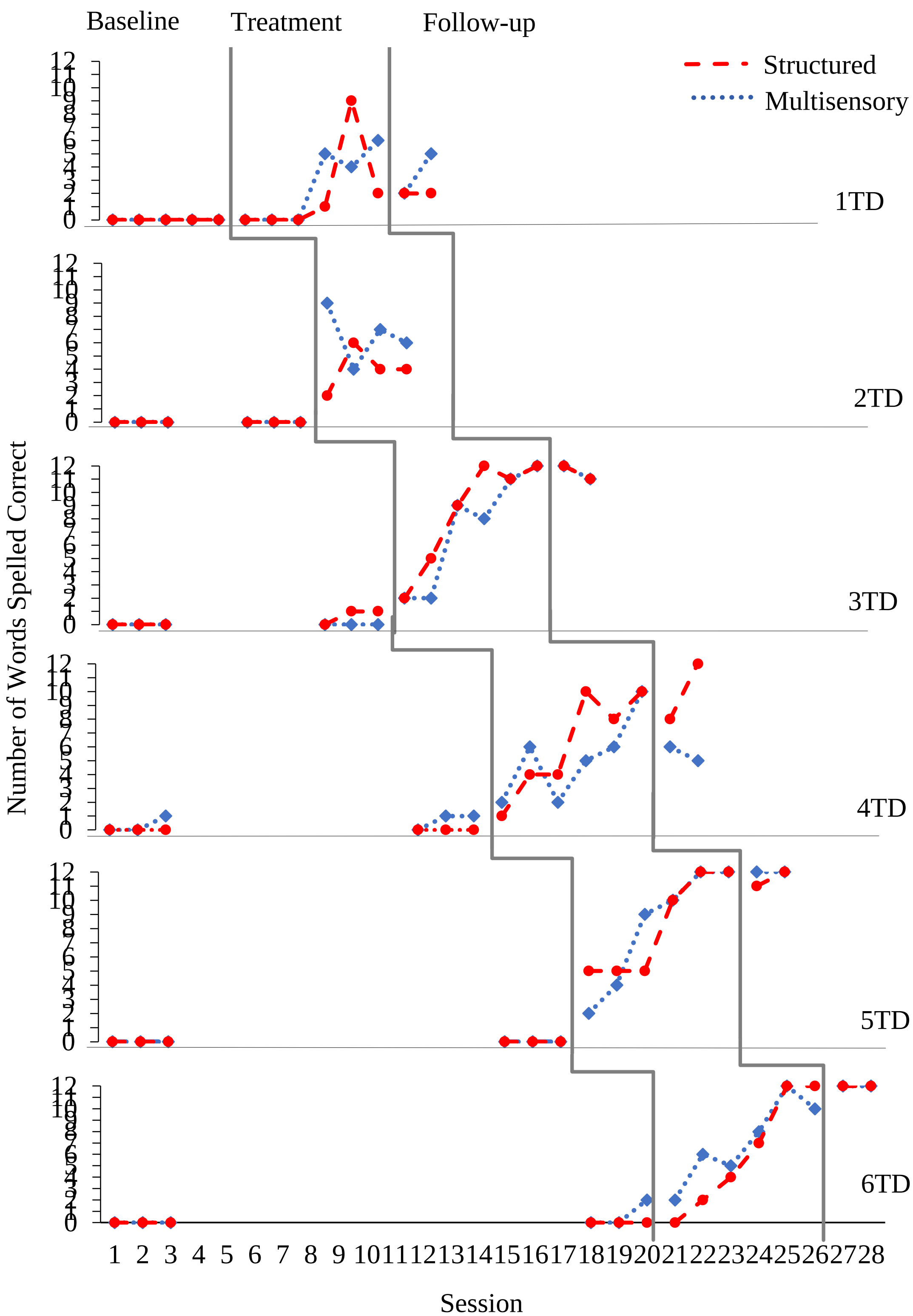


Figure 15. Accuracy of words spelled correct for each participant with typical development across three phases. TD = Typical development.

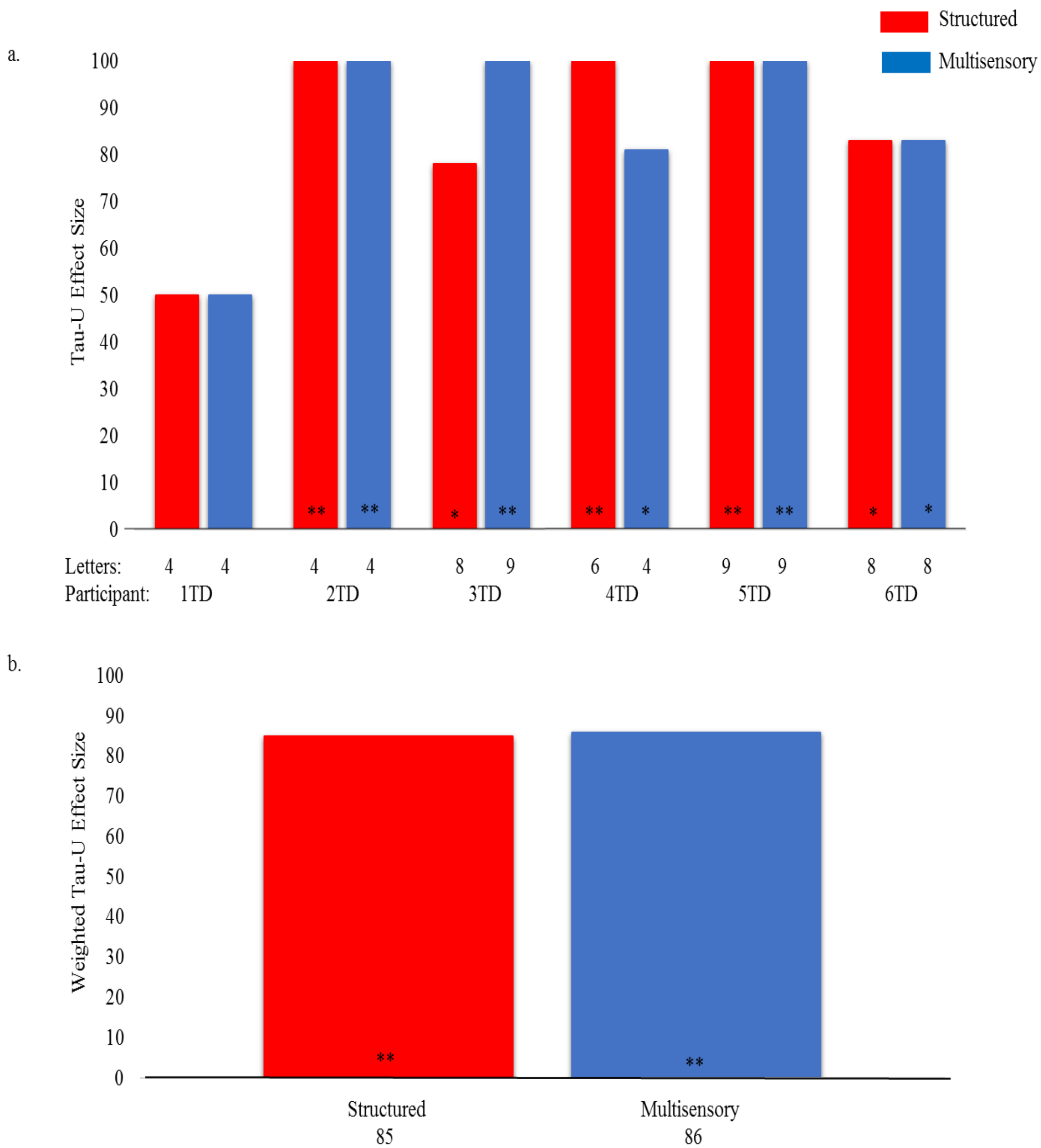


Figure 16. Number of words spelled correct Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with typical development. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; TD = Typical development.
* $p \leq .05$. **$p \leq .01$.

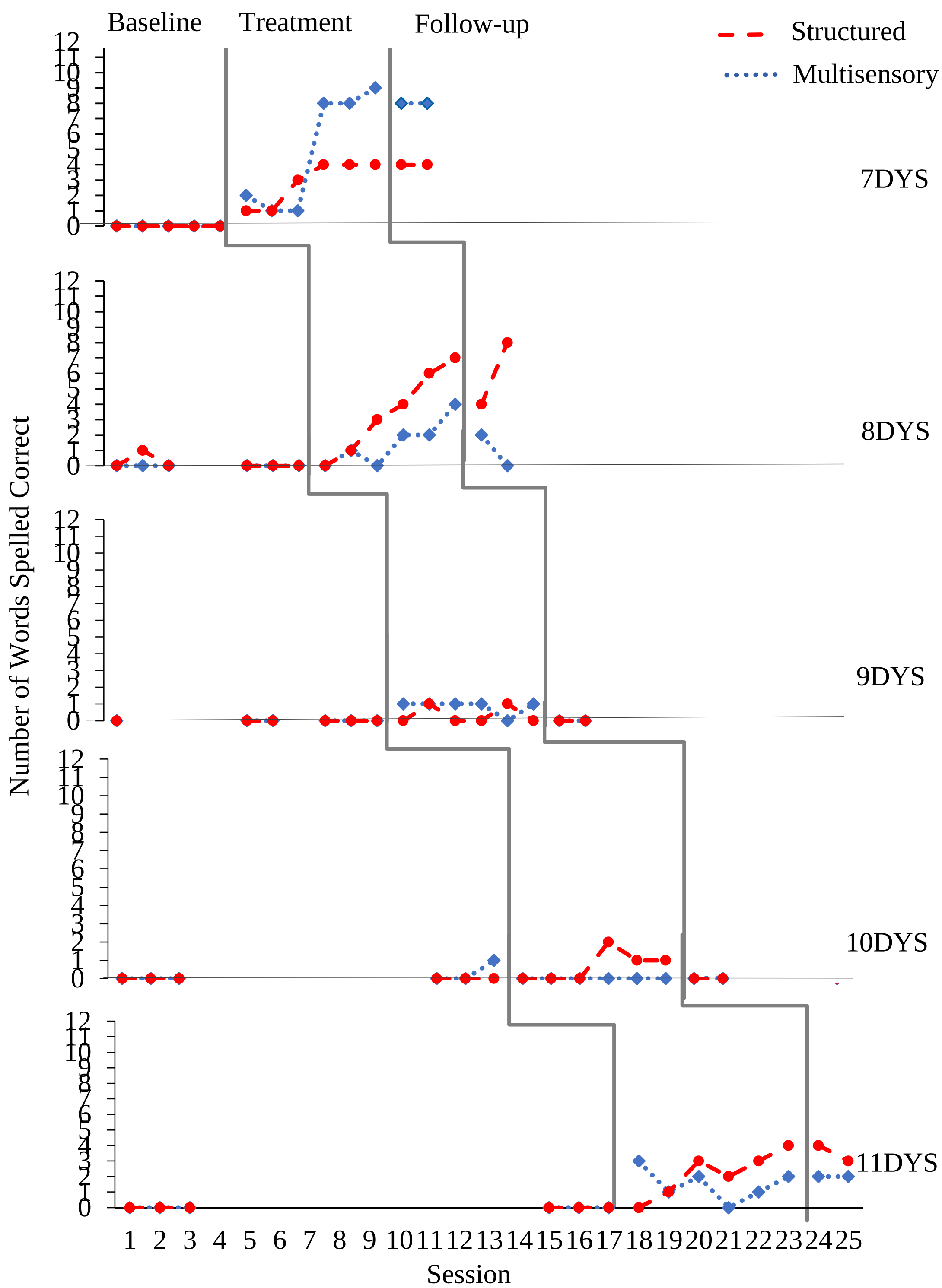


Figure 17. Accuracy of words spelled correct for each participant with dyslexia across three phases. DYS = Dyslexia.

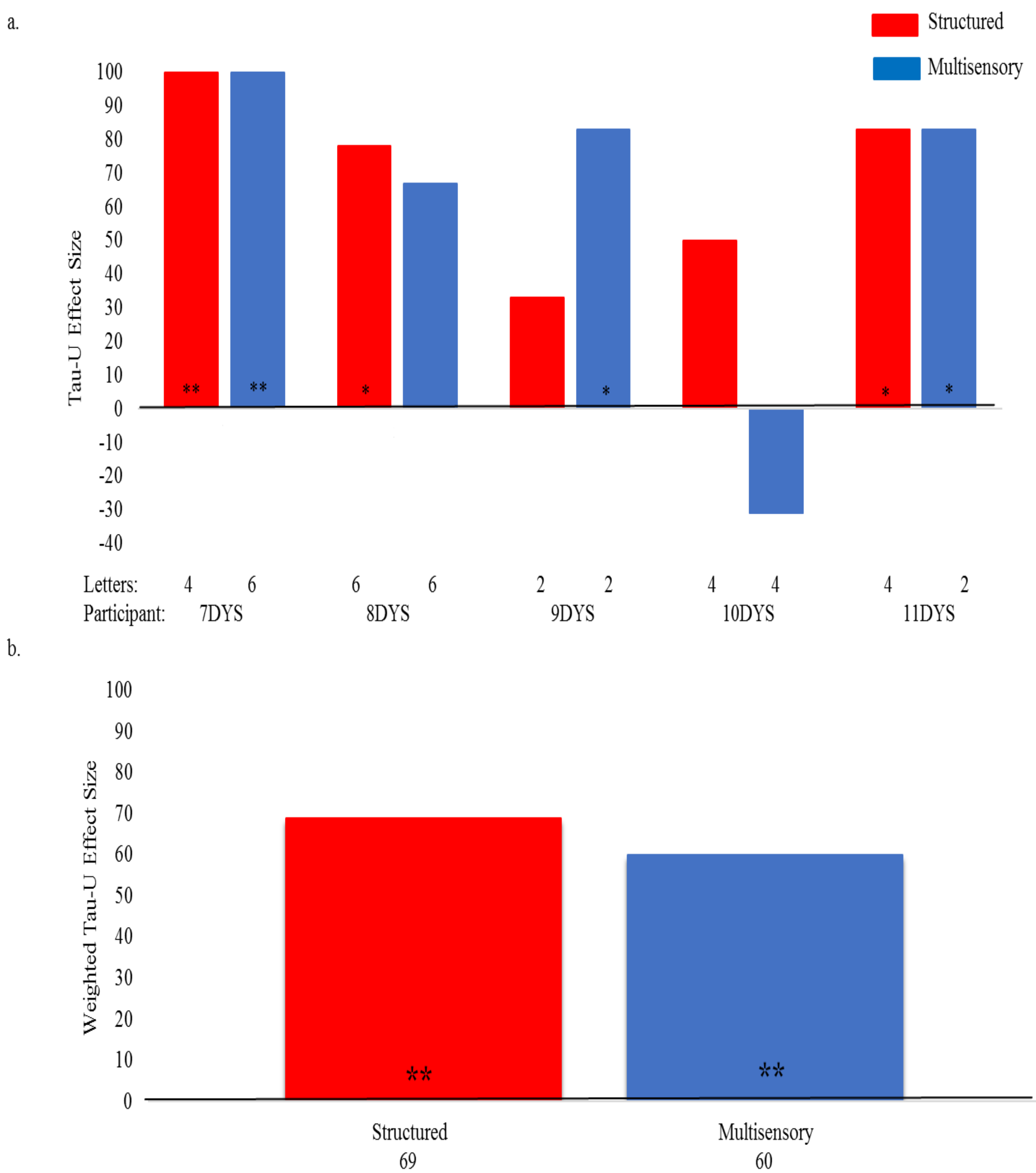


Figure 18. Number of words spelled correct Tau-U effect sizes (a) and Weighted Tau-U effect sizes (b) for children with dyslexia. Letters = Number of letters participant was introduced to for each intervention; Participant = Participant number; DYS = Dyslexia. * $p \leq .05$. ** $p \leq .01$.

APPENDIX C

ARIZONA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD APPROVAL

ASU Knowledge Enterprise Development

APPROVAL: EXPEDITED REVIEW

Shelley Gray
Speech and Hearing Science
480/965-6796
Shelley.Gray@asu.edu

Dear Shelley Gray:

On 10/16/2014 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	The Impact of Multisensory Instruction on Learning Letter Names and Sounds, Word Reading, and Spelling
Investigator:	Shelley Gray
IRB ID:	STUDY00001728
Category of review:	(4) Noninvasive procedures, (7)(b) Social science methods, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Child Assent, Category: Consent Form; • Parent Consent, Category: Consent Form; • Social Behavioral Application, Category: IRB Protocol; • Attention Questionnaire, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Copies of Assessment Protocols, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Parent Questionnaire, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Director-Principal Summary, Category: Recruitment Materials; • Participant Solicitation, Category: Recruitment Materials;

Page 1 of 2

The IRB approved the protocol from 10/16/2014 to 10/15/2015 inclusive. Three weeks before 10/15/2015 you are to submit a completed "FORM: Continuing Review (HRP-212)" and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 10/15/2015 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc:
Nora Schlesinger
Diala Manfoukh
Shelley Gray
Sunil Kataria

APPENDIX D

COURTESY OF LUCASFILM LTD.

WRITTEN APPROVAL TO USE THE

AUREBESH LETTERS ***STAR WARS*** © & ™ LUCASFILM LTD.

LUCASFILM Ltd

VIA EMAIL &
REGULAR MAIL

February 4, 2014

Nora Schlesinger
Doctoral Student
Arizona State University
Coor Hall #2222
Tempe, AZ 85287
Email: Nora.Schlesinger@asu.edu

Re: Aurebesh letters and names from the ***Star Wars*** motion pictures as part of your dissertation for the Department of Speech and Hearing Science at Arizona State University

Dear Nora,

Lucasfilm Ltd. LLC ("Lucasfilm") is pleased to approve the non-commercial, non-exclusive, non-transferable, revocable use of various Auerbesh letters and names from the ***Star Wars*** motion pictures (collectively, the "Star Wars Material") as part of your Ph.D. dissertation (the "Dissertation") for the Department of Speech and Hearing Science (the "Department") at Arizona State University (the "University") in substantially the same form as described in your email dated January 25, 2014 provided that: (a) it is understood that Lucasfilm is the sole and exclusive owner of all rights in the Star Wars Material, with all uses enuring to Lucasfilm's benefit; and (b) you never agree to challenge Lucasfilm's ownership of all rights in the Star Wars Material. Lucasfilm retains all intellectual property rights in and to the Star Wars Material, such as copyright rights and trademark rights.

The Star Wars Material may not be modified in any way, and may not be used in any manner which would be derogatory to or critical of the motion pictures from which the Star Wars Material was taken or to the persons or companies involved with the making of the motion pictures from which the Star Wars Material was taken. No use of the Star Wars Material: (a) may be used for any purposes in connection with the advertising, publicizing or any other promotion of the Department, Dissertation or University; (b) may be used in connection with any merchandising, promotional tie-ins, or other goods, services, or products of any nature whatsoever associated with the Department, Dissertation or University; and/or (c) may be used on the front or back cover of the Dissertation.

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The following credit must appear in the following form:

COURTESY OF LUCASFILM LTD.

We wish you the best of luck with your Dissertation!

Sincerely,

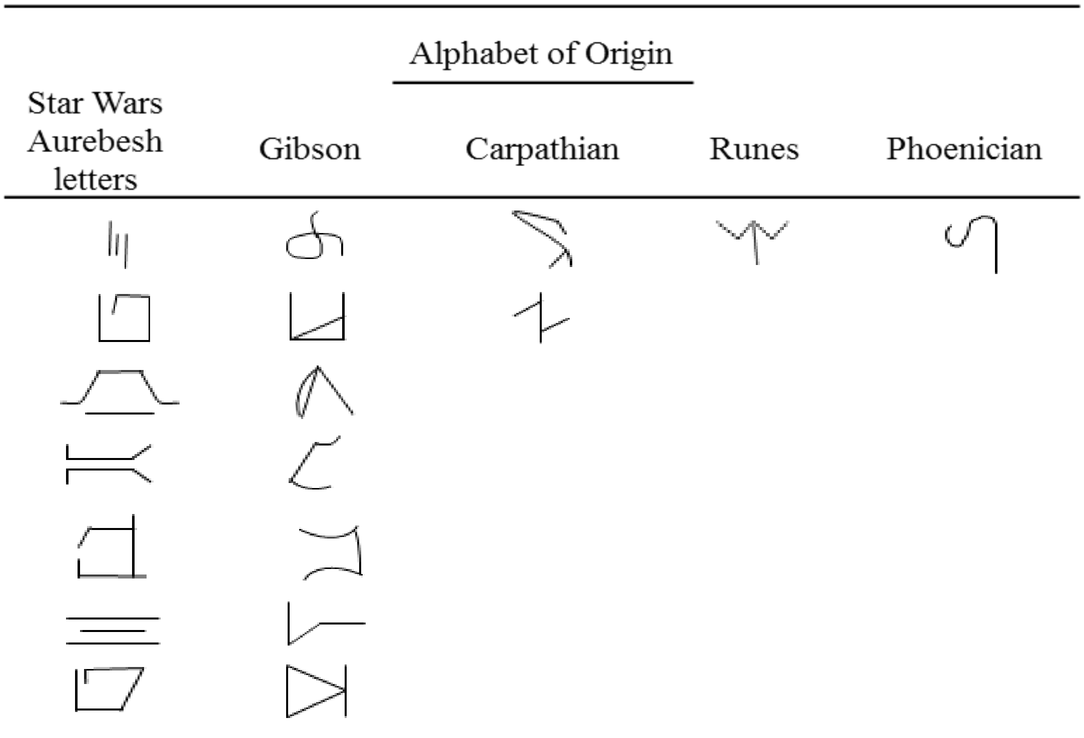
Christopher Holm
Business Affairs

CH/sg

cc: David Anderman
Sharron Drake
Mary Franklin

APPENDIX E

GRAPHEMES



Note. Courtesy of Lucasfilm Ltd. permission granted for the use of the Aurebesh Letters, *Star Wars* © and ™ Lucasfilm Ltd. Aurebesh letters from, "Star Wars Miniature Battles Imperial Entanglements," by S. Crane, 1996. Gibson letter forms from "A Developmental Study of the Discrimination of Letter-Like Forms," by Gibson, Gibson, Pick, and Osser, 1962, *Journal of Comparative and Physiological Psychology, 55*, pp. 897-906. Carpathian letters adapted from "Heritage of Scribes: The Relation of Rovas Scripts to Eurasian Writing Systems," by Hosszu, 2012. Rune letter from "The Old English Rune for S," by Nicholson, 1982, *The Journal of English and Germanic Philology, 81*, pp. 313-319. Phoenician letter from "The Languages of the World Ancient and Modern," by Wemyss, 1950.

APPENDIX F

PHONEMES

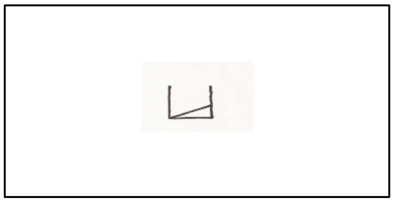
Place of articulation Manner of articulation Voiced or unvoiced Phoneme	Place of articulation Manner of articulation Voiced or unvoiced Phoneme
Bilabial	Bilabial
Stop	Stop
Unvoiced	Voiced
/p/	/b/
Labiodental	Labiodental
Fricative	Fricative
Voiced	Unvoiced
/v/	/f/
Alveolar	Alveolar
Stop	Stop
Voiced	Unvoiced
/d/	/t/
Velar	Velar
Stop	Stop
Voiced	Unvoiced
/g/	/k/
Alveolar	Alveolar
Fricative	Fricative
Unvoiced	Voiced
/s/	/z/
Bilabial	Alveolar
Nasal (stop)	Nasal (stop)
/m/	/n/
Alveolar	Palatal
Liquids	Liquids
/l/	/r/
Front high vowel sound	Front medium vowel sound
/I/	/ɛ/
Front low vowel sound	Back low vowel sound
/æ/	/ɑ/

Note. Classification of speech sounds from, Zemlin, W. (1998). *Speech and hearing science anatomy and physiology, fourth edition.* Boston: Allyn and Bacon.

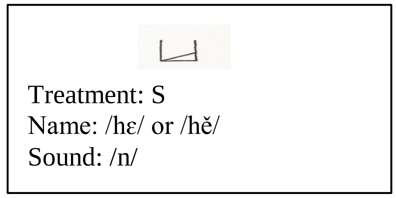
APPENDIX G

CARDS

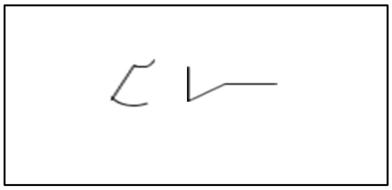
Front of Grapheme Card



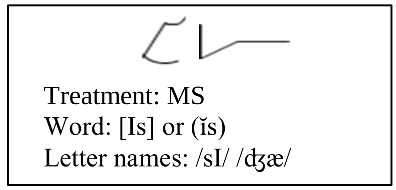
Back of Grapheme Card



Front of Word Card

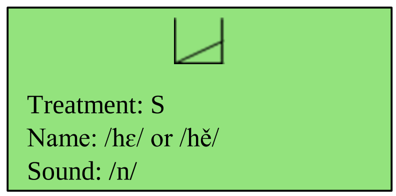


Back of Word Card



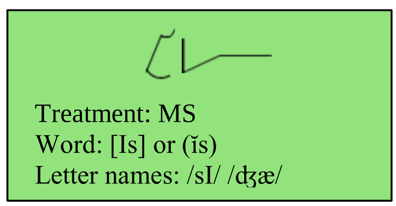
Front of Phoneme Card

Back of Phoneme Card



Front of Spelling Card

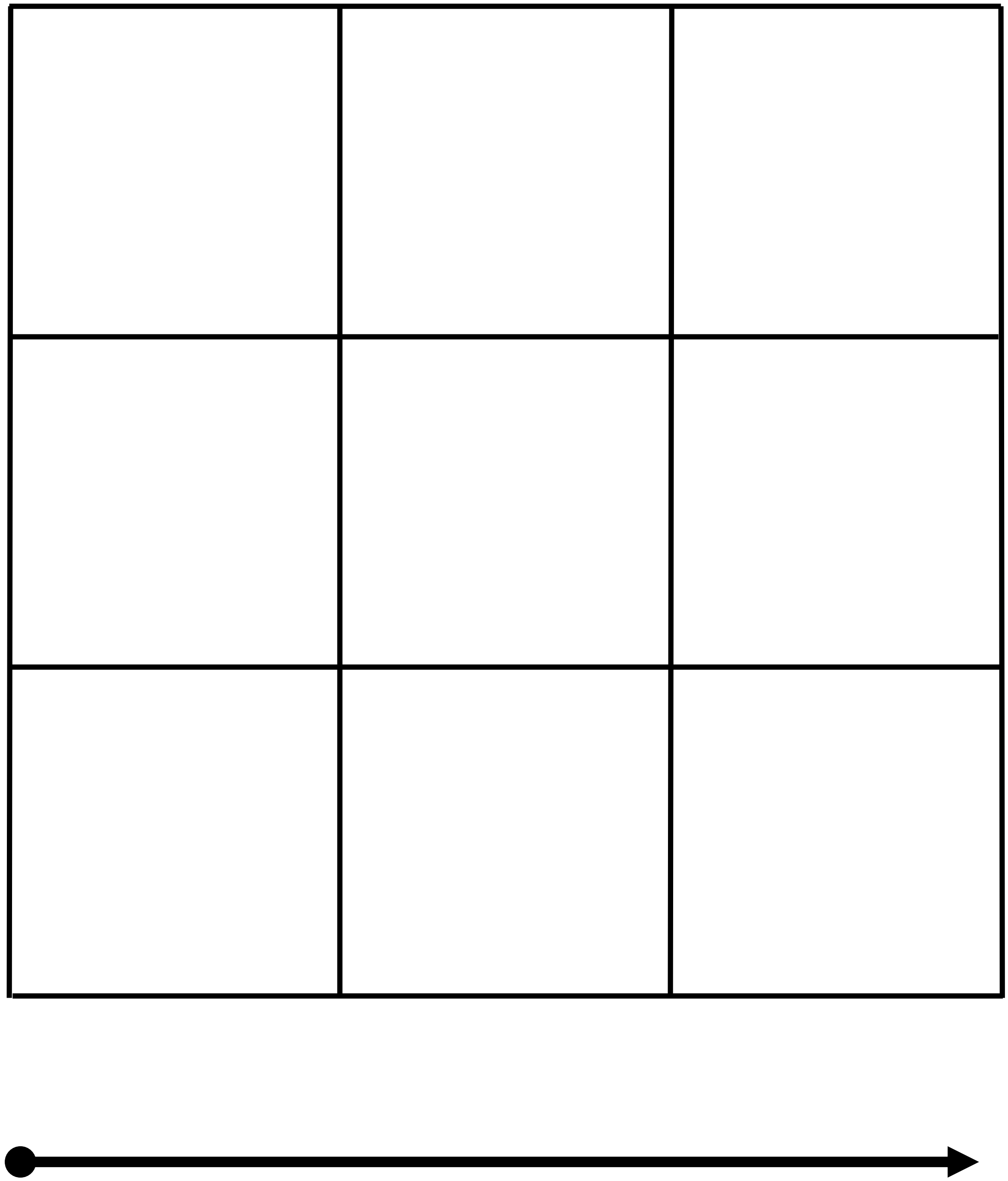
Back of Spelling Card



Note. S = Structured Language Intervention; MS = Multisensory Intervention. Cards were 4 x 6 inches for the structure language intervention and 3 x 5 inches for the multisensory intervention to make them easy to differentiate for interventionists. Graphemes were printed in black ink (approximately 1 x 1 inch). Words were coded phonetically and with common phonics symbols for interventionist use. Cards were based on the *Initial Reading Deck* and *Instant Spelling Deck* from Alphabetic Phonics (Cox, 1992).

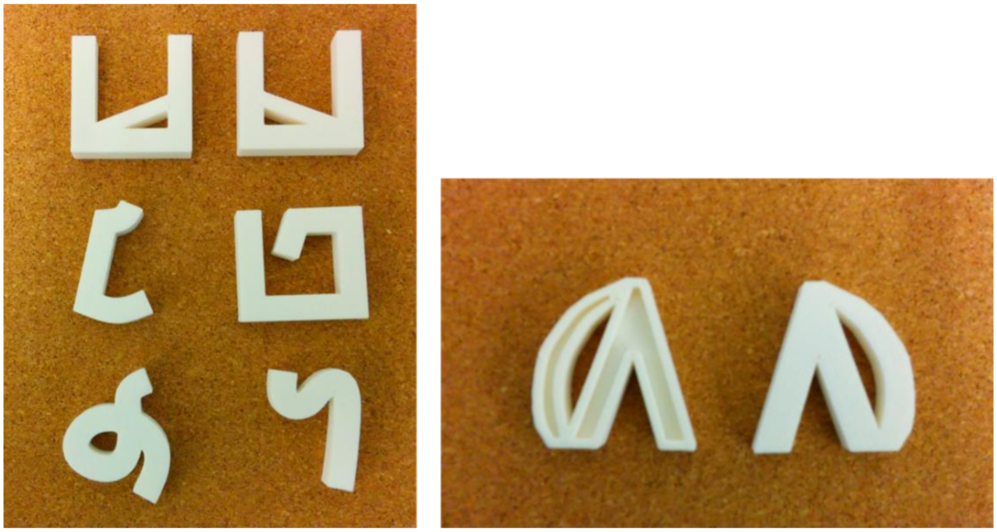
APPENDIX H

SPELLING MATRIX



APPENDIX I

3D GRAPHEMES



Note. Example of 3D plastic graphemes used in the multisensory intervention. The left picture depicts the front of the graphemes; the top two graphemes are mirror images. The picture on the right depicts the back and front of the graphemes. 3D = Three dimensional.