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THE FACTOR STRUCTURE OF VERBAL LEARNING AND MEMORY AND ITS RELATION TO TEXT READING COMPREHENSION IN CHILDREN WITH DEVELOPMENTAL DYSLEXIA

by

EMILY RIGGALL

Under the Direction of Robin Morris, PhD

ABSTRACT

Verbal learning and memory abilities support development of core language and academic skills, particularly reading (e.g., Kibby, 2009; Perez, Majerus, & Poncelet, 2012; Pham & Hasson, 2014; Roch, Florit, & Levorato, 2012). The California Verbal Learning Test, Children's Version (CVLT-C) is one of the most commonly used measures of verbal learning and memory among children (Delis, Kramer, Kaplan, & Ober, 1994). The CVLT-C's internal latent structure has been confirmed in the standardization sample and in many clinical groups (e.g., Carlew et al., 2018; Dejong & Donders, 2009; Griffiths et al., 2006), but remains unexamined among children with Developmental Dyslexia (DD). This is despite a well-

documented pattern of verbal learning and memory deficits in this population (Kramer, Knee, & Delis, 2000; Oyler, Obrzut, & Asbjornsen, 2012). This study investigated the internal structure of the CVLT-C in a sample of elementary school children with DD using confirmatory and exploratory factor analyses (CFA and EFA). It also explored the relationship between verbal learning and memory abilities and functional reading outcomes in these children with DD. Results did not confirm previously proposed models of CVLT-C factor structure. While EFA did not reveal an adequate alternative model, discrepancies between the best-fitting 3-factor model from the EFA and the previously proposed models provide insights into potential differences in verbal learning and memory strategies and performance patterns within this population. Correlational analyses highlighted a significant relationship between verbal learning and memory performance on the CVLT-C and passage comprehension, while word reading accuracy was not related. Present findings underscore the importance of understanding the internal structure of the CVLT-C within this vulnerable population. This is particularly important given the functional implications for interpreting the CVLT-C results and understanding the academic impacts of a child's verbal learning and memory profile.

INDEX WORDS: Verbal learning, Verbal memory, California Verbal Learning Test – Children's Version (CVLT-C), Developmental Dyslexia, Children, Factor analysis

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DEDICATION

This dissertation is dedicated to my husband, Alex Kinsey. You have unwaveringly supported me through it all. Thank you for all that you do. Here’s to our next adventures!

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1 INTRODUCTION

1.1 Verbal Learning & Memory Underlies Language and Reading Development

Verbal learning and memory are essential abilities that support development of core language and academic skills, particularly reading. Extensive evidence highlights that a child's ability to encode, store, and recall verbal information represents the foundation for language development across childhood (Cohen et al., 2000; Engel de Abreu, Gathercole, & Martin, 2011; Gathercole & Baddeley, 1989; Jarrold, Thorn, & Stephens, 2009; Montgomery, 2014). Verbal learning and memory has also been directly tied to reading skills across age groups and levels of complexity, including basic decoding (Kibby, 2009; Littlefield & Klein, 2005; Perez et al., 2012), spelling (Binamé & Poncelet, 2016), and higher-level reading fluency and passage comprehension (Pham & Hasson, 2014; Roch et al., 2012). It has also been proposed that this verbal learning – reading relationship may be reciprocal, such that improved reading abilities promote verbal short term memory performance (Demoulin & Kolinsky, 2016). Taken together, it is clear that a child's verbal learning and memory ability underlies and interacts with language and reading development across childhood.

One of the most common psychometric measures of verbal learning and memory abilities among children, the California Verbal Learning Test, Children's Version (CVLT-C), was developed to assess multiple components of verbal learning and memory (Delis, Kramer, Kaplan, & Ober, 1994). While the internal structure of this measure has been confirmed among the standardization sample as well as many clinical groups (e.g., Carlew et al., 2018; Dejong & Donders, 2009; Griffiths et al., 2006), it remains unexamined among children with Developmental Dyslexia (DD). This notable gap in the literature is particularly glaring given a well-documented pattern of verbal learning and memory deficits among children with DD

(Kramer et al., 2000; Oyler et al., 2012). Thus, this study aims to test the internal factor structure of the CVLT-C in this important population, and to explore the relation between these verbal learning and memory factors and reading comprehension abilities in elementary school-aged children with DD.

1.2 Overview of Verbal Learning & Memory

Defining verbal learning and memory and conceptualizing the core components encompassed therein have been the work of many researchers for decades (for review, see Malmberg, Raaijmakers, & Shiffrin, 2019). Theories of learning have been traditionally organized in terms of three primary components: encoding (i.e., learning), storage, and retrieval (i.e., recall and recognition) (e.g., Atkinson & Shiffrin, 1968; Craik & Lockhart, 1972; Healy & Mcnamara, 1996; Lockhart & Craik, 1990; Malmberg et al., 2019). Importantly, these core components of learning and memory are not considered to be modality-specific. In other words, in order to learn and remember information presented in any modality (i.e., auditory, visual, tactile, olfactory, gustatory), all of these processes are necessary (Malmberg et al., 2019). In the present study, verbal learning and memory occurs in the context of information presented in the auditory (i.e., oral list learning) or visual modality (i.e., reading). More specifically, auditory perception (for orally presented information) or visual perception (for textually presented information) are both considered modality-specific routes for the subsequent encoding, storage, and retrieval of verbal information (Malmberg et al., 2019). Therefore, because of our particular interest in the assessment of auditory-verbal learning and memory abilities, or disabilities, in children in developmental dyslexia, the following descriptions of verbal learning and memory processes primarily highlight the literature on the auditory route for specific encoding, storage,

and retrieval processes for verbal information, which involve language-related functions, including phonological processing and semantic knowledge.

1.3 History and Development of the California Verbal Learning Test

The California Verbal Learning Test (CVLT) is a standardized measure that has a long history of clinical and research use in documenting verbal learning and memory abilities and related deficits. This measure offers the opportunity to evaluate performance across many of the components and levels of verbal learning and memory, including multiple aspects of the encoding, storage, and retrieval processes. Administration of the CVLT consists of a word list learning and memory paradigm that was developed to capture all of the broad components of verbal learning (Delis, Kramer, Kaplan & Ober, 1987; Delis, Kramer, Kaplan, & Ober, 1994; Delis, Kramer, Kaplan, & Ober 2000; Malmberg et al., 2019).

Versions of the CVLT have been widely used to characterize list learning and memory of verbal information among a broad range of pediatric and adult populations, including in typical development (Beebe, Ris, & Dietrich, 2000; Donders, 1999; Donders, 2006, 2008; Shear, Wells, & Brock, 2000), as well as in patients with epilepsy (Griffiths et al., 2006; Hernandez et al., 2003; Williams et al., 2001), traumatic brain injury (TBI; Dejong & Donders, 2009, 2010; Donders & Minnema, 2004; Jacobs & Donders, 2007; Mottram & Donders, 2005; Salorio et al., 2005), dyslexia (Kramer et al., 2000; Oyler et al., 2012), trauma-exposure (Carlew et al., 2018), low birth weight (Taylor, Klein, Minich, & Hack, 2000), phenylketonuria (PKU; White, Nortz, Mandernach, Huntington, & Steiner, 2001), myelomeningocele (Yeates, Enrile, Loss, Blumenstein, & Delis, 1995), fetal alcohol syndrome (Lewis et al., 2015), and leukemia (Précourt et al., 2002), among others.

Contributing to its utility, the CVLT provides a multitude of theoretically founded and norm-referenced scores. First developed in 1987 (Delis, Kramer, Kaplan, & Ober), the original CVLT was established for an adult population with an age range of 16-89 years. However, concerns about the degree to which the standardization sample of the original CVLT was representative of national demographics prompted the development of the California Verbal Learning Test – Second Edition (CVLT-II; Delis, Kramer, Kaplan, & Ober 2000). This substantially revised version of the measure, which maintains the age range of 16-89 years, was normed on a more representative sample of adults. Additional component indices of learning and memory were modified or expanded in order to reflect specific underlying cognitive processes (Stricker, Brown, Wixted, Baldo, & Delis, 2002). For example, a trial that assessed level of effort and motivation on the test was added (Moore & Donders, 2004).

The children's version of this assessment, the California Verbal Learning Test – Children's Version (CVLT-C), was later developed and has an age range of 5-16 years (Delis, Kramer, Kaplan, & Ober, 1994). Like its adult counterpart, the CVLT-C offers rich information about verbal learning and memory abilities through norm-referenced quantitative and qualitative scores that are theoretically founded. The quantitative scores describe performance levels, such as the number of words that the child recalls or recognizes on a given trial compared with the standardization sample. Qualitative scores provide measures of process or strategy use, such as the percent of words that a child freely recalls that were from the beginning of the list, therefore suggesting a recency effect (described below).

Developmental changes are inherent in any study of cognitive ability among children. The CVLT-C addresses the broad implications of development by providing age-based norm-referenced z-scores for learning and memory performance in order to characterize a child's

performance in relation to that of same-aged peers (Delis, Kramer, Kaplan, & Ober, 1994). Thus, CVLT-C scores in this study control for typical developmental changes in verbal learning and memory performance across age groups. Notably, the present study only includes children enrolled in grades 3 and 4 (ages 8-11). Thus, performance is not expected to be significantly impacted by different stages of development.

1.4 CVLT-C Theoretical Framework and Structure

The CVLT-C is founded upon an evidence-based framework (Delis, Kramer, Kaplan, & Ober, 1994; Malmberg et al., 2019) that is broadly organized into the three primary components of learning and memory: encoding, storage, and retrieval. The structure of the CVLT-C and the scores generated by the measure were designed to evaluate and reflect multiple aspects of each of these processes. Table 1 presents the scores that represent the key elements of verbal learning and memory theories and that are included in the present study.

Table 1
Descriptions of California Verbal Learning Test-Children's Version (CVLT-C) scores of interest in the present study

Score	Description
List A – Trial 1	Number of words the child is able to freely recall after the first presentation (learning trial) of List A.
List A – Trial 5	Number of words the child is able to freely recall after the fifth presentation (learning trial) of List A.
List B	Number of words the child is able to freely recall from an interference word list, List B, which is presented once.
Short Delay, Free Recall	Number of words from List A that the child is able to freely recall after a short delay during which List B is presented.
Short Delay, Cued Recall	Number of words from List A that the child is able to recall with semantic cues after a short delay during which List B is presented.
Long Delay, Free Recall	Number of words from List A that the child is able to freely recall after a delay of approximately 20 minutes.

Long Delay, Cued Recall	Number of words from List A that the child is able to recall with semantic cues after a delay of approximately 20 minutes.
Semantic Clustering	Number of words from List A recalled across learning trials that are grouped by semantic category.
Middle	Percent of all recalled words across learning trials that represent the middle third of List A.
Recall Consistency	Number of words from List A recalled consistently across learning trials.
Intrusions	Number of incorrect words recalled during learning trials (i.e., not members of List A).
Recognition Hits	Number of words from a list of targets and distractors that are correctly identified as members of List A.
Recognition False Positives	Number of words from a list of targets and distractors that are incorrectly identified as members of List A.

1.4.1 Encoding and rehearsal

During the encoding stage of learning, in which learners are presented with novel information to recall, they typically utilize rehearsal strategies that serve two primary functions: maintenance (encoding and storage of shallower information about the physical form of the stimulus) and coding (encoding and storage of the deeper semantic meaning of the information) (Malmberg et al., 2019). Substantial evidence has shown that the strength of learning is closely related to the depth of stimulus processing (Craik & Lockhart, 1972; Lockhart & Craik, 1990; Malmberg et al., 2019; Malmberg & Shiffrin, 2005). Specifically, more elaborative, meaningful rehearsal, characterized by the learner processing the material's semantic meaning and connecting it with larger concepts, is associated with stronger learning. In other words, associating the new information with semantic meaning (i.e., elaborative rehearsal or semantic coding), rather than merely rehearsing the physical form of the verbal information (i.e.,

maintenance rehearsal or shallow processing), predicts stronger encoding and more accurate subsequent recall of verbal information (Lockhart & Craik, 1990; Malmberg et al., 2019). This enduring theory of rehearsal impacting encoding was demonstrated in a recent study when healthy adults were asked to identify whether previously presented words matched a given category (Rudner, Karlsson, Gunnarsson, & Rönnberg, 2013). Participants showed poorer and slower recall performance for words that were encoded in phonological and orthographic conditions, reflecting shallower processing, than for those encoded in the semantic encoding condition. Across development, the most notable changes in verbal learning and memory processes occur with regard to semantic comprehension and associated rehearsal strategy use (e.g., Delis, Kramer, Kaplan, & Ober, 1994; Meijs, Hurks, Wassenberg, Feron, & Jolles, 2016). For example, in a recent study of how presentation modality impacts verbal learning in children ages 5 to 16, researchers found pictures were preferentially recalled over oral and textual presentations of information that was presented only once (Meijs et al., 2016). This study also found that this effect emerges at approximately age 7 and increases with age. Taken together, it appears that when semantic meaning was visually presented, thus not requiring a child to independently produce or recall the word presented orally or in text, the child was more easily able to deeply encode and subsequently recall the word. This mechanism relating to the ease of semantic imaging supporting depth of encoding and recall is also supported by findings suggesting children learn, recall, and use words with high iconicity, or correspondence between the word’s form or sound and meaning (Perry, Perlman, Winter, Massaro, & Lupyan, 2017).

The CVLT-C standardization sample shows a parallel pattern of increasing spontaneous use of a semantic clustering strategy with age (Delis, Kramer, Kaplan, & Ober, 1994). Specifically, the authors found that older children (i.e., starting at approximately age 9) were

more likely to independently use semantic clustering strategies for encoding and recall, whereas younger children tended to rely on less efficient and more shallow serial clustering strategies. Therefore, it is important from a developmental theoretical framework that use of rehearsal strategy and strength of encoding is evaluated by the CVLT-C. The degree to which the child organizes recalled words by semantic category is conceptualized as a reflection of her semantic organization resulting from both semantic encoding and rehearsal strategies. Of note, the present study only includes children enrolled in grades 3 and 4 (ages 8-11 years), thus a limited age span. Therefore, differences in encoding strategy use are not expected to be significantly impacted by age or developmental stage, although other factors may impact it.

In addition to developmental considerations, rehearsal strategy use is not uniform across a learning trial. Rather, rehearsal strategy mechanisms predict the strength of encoding for each unique piece of information. Rehearsal strategy use is impacted by the attentional capacity of the learner as well as the amount of information presented over a given time period. The serial position effect is a widely demonstrated phenomenon that arises from these factors during list learning (Bauer & Emhert, 1984; Healy & Mcnamara, 1996; Morrison, Conway, & Chein, 2014). In this effect, words at the beginning and end of a list are most likely to be recalled. The primacy effect, that there is improved recall of words at the beginning of the list, is explained by the increased opportunity for both maintenance and elaborative rehearsal during the learning period (e.g., Capitani, Della Sala, Logie, & Spinnler, 1992; Healy & Mcnamara, 1996; Li, 2010). The recency effect, on the other hand, an improved recall of words at the end of the list, is accounted for by short-term storage of physical aspects of the words (i.e., maintenance of phonological features) due to the limited time available for their rehearsal (Bhatarah, Ward, &

Tan, 2006; Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Davelaar, Haarmann, Goshen-Gottstein, & Usher, 2006; Howard & Kahana, 1999).

On the CVLT-C, encoding and rehearsal strategies are described by both quantitative and qualitative performance scores (Delis, Kramer, Kaplan, & Ober, 1994). Across the word list learning trials, quantitative performance scores reflect the number of words encoded and immediately recalled by the learner. Qualitative performance scores provide more information about serial position effects, which are thought to reflect attentional capacity. For example, serial position effects are captured by qualitative scores describing the percent of recalled words that originate at the beginning, middle, or end of the original word list.

1.4.2 Memory storage

Memory is frequently conceptualized as information that includes attributes about the information item itself, as well as inter-item information, and context or time-linked information that is stored over a particular period of time (Malmberg et al., 2019; Raaijmakers & Shiffrin, 1980). Memory storage components are traditionally subdivided into temporary short-term memory and relatively permanent long-term memory (Malmberg et al., 2019). Short-term memory is further separated into “sensory registers” and longer lasting “short-term store,” which encompasses active rehearsal and the ability for short-term recall of the information. Of note, much research has pitted theories of working memory (e.g., Baddeley, 2010, Baddeley & Hitch, 1974) against this conceptualization of “short-term store” or short-term memory (e.g., Atkinson & Shiffrin, 1968; Malmberg et al., 2019). However, it has been suggested that these variations reflect different perspectives rather than a functional distinction (Malmberg et al., 2019). Indeed, overt similarities exist between traditional conceptualizations of the audio-verbal-linguistic store (Atkinson & Shiffrin, 1968; Malmberg et al., 2019) and the phonological loop (Baddeley, 2010,

Baddeley & Hitch, 1974). The similarity between the active rehearsal processes and the central executive loop can be considered equally evident, in that both reflect a learner's ability to organize and strategically encode information. These substantial overlaps, despite slightly different theoretical foundations, make it difficult to empirically distinguish between these two frameworks (Malmberg et al., 2019). Regardless of perspective, the distinction highlighted between short-term store (or working memory) and long-term store has been widely supported by cognitive, neurocomputational and neuroimaging studies (e.g., Davelaar et al., 2006; Salorio et al., 2005; Vakil, Blachstein, Wertman-Elad, & Greenstein, 2012).

Unfortunately, it is impossible to directly assess memory storage (Davelaar et al., 2005). Rather, strength and organization of memory storage is indirectly evaluated through immediate, short-term, and long-term recall and recognition trials. That being said, the structure of the CVLT-C reflects the conceptual distinction between short-term store and long-term storage with the inclusion of both short delayed recall and long delayed recall assessment components (Delis, Kramer, Kaplan, & Ober, 1994).

1.4.3 Memory retrieval

Retrieval, or recall, of verbal information requires an individual to search for and recover memories from storage based upon semantic and feature networks organized by various characteristics of the stored words (Malmberg et al., 2019; Raaijmakers & Shiffrin, 1980). According to this conceptualization, memories are retrieved most efficiently if they were initially encoded and stored based on larger semantic networks (i.e., through deeper semantic encoding and rehearsal). Indeed, accurate and efficient retrieval of verbal information from long-term memory has been directly linked to semantic rehearsal processes in terms of both behavioral and neuroimaging findings (e.g., Polyn & Kahana, 2007; Rudner et al., 2013).

On the CVLT-C, participants are asked to freely recall words from the target list after both short and long delays, without the support of any semantic cues (Delis, Kramer, Kaplan, & Ober, 1994). In order to evaluate semantic category comprehension and use in word encoding, storage, and retrieval, the measure also asks the child to recall words in each word category following a semantic cue. Thus, the CVLT-C allows for investigation of whether the child is able to independently recall words from the list, which could suggest effective encoding, storage, and retrieval processing based on semantic networks, or if she additionally benefits from provision of semantic cues in recalling information.

The final component of memory retrieval, recognition, has been hotly debated over the years (for review, see Malmberg et al., 2019). Recognition memory performance is broadly considered to reflect the degree to which a particular stimulus produces a sense of familiarity (Cox & Shiffrin, 2017; Malmberg, Holden, & Shiffrin, 2004). In other words, recognition paradigms circumvent the need for the individual to independently search for and recall information freely or with the assistance of semantic cues. Rather, recognition memory models assume that features of each stored item, such as a word from a word list, including its context, phonological features, semantic meaning, and temporal information, are compared to traces of other previously stored information to produce a value of familiarity (Cox & Shiffrin, 2017). Thus, recognition memory performance is thought to reflect aspects of the encoding and storage processes with a lower demand for independent search and recall of memory traces across storage networks.

The CVLT-C recognition trial asks the child to identify original target words among distractor words (Delis, Kramer, Kaplan, & Ober, 1994). Two quantitative performance scores are generated from this portion of the measure. The first, recognition hits, reflects the number of

words that the child accurately identifies as members of the original target word list. The second, recognition false positives, is a norm-based score indicating how many words the child incorrectly identified as a target word. Consistent with the theoretical framework, this task taps a child's ability to retrieve words without independently searching for or recalling the information.

In summary, the theoretical construct of verbal learning and memory represents a large umbrella that encompasses many different processes including encoding, short- and long-term storage, and retrieval. Importantly, each of these learning and memory processes necessarily requires multiple cognitive skills including attention, vocabulary knowledge, and executive functioning, among others. In this study, verbal learning and memory is intentionally used to describe this high-level, integration of cognitive components in order to gain the most holistic and comprehensive understanding of verbal learning and memory performance and its relationship with higher-level reading outcomes.

1.5 Underlying Factor Structure of the CVLT

The CVLT-II and CVLT-C have been extensively used in research and clinical contexts to characterize verbal learning abilities of adults and children with a wide range of clinical conditions. Recent research has confirmed that the internal structure of this ubiquitous measure aligns well with its theoretically derived foundations, but also has shown that this structure may vary across clinical populations. Early studies of the CVLT internal factor structure (i.e., how the theoretically-derived performance scores interrelate systematically and reflect larger constructs) highlighted the importance of confirming the internal structure of the measure among clinical populations (Donders, 1999). However, subsequent studies have found varying results that suggest the CVLT structure may best be described by different factor structures in different

clinical groups (e.g., Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b; Griffiths et al., 2006; Mottram & Donders, 2005).

A foundational study by Donders (1999) examined the construct validity and clarified the internal structure of CVLT-C within the standardization sample by proposing and evaluating six hypothetical models representing alternate statistical and theoretical models of verbal learning and memory. This study selected 13 qualitative and quantitative variables from the CVLT-C, which were identified based on theoretical, clinical, and practical criteria. Specifically, variables were chosen that avoided interdependency, used z-scores (in order to allow for comparison across scores and to control for age-related variation in performance), and had satisfactory distribution characteristics. For example, z-scores for the semantic clustering variable and serial clustering variable are moderately inversely related (Donders, 1999). Therefore, the authors only included semantic clustering scores in order to reflect higher-level learning efficiency. Maximum-likelihood confirmatory factor analyses were then applied to these key variables to evaluate which of the six models best described verbal learning and memory performance among the standardization sample as measured by the CVLT-C.

1.6 Description of Proposed Models and Support for Each

Donders (1999) evaluated six proposed factor models, described in more detail below, that reflect somewhat different conceptualizations of learning and memory based upon his review of the literature, as well as the theoretically distinct components of learning and memory (i.e., aspects of encoding, storage, retrieval) suggested by the CVLT-C format, which itself was founded in theory.

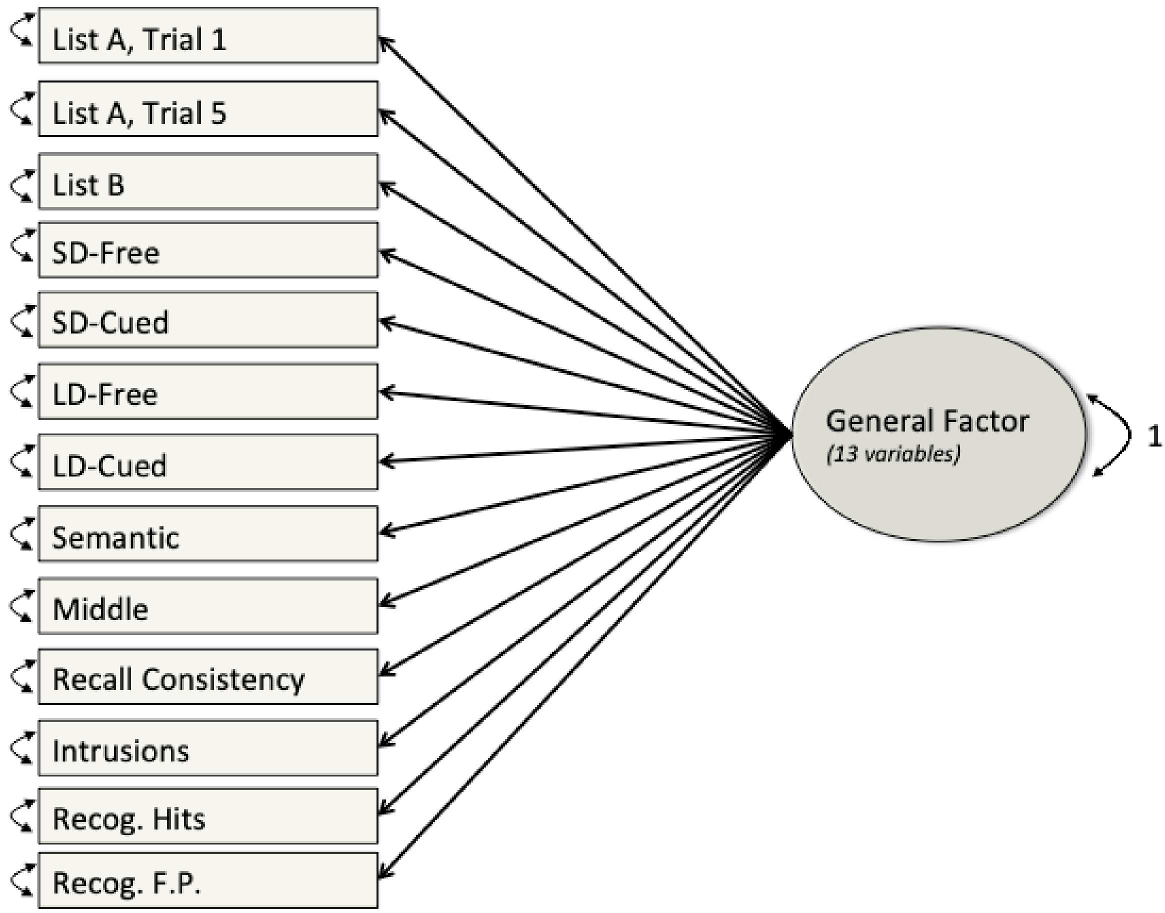

Figure 1. General factor model of verbal learning and memory (Model 1).

1.6.1 Model 1: General factor

Model 1 is a one-factor model that tested the hypothesis that all aspects of verbal learning and memory measured by the CVLT-C, including learning, delayed recall, and recognition could be accounted for by a general factor (Donders, 1999). This most conservative representation primarily functioned as a null-hypothesis, rather than being founded upon any specific learning theory or other empirical findings. In other words, this general factor model was intended to test whether all learning and memory scores from the CVLT-C represent a single, unified construct.

Unsurprisingly, given that this hypothesis is unsupported from a theoretical standpoint, it did not fit the verbal learning and memory data in the original CVLT-C standardization sample (Donders, 1999), and has not found support in subsequent studies across multiple clinical

populations (Carlew et al., 2018; Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b; Griffiths et al., 2006; Mottram & Donders, 2005).

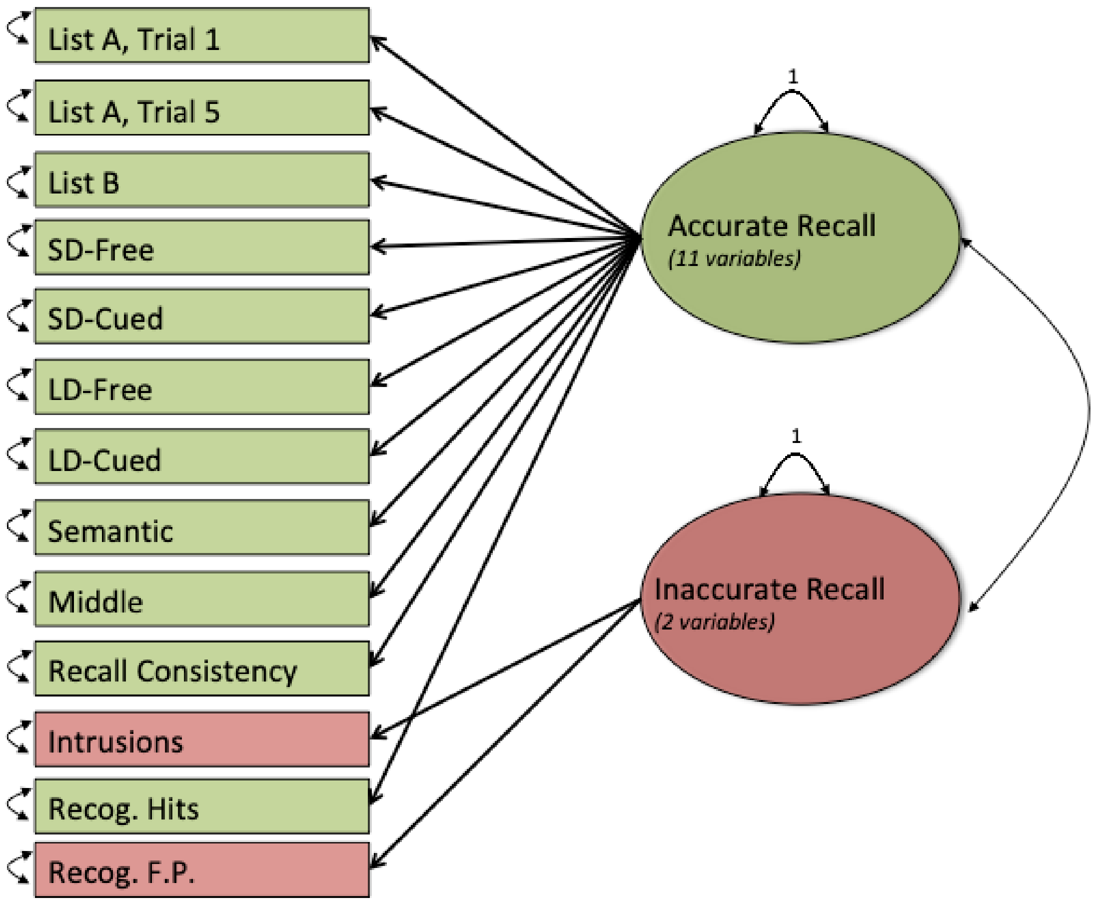

Figure 2. *Two-factor model of verbal learning and memory (Model 2).*

1.6.2 Model 2: Two-factor model

Model 2 is a two-factor model that hypothesizes verbal learning and memory performance can be explained by Accurate Recall (11 variables) and Inaccurate Recall (2 variables) constructs. A statistical and theoretical improvement on Model 1, this conceptualization distinguishes between two latent factors that are theoretically negatively correlated. Specifically, Inaccurate Recall includes the number of intrusion errors made during the free and cued recall trials, and the number of false positive errors made during the recognition trial. These errors have been shown to negatively correlate with successful

performance on the CVLT-C (Roman et al., 2002; Yeates et al., 1995). More recent factor analysis has suggested that the inclusion of a distinct Inaccurate Recall factor significantly improves CVLT-II model fit among adults with epilepsy (Banos et al., 2004).

However, this dichotomy on its own has not been theoretically or empirically supported in describing overall verbal learning and memory performance. It failed to fit the original CVLT-C standardization sample (Donders, 1999) and has not been found to effectively explain verbal learning and memory in subsequent studies of clinical populations (Carlew et al., 2018; Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b; Griffiths et al., 2006; Mottram & Donders, 2005). Thus, Model 2 primarily represents a statistically-based model under which Model 1 is nested.

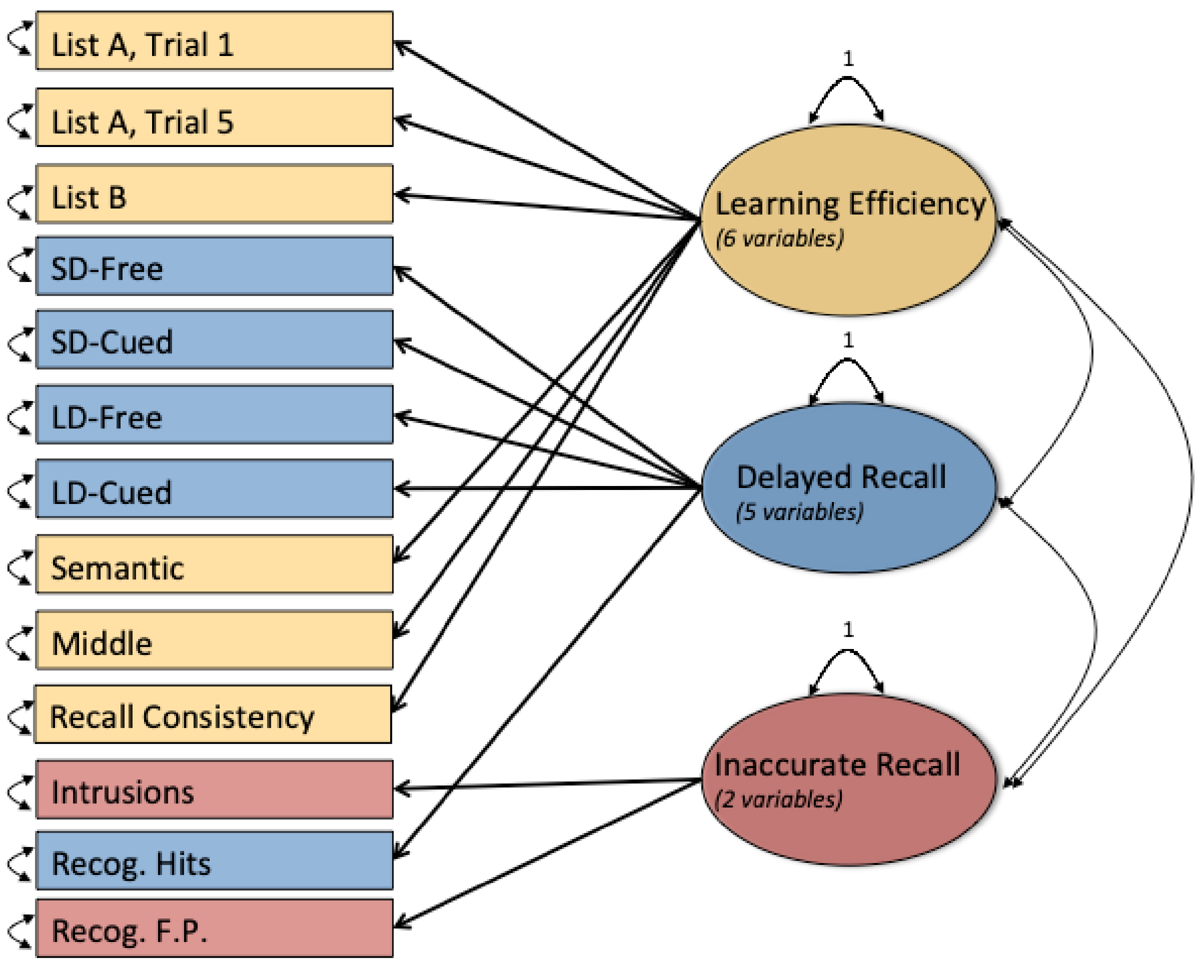

Figure 3 Three-factor model of verbal learning and memory (Model 3).

1.6.3 Model 3: Three-factor model

Model 3 is a three-factor model hypothesizing CVLT-C performance can be accounted for by Learning Efficiency (6 variables), Delayed Recall (5 variables) and Inaccurate Recall (2 variables). While it is primarily a statistically-based model under which Models 2 and 3 are nested, Model 3 also reflects theoretical (Atkinson & Shriffin, 1968; Malmberg et al., 2019) and empirical findings that suggest a distinction between learning and delayed memory performance among healthy adults (Burton, Mittenberg, & Burton, 1993), adults with epilepsy (Banos et al., 2004), and child clinical samples (Burton, Mittenberg, Gold, & Drabman, 1999). Additionally, the CVLT-C manual suggests certain qualitative characteristics of participant's performance across learning trials (i.e., Learning Efficiency) are likely to result in better memory performance over successive trials (Delis, Kramer, Kaplan, & Ober, 1994). This distinction of learning efficiency is supported by findings among children with TBI showing that increased organization processing strategies, observed in terms of recall consistency and semantic organization, are associated with better overall learning (Delis, Kramer, Kaplan, & Ober, 1994).

Despite the improved theoretical and empirical evidence supporting it, this model was not found to be a good fit for learning and memory performance among the CVLT-C standardization sample (Donders, 1999) nor in subsequent research on clinical populations (Carlew et al., 2018; Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b; Griffiths et al., 2006; Mottram & Donders, 2005).

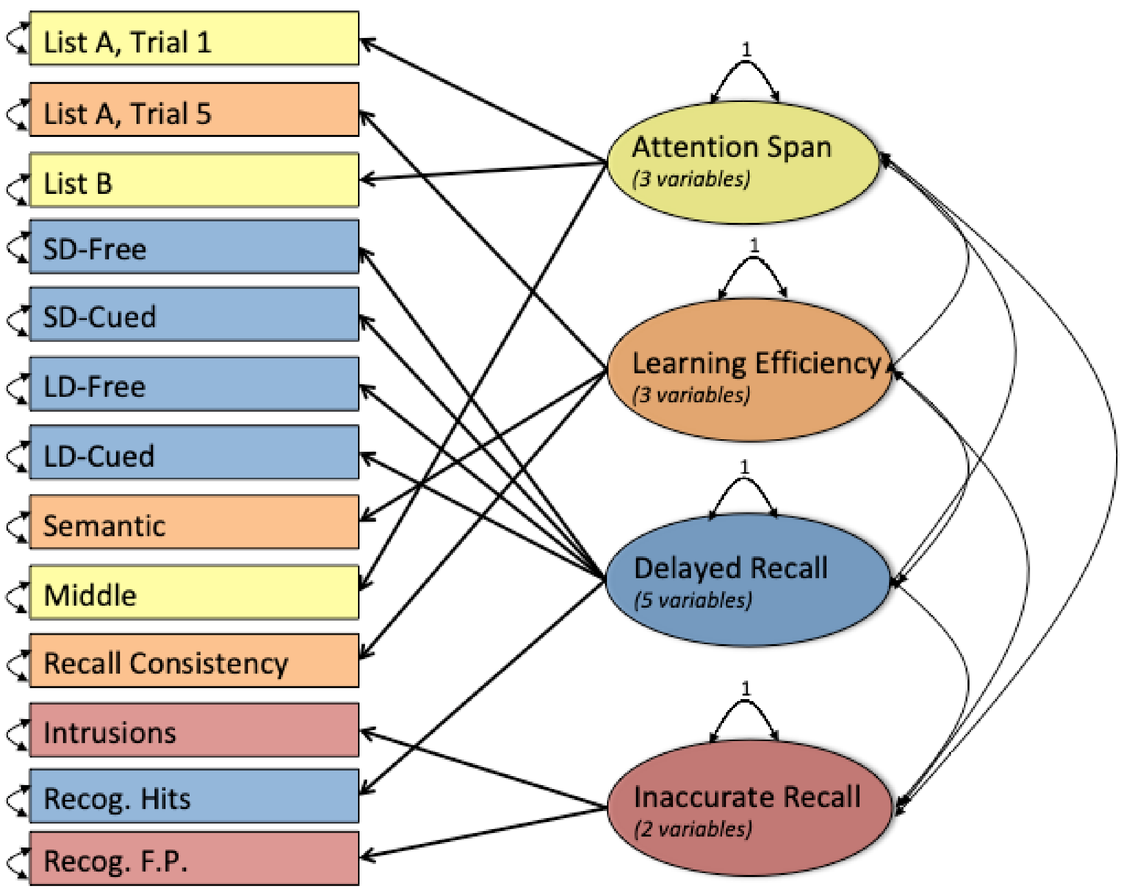

Figure 4 Four-factor model of verbal learning and memory (Model 4).

1.6.4 Model 4: Four-factor model

Model 4 is a four-factor model that hypothesizes CVLT-C performance can be represented by the three factors from Model 3 and the addition of an attention factor (which arises from, and is differentiated from, the learning efficiency factor in Model 3) is consistent with long-standing theoretical foundations (e.g., Broadbent, 1957; Treisman, 1964), findings from other verbal learning and memory studies both in child and adult standardization samples (Burton et al., 1993; Burton, Donders, & Mittenberg, 1996), as well as in child clinical samples (Burton et al., 1999). Importantly, this distinction was found to substantially improve CVLT-II model fit in adults with epilepsy (Banos et al., 2004). The attention construct is hypothesized to

consist of quantitative scores, including immediate recall of words presented only once, as well as qualitative scores, including the number of words recalled from the middle of the list.

While Model 4 was not the best fit of the proposed models within the CVLT-C standardization sample, it did meet the a priori specified minimum criteria for potential acceptability (Donders, 1999). That being said, the model was the best fit in samples of pediatric TBI (Mottram & Donders, 2005), as well as adult TBI (Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b), and trauma-exposed adults (Carlew et al., 2018). Taken together, Model 4 has theoretical as well as empirical support among both pediatric and adult samples. Importantly, these findings provide evidence that different internal structures of verbal learning and memory performance may fit particular clinical populations better than others.

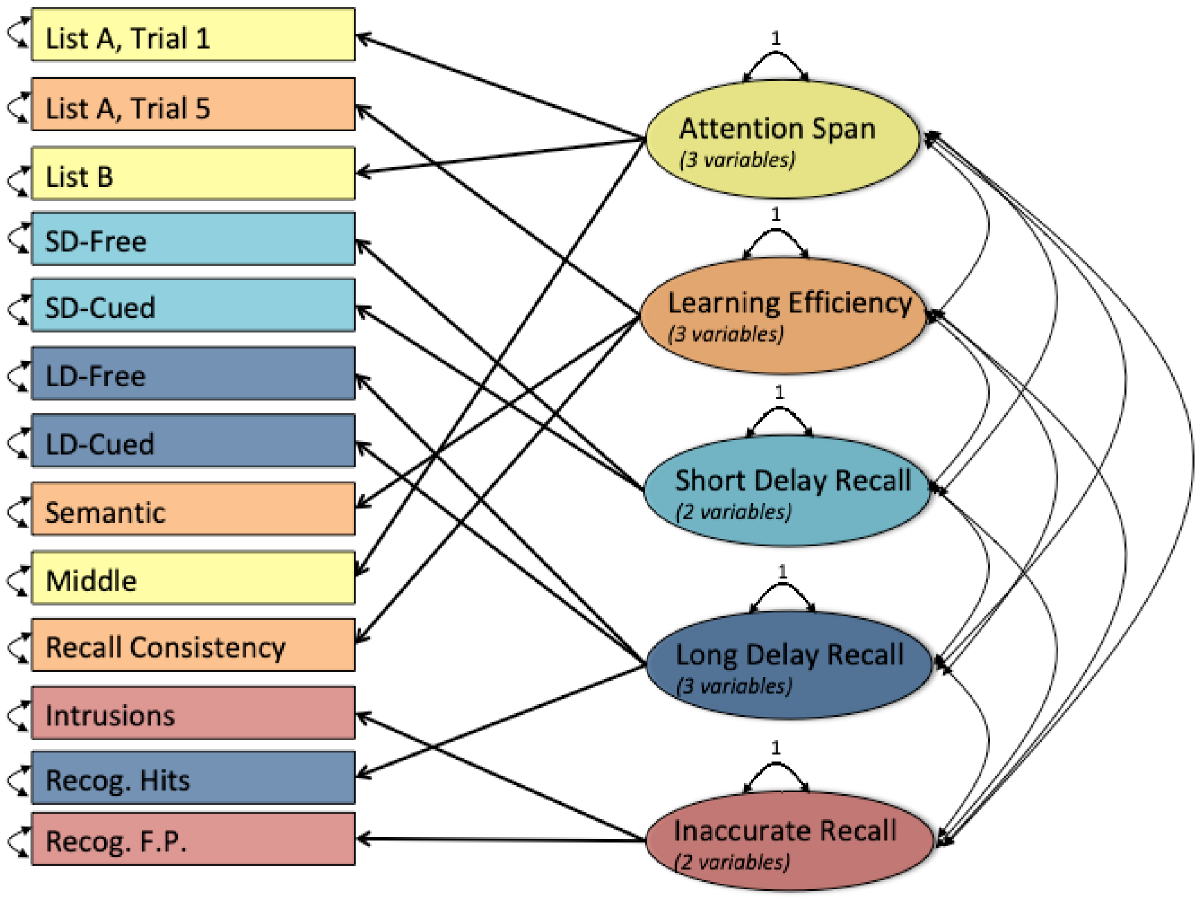

Figure 5. *Five-factor model of verbal learning and memory that conceptualizes delayed memory as a dichotomy between short and long delays (Model 5).*

1.6.5 Model 5: Five-factor model (dividing short/long delay)

Model 5 is a five-factor model that differentiates between delayed recall variables (short- and long-delayed recall) but otherwise maintains all factors from Model 4 (i.e. Attention, Learning Efficiency, and Inaccurate Recall). This distinction between short- and long- delayed recall reflects the theoretical framework originally proposed by Atkinson and Shriffin (1968), as well as substantial recent empirical evidence that suggests discrepant recall in short-term versus long-term performances (for review, see Malmberg et al., 2019).

While this model met a priori specified minimum criteria for potential acceptability, and the addition of the 5th factor indicated a significant increase in predictive validity over the 4-

factor model (Model 4), it was still not the best fit for the CVLT-C standardization sample data (Donders, 1999). Further, it has not been supported by subsequent research in standardization or clinical populations (Carlew et al., 2018; Dejong & Donders, 2009, 2010; Donders, 2008a, 2008b; Griffiths et al., 2006; Mottram & Donders, 2005).

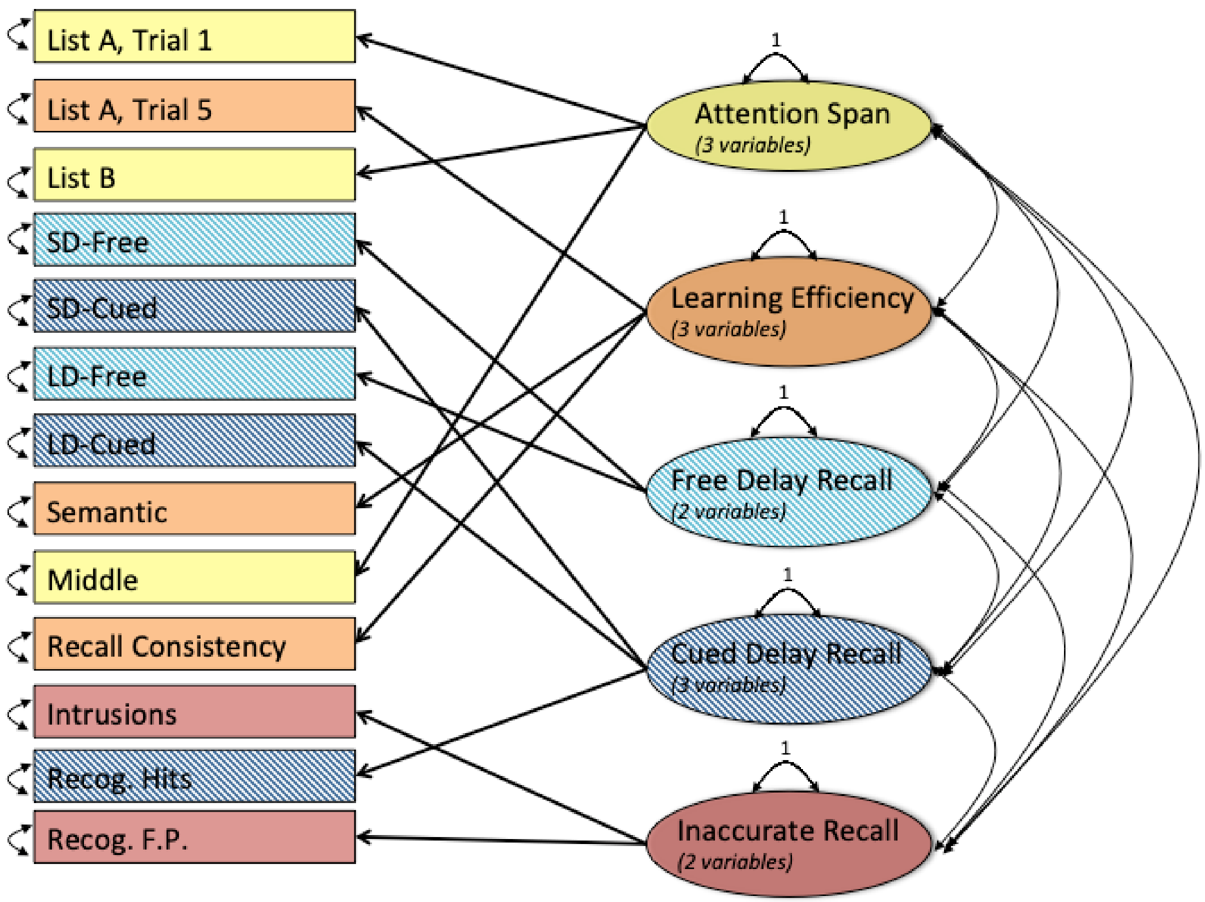

Figure 6. *Five-factor model of verbal learning and memory that conceptualizes delayed memory as a dichotomy between free and cued recall performance (Model 6).*

1.6.1 Model 6: Five-factor model (dividing free/cued recall)

Model 6 is also a five-factor model. It is the same as Model 4 except that it hypothesizes that delayed recall is separated into free delayed recall and cued delayed recall components. From a theoretical standpoint, this model reflects the framework that deeper encoding (i.e., rehearsal of semantic information) will lead to both more effective storage and retrieval of verbal

information (Malmberg et al., 2019; Rudner et al., 2013). Empirical evidence also suggests semantic retrieval cues support subsequent organization and recall of word lists (Shear et al., 2000).

This model was found to be the best fit of all proposed models among the CVLT-C standardization sample (Donders, 1999) as well as within a sample of children with epilepsy (Griffiths et al., 2006). In the CVLT-C standardization sample, all factor indications were statistically significant (Donders, 1999). Several interesting features of this model and these results should be noted. First, consistent with expectations, Inaccurate Recall was negatively correlated with all other factors (Roman et al., 2002; Yeates et al., 1995). Second, Learning Efficiency was strongly correlated with Free Delayed Recall, which is in line with verbal learning and memory theory that suggests the elaborative rehearsal strategy use leads to stronger overall memory performance (Malmberg et al., 2019; Rudner et al., 2013). Third, while the results indicate verbal delayed recall is better described by a distinction between Free and Cued recall, these factors were noted to share approximately 90% of common variance. This finding is again consistent with early conceptualizations of strength of verbal learning and memory performance being fundamentally supported by depth of encoding.

1.7 Verbal Learning & Memory and Language Development

Verbal learning and memory abilities form the foundation for expressive and receptive language development. At the fundamental level, children's performance on verbal short-term memory tasks is strongly related to their ability to learn phonological forms of novel vocabulary words (Jarrold et al., 2009). In fact, one longitudinal study of pre-reading children revealed that short-term memory for phonemes, or word sounds, accounted for significant variance in vocabulary scores at age 5, over and above children's vocabulary knowledge the previous year,

as well as the children's age and non-verbal intelligence (Gathercole & Baddeley, 1989). Just as verbal learning and memory underlies vocabulary development, it also has been shown to relate to broader expressive language abilities (Cohen et al., 2000). Children appear to rely upon their phonological memory and verbal short-term memory to grow their vocabulary stores in terms of learning and remembering novel word forms as well as in terms of gaining semantic knowledge.

Given the link between phonological short-term memory and vocabulary development, it is not surprising that verbal learning and memory is also related to vocabulary knowledge. In a cross-sectional study, verbal short-term storage among typically developing kindergarteners was strongly related to vocabulary scores (Engel de Abreu et al., 2011). Similarly, children's receptive vocabulary skills have been shown to correlate with verbal short-term memory, such that children with higher receptive vocabulary knowledge performed better on measures of verbal working memory (Montgomery, 2014). In particular, children with language impairment and those matched for receptive vocabulary abilities who were typically developing, but younger chronological ages, exhibited equivalent verbal short-term memory difficulties compared with age-matched, typically developing children. This pattern of vocabulary development, rather than chronological age, corresponding to verbal short-term memory abilities highlights the relationship across childhood. Taken together, learning and memory for words and word sounds is critical for and strongly related to vocabulary development as well as to more complex language functioning.

1.8 Verbal Learning & Memory and Broad Reading Outcomes

Not surprisingly, given its strong relationship to language development, verbal learning and memory abilities are also highly related to successful reading outcomes at multiple levels: from simpler decoding and spelling to more complex reading fluency and text comprehension. In

particular, verbal learning and memory has been repeatedly shown to strongly relate to foundational reading skills, including phonological awareness, word form learning, semantic learning, decoding, and spelling. For example, short-term memory for phonological information (i.e., non-word repetition) in children aged 9-13 years was moderately to strongly correlated with word identification and non-word decoding, and semantic short-term memory was also correlated (Kibby, 2009). Non-word decoding in first graders was predicted by their kindergarten verbal short-term memory for word list order (Perez et al., 2012). Similarly, verbal short-term memory for order was found to be predictive of non-word decoding and spelling abilities both one and two years later, in first and second grade (Binamé & Poncelet, 2016)**.** Finally, word recall ability was the best predictor of single-word reading performance among 10 year olds with DD and typically developing readers in a study of visual and verbal short-term memory (Littlefield & Klein, 2005). Taken together, verbal learning and memory is associated with both concurrent decoding skills as well as decoding and spelling abilities years later.

In addition to its clear association with basic facets of reading, verbal learning and memory abilities have also been linked directly to higher-level reading outcomes. Verbal learning abilities among children aged 9-12 years have been found to be associated with both reading fluency and comprehension performance (Pham & Hasson, 2014). Specifically, reading fluency, which captures the speed and accuracy with which a child can read and comprehend sentences, was predicted strongly by verbal short-term memory for semantically organized word lists among typically developing children. This relation also exists within more clinically diverse populations. For example, when children who were typically developing and those with Down syndrome were matched by reading comprehension performance, they exhibited equivalent verbal learning and memory capacity for lists of orally or visually presented words (Roch et al.,

2012). Further, among typically developing children, reading comprehension performance was found to be comparable to listening comprehension for short stories. In other words, the ability to read and analyze text was associated with the ability to learn, remember, and interpret orally presented complex verbal information. These findings highlight that the complex cognitive processes involved in verbal learning and memory are also associated with higher-level reading abilities beyond phonology and single word decoding.

Taken together, substantial empirical evidence has illustrated the multi-level relationship between verbal learning and memory and reading outcomes. Moreover, the close link between this complex cognitive ability and reading performance across levels of complexity (from the most basic phonological awareness and decoding to higher-level text reading comprehension) has been repeatedly demonstrated in clinical and typically developing populations, in both cross-sectional as well as longitudinal studies.

Interestingly, recent research has also offered a compelling argument for the possibility that this association between verbal learning and memory and reading outcomes may be more reciprocal. Demoulin and Kolinsky (2016) proposed the converse hypothesis: learning to read influences and shapes the development of verbal learning and memory abilities. Specifically, they argue that the process of learning to decode words supports the development of subvocal rehearsal, which in turn strengthens memory for serial order of phonemes and words. Additionally, they suggest that the mastery of the alphabetic system promotes or allows for increased phonological awareness as well as phonemic and orthographic representations of sounds and words. Their research provides a compelling theory for the strong reciprocal association between these high-level cognitive skills.

1.9 Importance of Studying Reading Outcomes

With prevalence rates of DD ranging from 6 to 17% of school-aged children (Fletcher et al., 2007, p. 105), as well as the larger context of a majority of elementary school students in the United States demonstrating below-grade level reading achievement (NAEP, 2017), it is clear that accurate and effective assessment, characterization, and intervention development for underachievement in reading is a critical issue. Given the extensive association of verbal learning and memory with broad reading outcomes from the most basic to most complex, evaluation of these abilities is an important component of assessments that support educational planning and reading intervention development. Accurate understanding of the constructs assessed and the interpretation of standardized measures are critical to achieve these goals. According to Howes, Bigler, Lawson, and Burlingame (1999), understanding learning and memory processes in children with DD is valuable for both clinicians and educators.

1.10 Verbal Learning & Memory Deficits among Individuals with DD

Deficits in verbal learning and memory have been widely documented among children who meet criteria for Developmental Dyslexia (DD; Kramer et al., 2000; Oyler et al., 2012). DD is defined by "difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction" (definition from the International Dyslexia Association; Lyon, Shaywitz, & Shaywitz, 2003). Given the well-documented relation between verbal learning and memory abilities and reading outcomes, it is perhaps unsurprising that children with DD demonstrate verbal learning and memory weaknesses, including memory for

letters, words, digits, and sentences (O'Shaughnessy & Swanson, 1998; Swanson, Cooney & McNamara 2004; Swanson, Kehler, & Jerman, 2010; Swanson, Zheng, & Jerman, 2009).

In fact, a reliable profile of verbal learning and memory for word lists has been observed among children with DD. Two studies systematically compared the performance of children with DD and those who are typically developing on broad measures designed to assess components of verbal learning, retrieval after short and long delays, and recognition. Oyler et al. (2012) examined the performance of adolescents with DD and their typically developing peers on the Bergen-Tuscon Verbal Learning Test (BTVLT), which was modeled after the CVLT-C and includes supplemental measures of word recall based on phonological and semantic features of words. In a similar study, Kramer et al. (2000) compared CVLT-C performances of children aged 8-10 who met criteria for DD to those who were typically developing. Despite the different measures and age groups, results from these studies revealed a consistent verbal learning and memory profile for children with DD compared to their typically developing peers.

With regard to performance across the learning trials, children with DD showed intact immediate recall performance on the first learning trial (Kramer et al., 2000; Oyler et al., 2012). However, their slower learning across subsequent learning trials compared with typically developing peers resulted in fewer words learned overall across the five learning trials among children with DD (Kramer et al., 2000; Oyler et al., 2012). Both studies provided insights into this pattern across the learning trials from their qualitative scores. Specifically, children with DD recalled the same number of words from the beginning and end of the lists, suggesting intact primacy and recency effects (Kramer et al., 2000; Oyler et al., 2012). However, typically developing children were able to recall more words from the middle portion of the list than the children with DD (Kramer et al., 2000; Oyler et al., 2012). This performance discrepancy

suggests less elaborate rehearsal of words from the middle of the list, which is associated with limited attention resources. This finding is also in line with previous research indicating children with DD use less effective elaborate encoding and rehearsal strategies than their typically developing peers (Bauer & Emhert, 1984).

Delayed free recall and recognition was also intact for children with DD, reflecting retention abilities commensurate with their typically developing peers. Recall performance after both short and long delays also reflected intact retention of those words initially encoded by children in both groups (Kramer et al., 2000; Oyler et al., 2012). In other words, while children with DD recalled fewer words overall in delayed recall conditions, the same proportion of the words recalled during the final learning trial was recalled following both short and long delays for both groups. Interestingly, use of the BTVLT allowed for more nuanced insight into cued recall performance: children with DD showed intact recall in response to semantic cues, but had more difficulty recalling words based on phonemic cues compared with typically developing peers (Oyler et al., 2012). This pattern is consistent with a broad literature suggesting a cognitive core deficit underlying reading difficulty in children with DD is a deficit in phonological awareness (e.g., Lyon, Shaywitz, & Shaywitz, 2003). Finally, recognition performance was commensurate between the groups (Kramer et al., 2000; Oyler et al., 2012), again highlighting the primary difference between the groups lies in learning efficiency.

1.11 CVLT-C Structure in DD is Unconfirmed

Despite this clearly defined pattern of verbal learning and memory performance and the high prevalence of DD as well as broader reading underachievement, the internal factor structure for the CVLT-C among children with DD has not yet been evaluated. When using psychometric measures in research or in clinical practice, it is critical that a foundation of research ensures that

there is sufficient construct validity to use a particular measure with a specific population. Even Donders (1999) emphasized the importance of evaluating the internal structure of the CVLT in different clinical samples in order to assess for potential discrepancies across diagnoses and to ensure accurate interpretation of scores. To date, despite the prevalence of the disorder as well as the frequency with which this measure is used, little is known about the internal structure of the CVLT-C in DD.

Therefore, this study aims to (1) clarify the factor structure of the CVLT-C in this vulnerable and highly prevalent population, as well as (2) to explore the link between specific components of verbal learning and memory and reading comprehension, in order to advance the accurate assessment and interpretation of cognitive difficulties and related reading outcomes.

1.12 Verbal Learning & Memory Factors Relate to Reading Comprehension

In learning to read, children must develop the ability to efficiently and accurately identify phonemes with their visually symbolic representations, connect these word forms with semantic meaning, and hold these individual words in mind while integrating them with larger syntactic information in order to comprehend complex sentences and even longer texts (e.g., Cain, Oakhill, & Bryant, 2004). While substantial evidence for the relation between verbal learning and these varied reading skills is well documented, the nature of this relationship remains somewhat unclear. In particular it is unknown how the various factors or components of verbal learning and memory processes relate to reading comprehension.

One interesting line of research may provide some insight into this particular interaction. Recent studies have identified a subset of individuals who exhibit reading comprehension difficulties despite average word reading abilities, known as Specific Reading Comprehension Deficit (SRCD; Landi & Ryherd, 2017). This clinical profile has received substantial attention in

recent years, although a unifying theory or consensus regarding the core deficits that underlie SRCD remains elusive (Landi & Ryherd, 2017). That being said, several component skills, including foundational basic reading abilities (Cain et al., 2004; Nippold, 2017), short-term verbal learning and memory (Cain et al., 2004; Spooner, Gathercole, & Baddeley, 2006), and higher-level executive functioning (Landi & Ryherd, 2017; Locascio, Mahone, Eason, & Cutting, 2010) have been identified as contributing factors to deficits in reading comprehension across development. In other words, reading comprehension is a multi-factorial skill that is supported by multiple concurrent abilities and processes.

Basic reading skills, which are well known to relate to verbal learning and memory abilities, contribute significantly to higher-level reading comprehension performance. For example, in a recent study of adolescents, concurrent word reading abilities, lexical development, and syntactic development were found to predict reading comprehension difficulties (Nippold, 2017). While clearly these are important building blocks that form the foundation for text reading, deficits in comprehension are not fully accounted for by these lower-level skills. In a 3-year longitudinal study of typically developing 8 year olds, word reading abilities and reading comprehension appeared to diverge over time (Cain et al., 2004). The study indicated that participants' average word reading skills did not independently enable them to develop good text comprehension skills. In other words, as higher-level reading comprehension demands increased, some children were unable to comprehend complex text despite intact word reading abilities. The factors that explain this apparent disconnection between lower-level reading skills and higher-level text comprehension have been the subject of considerable research.

One possible factor, verbal short-term memory (or working memory), has been identified as a weakness among university students with SRCD (Georgiou & Das, 2015). Verbal memory

has also been shown to correlate with sentence reading comprehension performance among 7-8 year olds (Spooner et al., 2006). Moreover, verbal short-term memory (or working memory) explained unique variance in reading comprehension performance even when word reading and lexical abilities were controlled for among typically developing 8-11 year olds (Cain et al., 2004). Taken together, verbal learning and memory, and in particular short-term verbal memory, appears to be closely tied to reading comprehension abilities in both typical and struggling readers across development.

Substantial evidence also suggests that executive functioning underlies and contributes to both reading and verbal learning and memory processes. As previously discussed, the ability to independently organize semantic information, reflective of executive functioning abilities, results in more efficient encoding, storage and retrieval of verbal information. With regard to its contribution to reading, cognitive-flexibility, which is defined by the ability to simultaneously manage and actively switch between multiple tasks, predicted reading comprehension abilities in typically developing 1st and 2nd graders above and beyond decoding skills, verbal abilities, nonverbal reasoning, and vocabulary knowledge (Cartwright et al., 2017). Similarly, children who met criteria for SRCD exhibited deficits in planning, organization, and self-monitoring, which predicted reading comprehension performance after controlling for phonological processing abilities (Locascio et al., 2010). A recent review identified three consistent areas of weakness that may underlie deficits in reading comprehension among individuals with SRCD: semantic and grammatical processing, inference making, and other higher-level language skill such as comprehension monitoring (Landi & Ryherd, 2017). Finally, a recent exploratory principal component analysis of executive functioning performance revealed that children who met criteria for SRCD exhibited a primary deficit in executive functioning tasks involving

planning (Locascio et al., 2010). Taken together, executive functioning potentially represents a shared construct contributing to effective verbal learning and memory as well as to effective reading comprehension above and beyond the influence of basic reading skills.

The contribution of these varied factors to reading comprehension was demonstrated in a study of typically developing 5th graders' reading performance (Nouwens, Groen, & Verhoeven, 2016). Consistent with theoretical and empirical evidence outlined above, results indicated that word reading, vocabulary, cognitive flexibility, and listening span all significantly contributed to reading comprehension performance. Interestingly, subsequent analyses revealed that verbal short-term memory, inhibition, and cognitive flexibility contributed directly to listening span, and therefore indirectly to reading comprehension. This study provides a coherent representation of the complex and interactive components necessary to produce intact reading comprehension.

In summary, the relation between reading comprehension and verbal learning and memory abilities is clearly multifactorial and this association exists across levels of complexity. At the level of basic reading abilities, verbal learning and memory has been shown to relate to the development of phonological awareness, decoding, spelling, and vocabulary knowledge. At higher levels of complexity, reading comprehension has been repeatedly shown to be supported by verbal short-term memory (or working memory). Further, these two processes share underlying contributions from executive functioning abilities, particularly planning and monitoring, which influence the level of encoding, as well as efficient storage and retrieval of verbal information. Taken together, both successful word list learning and memory and successful text reading comprehension involve a child integrating multiple perceptual and cognitive processes including attention, auditory and visual processing, short-term storage (or working memory), executive functioning, and language comprehension.

Despite the substantial overlap in underlying component cognitive skills as well as the demonstrated relation between verbal learning and reading outcomes, no study has yet evaluated the relation between the proposed models of verbal learning and memory and higher-level text reading comprehension. Given the frequency with which the CVLT-C is utilized in research and in clinical settings, it is important to understand not only the internal structure of the CVLT-C in this population, but also how its components relate to higher-order text reading. The current study, therefore, attempts to understand the differential contribution of its latent constructs in contributing to reading outcomes.

2 Aims & Hypotheses

2.1 Aim 1

While the CVLT-C internal structure has been long established in the standardization sample, substantial theoretical and empirical evidence suggests that this structure may vary across clinical samples. The internal structure has not been confirmed among children with DD, despite the high prevalence of this disorder as well as broader reading underachievement. Therefore, the first aim of this study was to evaluate the 6 proposed conceptual models of the internal, latent structure of the CVLT-C in a sample of children with DD.

2.1.1 Aim 1: Hypothesis

Model 6 was hypothesized to best describe the structure of the CVLT-C performance in this sample of children with DD. This hypothesis was based upon the previous findings that this model has been supported the most consistently across both typically developing as well as diverse clinical populations of adults and children.

While substantial evidence indicates that scores contributing to the Attention and to the Learning Efficiency factors represent performance-level weaknesses among children with DD, these differences in performance do not suggest a different internal structure in this population. In other words, these performance-level differences do not suggest that CVLT-C scores of children with DD vary systematically in a different way from those of typically developing children.

Indeed, it was expected that the same model factors would accurately describe children with DD's CVLT-C performance. For example, recent studies have revealed that despite performance-level weaknesses in attention- and learning efficiency-related scores, children with DD exhibit intact retention and recall performance. This pattern suggests that while mean-level differences exist, the individual z-scores tend to cluster in the same way (i.e., with the same latent factor structure) regardless of DD diagnosis. Thus, we expected that the factor structure of delayed recall, regardless of duration (i.e., short vs. long) or cuing (i.e., free vs. cued), and inaccurate recall factors in this population would closely resemble the factor structure observed among typically developing children.

2.2 Aim 2

While verbal learning and memory abilities are strongly associated with a wide range of reading outcomes, the nature of the relation between verbal learning latent factors and reading comprehension remains unknown. Thus, the second aim of this study was to explore the relation between CVLT-C factors and higher-level reading comprehension performance during connected text reading (using the Standardized Reading Inventory, Second Edition; SRI-2) among children with DD.

2.2.1 Aim 2: Hypothesis

Given the strong association between verbal learning and reading outcomes, we expected that the latent factors within the best fitting model of CVLT-C performance would share significant variance with concurrent text reading accuracy and with comprehension performance. If Model 6, as hypothesized, was found to be the most appropriate structure to represent CVLT-C performance in this sample, we expected differential relations of some of the verbal learning and memory factors with reading outcomes (see Figure 7). Specifically, it was expected that Attention and Learning Efficiency would more strongly relate to reading accuracy as well as to higher-level reading comprehension performance than the other verbal learning and memory factors (i.e., Free and Cued Delay Recall, Inaccurate Recall) because they most directly reflect attention capacity, verbal short-term memory, and executive functioning. Conversely, Free and Cued Delayed Recall and Inaccurate Recall factors were not expected to relate as strongly to reading accuracy or comprehension outcomes.

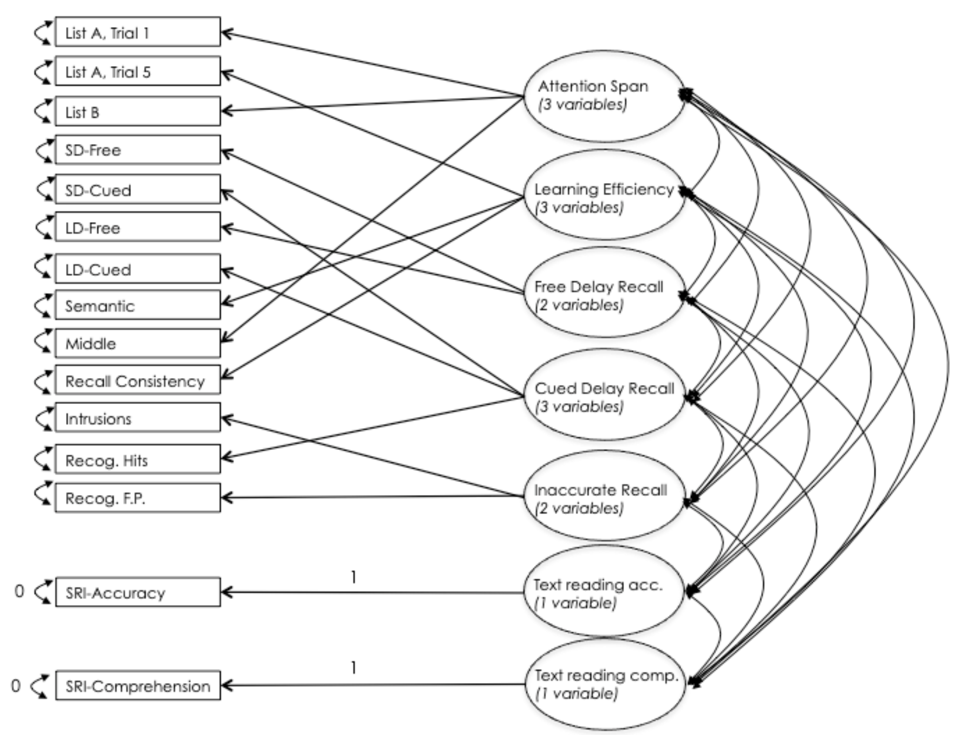

Figure 7. Proposed model of relation between CVLT-C factor structure, text reading accuracy and comprehension performances.

Importantly, this study is not longitudinal and therefore cannot provide insight into directionality of the relation between verbal learning and memory abilities, basic reading accuracy, and reading comprehension performance. Rather, this study aimed to assess the concurrent relationship among these abilities in order to provide insight into the shared, higher-level cognitive components that contribute to both verbal learning and reading comprehension. Additionally, given this study's restricted age range (8-11 years), it was not expected that age would significantly impact or contribute to differential performance in verbal learning and memory or reading. Indeed, any age-related differences were expected to be controlled for by the utilization of norm-referenced scores

3 METHODS

3.1 Participants

155 children with DD (86 males, 69 females) in grades 3 and 4 (aged 8.08 – 11.25 years; M = 9.23 years, SD = 0.67 years) participated in the study (Table 2). Participants were recruited from public schools in Atlanta, GA as part of an intervention study focused on children with dyslexia/reading disabilities. All participants were native speakers of English and had at least average intellectual functioning (SS $\geq$ 80) on at least one subscale of the Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler, 2011, Table 3). Children with chronic absenteeism (>15 absences per year), hearing impairment (<20/40), serious emotional/psychiatric disturbance, or chronic medical/neurological condition according to parent report were excluded.

Children met study criteria for DD (Table 3; for discussion of diagnostic criteria see Stuebing et al., 2002) if they scored at least 1 SD below age-norm expectations on any of the

following: Woodcock Johnson (WJ-3; Woodcock, McGrew, & Mather, 2001) Broad Reading Cluster subtests or the composite (Letter-Word Identification, Reading Fluency, Passage Comprehension), the Basic Reading Cluster subtests or composite (Letter-Word Identification and Word Attack); or Test of Word Reading Efficiency (TOWRE-2; Torgeson, Wagner, & Rashotte, 2011) subtests or composite (Sight Word Reading Efficiency and Phonemic Decoding Efficiency).

Table 2

Descriptive statistics of all participants' age, gender, race and income.

Characteristics	Participants with DD	
	M	*SD*
Age in years	9.23	0.67
Total N	155 total	
Gender	69 female	
Race N (% of total sample)		
Caucasian	29 (18.7%)	
African American	113 (72.9%)	
Asian American	1 (0.01%)	
Hispanic	2 (0.01%)	
Bi-racial	5 (0.03%)	
Not reported	5 (0.03%)	
Household Annual Income N (% of sample)		
<$20,000	43 (27.7%)	
$20,000-50,000	41 (26.4%)	
$50,000-100,000	27 (17.4%)	
>$100,000	20 (12.9%)	
Not reported	24 (15.4%)	

Note. DD = Developmental Dyslexia; M = mean; SD = standard deviation; N = number.

Table 3

Descriptive statistics of participants' scores on inclusion and diagnostic measures.

Characteristics	Participants with DD	
	M	*SD*
WJ-III LW St. Score	88.19	8.44
WJ-III WA St. Score	87.84	8.90
WJ-III RF St. Score	87.18	10.09
WJ-III PC St. Score	81.23	9.45
WJ-III Basic RC St. Score	86.87	8.20
WJ-III Broad RC St. Score	82.40	9.92
TOWRE-2 SWE St. Score	76.32	10.82
TOWRE-2 PDE St. Score	72.94	8.44

WASI-2 FSIQ St. Score	93.48	10.52

Note. DD = Developmental Dyslexia; N = number of participants; M = mean; SD = standard deviation; WJ-III = Woodcock Johnson, Third Edition; LW = Letter Word Identification subtest; WA = Word Attack subtest; RF = Reading Fluency subtest; PC = Passage Comprehension subtest; RC = Reading Cluster; TOWRE-2 = Test of Word Reading Efficiency, Second Edition; SWE = Sight Word Efficiency; PDE = Pseudoword Decoding Efficiency; WASI-2 FSIQ= Wechsler Abbreviated Scale of Intelligence, Second Edition Full Scale Intelligence Quotient (2- or 4-subtests); St. Score = Standard Score.

3.2 Materials

3.2.1 Verbal Learning

The *California Verbal Learning Test-Children's Version* (CVLT-C; Delis, Kramer, Kaplan, & Ober, 1994) is a verbal list learning and memory task that assesses children's (5-16:11 years) ability to learn, recall, and recognize unstructured verbal information. In the CVLT-C, the participant is read a 15-item unstructured word list (List A), consisting of words belonging to three semantic categories, and asked to recall as many words as possible over five learning trials. The learning trials are followed by a single presentation of distractor list (List B). Next, the child is asked to freely recall as many words as she can from the original list (Short Delay-Free Recall). The child is then provided with semantic clustering prompts and asked to recall words from the original list that fall within each category. After a delay of approximately twenty minutes, free and cued recall conditions are repeated. Finally, recognition memory is assessed by asking the child to identify whether presented words were members of the original list.

The CVLT-C quantifies performance levels of total recall and recognition, differentiates learning strategies (e.g., semantic clustering), allows for interpretation of

serial-positioning effects, learning rate and consistency of recall across trials, degree of vulnerability to proactive and retroactive interferences, enhancement of recall performance by category cuing and recognition testing, perseverations and intrusions in recall and false positives in recognition. The test takes approximately 30 minutes to administer with a 20-minute delay interval to test longer-term item retention.

The CVLT-C has been normed using a sample of 920 children divided into three age groups: 5-8 years, 9-12 years, and 13-16 years. The sample closely approximates the school-aged population of the United States as reported in the 1988 census data. A student's obtained raw scores are converted into norm-referenced z-scores, with a mean of 0 and a standard deviation of 1. On average, 8-12 year olds (the age of the current sample) show improvements of approximately 1 word per learning trial. The CVLT-C has shown good internal reliability, between .64 and .80, and modest test-retest stability, between .38 and .90. The CVLT-C also shows good construct validity; eigenvalues falling between .43 and .91, indicating the factor structure for the CVLT-C is the same as that for the CVLT adult version of the test.

3.2.2 Reading Accuracy & Comprehension

The *Standardized Reading Inventory, Second Edition* (*SRI-2*; Newcomer, 1999) was administered as a measure of text reading accuracy and comprehension. The SRI-2 stories are read by participants once aloud and then again silently, with comprehension measured using lexical, inferential, and factual open-ended questions about the text. Basal and ceiling levels are recorded separately for reading accuracy and comprehension components, and only finished once both ceilings have been reached. Recommended starting points are

offered for typical readers, however given the lower reading level of the study participants, most administrators began with the first story.

The SRI-2 was standardized on a sample of 1099 children living in 28 states between ages 6 and 14 years. Characteristics of the sample were compared to the 1997 consistently exceed .80, test-retest reliability exceeds .85, and inter-rater reliability ranged from .85 to .97. Item validities range from .49 to .85 across age groups, and criterion validity is extremely high at .76. The SRI-2 also discriminates between poor and strong readers, making it a strong measure for identifying children with reading deficiencies.

4 RESULTS

4.1 Aim 1: Confirmatory Factor Analyses of CVLT-C Structure in DD

All analyses used age norm-referenced z-scores (i.e., participants' CVLT-C performances on the key variables used within this study sample were transformed into z-scores referenced to the norm sample described in the testing manual; M = 0, SD = 1) from the 13 CVLT-C variables of interest in the present study (see Table 1). Higher z-scores represent better performance on all components except for Total Intrusions and False Positives.

4.1.1 Data Screening

Normality was evaluated for each variable. All data, for both Aim 1 as well as Aim 2, were processed in SAS to determine means and standard deviations, and to check each variable for skewness, outliers, and non-normality (see Table 4). Per Kline (2005), normality probability scatter plots and estimates were examined for each variable to determine skew and kurtosis. All variables fell below Kline's suggested cutoffs of <3 and <10 for skewness and kurtosis, respectively, and appeared to be normally distributed.

Seven participants were not administered the recognition component of the CVLT-C. Thus, only 148 scores are available for both the Recognition Hits and Recognition False Positives variables.

Table 4
Descriptive statistics of participants' performance on study-relevant California Verbal Learning Test-Children's Version (CVLT-C) z-scores and Standardized Reading Inventory, Second Edition (SRI-2)

Variable	Mean	St. Dev.	Range	Skew (SES)	Kurtosis (SEK)
CVLT-C					
List A – Trial 1	-.27	0.95	5.5	0.35 (.19)	0.24 (.38)
List A – Trial 5	-.31	1.07	6.0	-0.66 (.19)	0.80 (.38)
List B	-.39	1.15	5.5	0.37 (.19)	-0.33 (.38)
Short Delay, FR	-.23	0.99	5.0	-0.41 (.19)	0.01 (.38)
Short Delay, CR	-.44	1.08	6.0	-0.50 (.19)	0.52 (.38)
Long Delay, FR	-.30	1.09	5.5	-0.56 (.19)	0.45 (.38)
Long Delay, CR	-.33	1.03	5.5	-0.39 (.19)	0.20 (.38)
Semantic Clustering	-.28	1.16	6.5	0.04 (.19)	0.17 (.38)
Middle	-.15	1.16	5.5	-0.22 (.19)	0.01 (.38)
Recall Consistency	.00	1.03	5.5	-1.39 (.19)	2.26 (.38)
Intrusions	-.14	0.78	4.0	1.51 (.19)	2.48 (.38)
Recognition Hits	-.03	0.91	3.5	-0.69 (.19)	-0.23 (.38)
Recognition FP	-.28	0.94	6.0	2.43 (.19)	7.71 (.38)
SRI-2					
WRA – Sc. Score	5.63	2.33	10	0.05 (.19)	-0.64 (.38)
PC – Sc. Score	6.71	2.19	11	-0.40 (.19)	-0.02 (.38)

Note. DD = Developmental Dyslexia; M = mean; St. Dev. = standard deviation; SES = Standard Error of Skewness; SEK = Standard Error of Kurtosis; FR=Free Recall; CR=Cued Recall; FP=False Positives; WRA = Word Reading Accuracy; PC = Passage Comprehension; Sc. Score = Scaled Score (M = 10; SD = 3)

4.1.2 Correlations

Pearson correlations were calculated to explore the direction and strength of the relationships between variables in the models (see Table 5). Moderate positive correlations (.39 - .75) were found between List A-Trial 2 and each of the four Delay Recall variables as well as Recall Consistency; Recognition Hits and Short Delay Cued Recall, Long Delay Free Recall and Long Delay Cued Recall; Short Delay Free Recall and all other Delay Recall variables; Short

Delay Cued Recall and Long Delay Free Recall; and finally between the error variables, Intrusions and Recognition False Positives. Strong positive correlations (>.75) were found between Long Delay Cued Recall and Short Delay Cued Recall as well as with Long Delay Cued Recall. Moderate negative correlations were found between Long Delay Free Recall and the two error variables, Intrusions and with Recognition False Positives.

Table 5

Correlations among participants' study-relevant California Verbal Learning Test – Children's Version (CVLT-C) z-scores

Measure	Correlations											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. List A-Trial 1	-											
2. List A-Trial 5	.26**	-										
3. List B	.31**	.21**	-									
4. Short Delay, FR	.23**	.68**	.22**	-								
5. Short Delay, CR	.24**	.58**	.27**	.66**	-							
6. Long Delay, FR	.27**	.55**	.26**	.66**	.71**	-						
7. Long Delay, CR	.32**	.53**	.26**	.64**	.80**	.81**	-					
8. Semantic Clustering	.16*	.25**	.19*	.27**	.37**	.26**	.29**	-				
9. Middle	.23**	.14	.11	.11	.16*	.17*	.19*	.23**	-			
10. Recall Consistency	.07	.54**	.04	.37**	.32**	.29**	.24**	.00	-.20*	-		
11. Intrusions	-.21**	-.26**	-.21**	-.33**	-.32**	-.45**	-.33**	-.12	-.05	-.17*	-	
12. Recognition Hits	.12	.37**	.22**	.37**	.48**	.48**	.51**	.05	.24**	.02	-.10	-
13. Recognition FP	-.15	-.22**	.21**	-.28**	-.32**	-.39**	-.37**	-.16*	.00	-.11	.40**	-.11

Note. **p*<.05; ***p*<.01; green= strong positive correlations (>.75); red = moderate positive correlations (.39 - .75);

blue= moderate negative correlations; FR=Free Recall; CR=Cued Recall; FP=False Positives;

4.1.3 Confirmatory Factor Analyses

Using the SAS covariance of analysis of linear structural equations (CALIS) procedure (SAS Institute, 1990), maximum-likelihood confirmatory factor analyses (CFA) were calculated for each of the six models (Table 6). This procedure is a method to test the hypothesis of underlying latent factors that are reflected in observed variables. Here, we tested the fit of the six theoretically derived models to the 13 manifest variables of the CVLT-C performance in this sample.

Table 6
Hypothesized factor loadings for six California Verbal Learning Test-Children's Edition (CVLT-C) models (reproduced from Donders, 1999)

CVLT-C Variables	Model					
	1	2	3	4	5	6
List A, Trial 1	1	1	1	1	1	1
List A, Trial 5	1	1	1	4	4	4
List B	1	1	1	1	1	1
Short-delay free recall	1	1	3	3	5	5
Short-delay cued recall	1	1	3	3	5	3
Long-delay free recall	1	1	3	3	3	5
Long-delay cued recall	1	1	3	3	3	3
Semantic clustering	1	1	1	4	4	4
Middle region recall	1	1	1	1	1	1
Recall consistency	1	1	1	4	4	4
Total intrusions	1	2	2	2	2	2
Recognition hits	1	1	3	3	3	3
Recognition false positives	1	2	2	2	2	2

Note. Numbers indicate with which factor the test is associated

Since there is no complete agreement regarding acceptable criteria for model fit and parsimony (for reviews see: Arnau & Thompson, 2000; Browne & Cudeck, 1993, Fan & Sivo, 2005; Hatcher, 1994; Hu & Bentler, 1999), a review of Thompson (2004) and previous research on the factor structure of the CVLT-II (e.g., Donders, 2008) and CVLT-C (e.g., Griffiths, et al., 2006) provided the following widely supported minimal acceptable criteria for model fit and parsimony and were therefore set a priori: comparative fit index (CFI) $\geq$ 0.95, root mean squared

error of approximation (RMSEA) ≤ 0.06, parsimonious normed fit index (PNFI) ≥ 0.60, and Tucker-Lewis Index (TLI) ≥ 0.95. Additionally, chi-square to degrees of freedom ratio (χ^2/*df*) that is smaller than 2 was considered desirable, although larger values can still be acceptable if a particular model shows a clearly smaller χ^2/*df* ratio than the next best competing model.

4.1.4 Confirmatory Factor Analysis Results

None of the models (Table 6) met the a priori specified criteria for acceptability (i.e., CFI ≥ 0.95, PNFI ≥ 0.60, RMSEA ≤ 0.06, and TLI ≥ 0.95; Table 7). While all models met the criterion for the PNFI statistic, only Model 5 also met the criterion for the chi-square ratio statistic. Taken together, although Model 5 has met two of the five a priori criteria, these findings suggest that none of the proposed models adequately fit these CVLT-C data within this sample of children with DD.

Table 7
Goodness of fit and parsimony statistics for 6 California Verbal Learning Test-Children's Edition (CVLT-C) Models

Model	χ^2	*df*	χ^2/df (<2)	*P*	CFI (>.95)	PNFI (>.60)	RMSEA (<.06)	TLI (>.95)
Model 1 (1 factor)	175.04	65	2.69	<.0001	0.85	0.66^	0.10	0.83
Model 2 (2 factors)	162.92	64	2.54	<.0001	0.87	0.66^	0.10	0.84
Model 3 (3 factors)	155.51	62	2.50	<.0001	0.87	0.65^	0.10	0.84
Model 4 (4 factors)	126.51	59	2.14	<.0001	0.91	0.64^	0.08	0.88
Model 5 (5 factors)	109.38	55	1.98^	<.0001	0.93	0.61^	0.08	0.90
Model 6 (5 factors)	111.20	55	2.02	<.0001	0.92	0.61^	0.08	0.89

Note. χ^2 = chi-squared value, *df* = degrees of freedom; *p* = P-value of the chi-square statistic for model fit; CFI = Comparative Fit Index; PNFI = Parsimonious Normed Fit Index; RMSEA = Root Mean Squared Error of Approximation; TLI = Tucker-Lewis Index.

^ = met a-priori criterion.

4.2 Ancillary Exploratory Factor Analysis of CVLT-C Structure in DD

4.2.1 Factor Analysis

Given the limited acceptability in fit of the 6 proposed models illustrated by confirmatory factor analyses, a post-hoc exploratory factor analysis (EFA) was conducted to determine whether an alternative structure was present that had not been tested by the theoretically-derived models.

Using maximum-likelihood extraction and oblique rotation, we conducted an exploratory factor analysis of the 13 CVLT-C variables, allowing SAS to determine the number of factors that would best describe the data. Under these conditions, three factors were retained with a cumulative variance of 1.0376. Preliminary eigenvalues were 13.8, 1.5, and 0.8. Each factor explained 88%, 9% and 5% of the variance, respectively (see Table 8). Visual inspection of the scree plot also suggested 3 factors (see Appendix A). Hypothesis tests for the 3-factor EFA model were both rejected: no common factors were present ($df = 78$, $\chi^2 = 826.08$, $p < .0001$), and 3 factors were sufficient ($df = 42$, $\chi^2 = 70.40$, $p = .003$). Tucker Lewis's Reliability Coefficient indicated good reliability (TLRC = 0.92). Reliability is a value between 0 and 1 with a larger value indicating better reliability. Proportion of variance explained were 80.76%, 13.61%, and 5.63%. Cumulative variance explained for 3 factors was 100%.

In order to confirm that 3 factors would indeed best represent the data, we conducted exploratory factor analyses for 1 to 5 factors (Table 9). This approach was intended to evaluate the 3 factors retained by the SAS EFA, as well as to mirror the number of factors proposed in theoretically derived Models 1 - 6 (i.e., 1 – 5 factors).

Table 8
Preliminary eigenvalues for each additional factor within exploratory factor analysis of California Verbal Learning Test-Children's Version (CVLT-C)

Number of	Eigenvalue	Difference	Proportion	Cumulative

Factors				
1	13.78	12.28	0.889	0.88
2	1.50	0.69	0.096	0.98
3	0.80	0.25	0.051	1.03
4	0.54	0.17	0.035	1.07
5	0.36	0.20	0.023	1.09
6	0.16	0.09	0.010	1.10
7	0.06	0.15	0.004	1.11
8	-0.08	0.06	-0.005	1.10
9	-0.14	0.05	-0.009	1.09
10	-0.20	0.15	-0.013	1.08
11	-0.36	0.06	-0.023	1.05
12	-0.42	0.05	-0.027	1.03
13	-0.48	---	-0.031	1.00

Table 9
Goodness of fit and parsimony statistics for EFAs of the California Verbal Learning Test-Children's Version (CVLT-C) with different numbers of factors

Model	χ^2	*df*	χ^2/df	*p*	ΔAIC	SBC	TLRC
1 factor	168.09	65	2.58	<.0001	45.04	-149.77	0.83
2 factors	101.42	53	1.91	<.0001	0.11	-158.73	0.90
3 factors	70.40	42	1.67	0.003	-9.98	-135.86	0.92
4 factors	45.42	32	1.41	0.058	-16.01	-111.92	0.95
5 factors	N/A	N/A	N/A	N/A	700.17	466.39	0.00

Note. χ^2 = chi-squared value for null hypothesis that number of factors is sufficient, *df* = degrees of freedom; *p* = P-value of the chi-square statistic for model fit; AIC = Akaike's Information Criterion; SBC = Schwarz's Bayesian Criterion; TLRC = Tucker and Lewis's Reliability Coefficient.

The models resulting from EFAs specified to have 1, 2, 3, and 4 factors each converged, while the EFA with 5 factors specified did not converge due to a communality greater than 1.0 (Table 9). Thus, a structure with 5 latent factors was eliminated from consideration.

Next, comparing models with 1, 2, 3 or 4 factors, the hypothesis tests regarding whether the specified number of factors were sufficient indicated that only 1, 2, and 3 factors were sufficient. When 4 factors were included, the null hypothesis was not rejected ($p = 0.058$; Table

9). Thus, a structure with four latent factors was eliminated from consideration because four factors were determined to not improve model fit beyond three factors.

Comparing Tucker and Lewis's Reliability Coefficients of the remaining models (i.e., those with 1, 2, or 3 factors) indicated the EFA model with 3 factors showed the highest degree of reliability (Table 9). Similarly, the Akaike's Information Criterion and the Schwarz's Bayesian Criterion, which are general criteria for estimating the best number of parameters to include in a model when maximum likelihood estimation is used, were smallest, and therefore considered the best fit, for the model containing 3 factors.

Taken together, these findings regarding the exploratory models' fit were consistent with the number of factors retained by the SAS EFA results (i.e., 3 factors, described above). A structure containing 3 factors was also supported by visual inspection of the scree plot (see Appendix A; Cattell, 1966) as well as by the observation that addition of a fourth factor (or more) accounts for less than 5% of the overall variance (Table 8). Thus, it was determined that three factors were indeed the best fit for these data (Tables 10 and 11).

Table 10
Promax Rotation: Inter-Factor Correlations

Factor	Factor 1	Factor 2	Factor 3
Factor 1	--		
Factor 2	0.55	--	
Factor 3	-0.57	-0.53	--

Table 11
Promax: Rotated Factor Pattern (Standardized Regression Coefficients)

	Factor Indications		
Variables	Factor 1	Factor 2	Factor 3
List A, Trial 1	0.25	-0.02	-0.20
List A, Trial 5	0.26	**0.68**	0.07
List B	0.22	-0.07	-0.23
Short-delay free recall	**0.41**	**0.42**	-0.08
Short-delay cued recall	**0.62**	0.28	-0.06
Long-delay free recall	**0.51**	0.17	-0.35
Long-delay cued recall	**0.71**	0.13	-0.17

Semantic clustering	0.38	-0.04	-0.05
Middle region recall	**0.53**	-0.29	0.07
Recall consistency	**-0.40**	**1.01**	0.03
Total intrusions	0.14	0.00	**0.77**
Recognition hits	**0.70**	-0.03	0.13
Recognition false positives	0.00	0.06	**0.60**

Notes: Factor indications > .40 appear in bold and are shaded (only for visual contrast).

4.2.1 Labeling Factors

Factor 1 was labeled Attention & Verbal Memory due to the primary indications of the following variables: Short Delay Free Recall, Short Delay Cued Recall, Long Delay Free Recall, Long Delay Cued Recall, Middle Region Recall, Recall Consistency and Recognition Hits. This factor explained 69% of the variance. Factor 2 was labeled Executive Functioning due to the primary indications of List A-Trial 5, Short Delay Free Recall, and Recall Consistency. Of note, Short Delay Free Recall indicated approximately equally on Factors 1 and 2. Additionally, Recall Consistency indicates significantly on both Factors 1 and 2. Together, this second factor explained 58% of the variance. Finally, Factor 3 was labeled Inaccurate Recall due to the high indications on the Total Intrusions and Recognition False Positives variables. This third factor explained 47% of the variance.

4.2.2 Comparing Factor Analyses

Next, the retained 3-factor EFA model was compared with the previous, albeit poorly-fitting, CFA models (i.e., Models 1-6, see Table 7). Chi-square values were the statistic available for comparison across these models. By plotting chi-square values divided by degrees of freedom for all confirmatory and exploratory models that converged (see Figure 10), it is clear that as the number of factors increase across models, these statistics do not show an obvious bump or change but rather follow approximately the same general trend. This pattern suggests both the CFA and EFA are picking up on the same general internal structure or relationship among the

CVLT-C variables, with no simple, parsimonious solution. In other words, the EFA models do not appear to improve substantially upon the theory-driven CFA models from a statistical perspective.

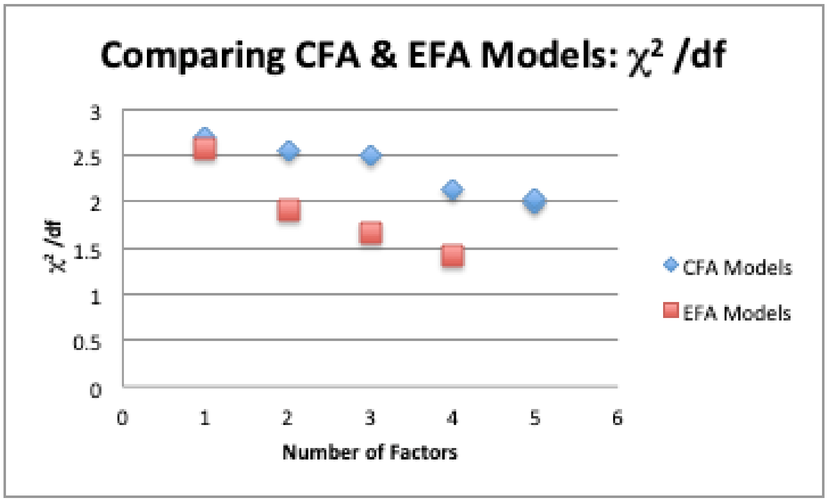

Figure 8. Comparing χ^2*/df of Confirmatory and Exploratory Factor Models of the California Verbal Learning Test – Children's Version (CVLT-C)*

4.3 Aim 2: Relationship between CVLT-C and Reading Outcomes

In order to address the second aim of this study, the relationship between participants' verbal learning and memory, as measured by CVLT-C performance, and text reading skills, as measured by the SRI-2 (Table 4), was explored.

4.3.1 Correlations

First, all study-relevant CVLT-C z-scores were correlated with the SRI-2 scores (Table 12). Word Reading Accuracy was correlated only with CVLT-C Recognition performance, while Passage Comprehension was significantly correlated with all CVLT-C z-scores except Semantic Clustering, Middle Region recall, and Recall Consistency. Of note, SRI-2 Passage Comprehension was only negatively correlated with the two error variables: Total Intrusions and

False Positives. Additionally, the components of SRI-2 are significantly correlated with each other.

Table 12
Correlations among participants' California Verbal Learning – Children's Version (CVLT-C) performance scores and Standardized Reading Inventory, Second Edition (SRI-2) performance scores

CVLT-C scores	SRI-2 Word Reading Accuracy	SRI-2 Passage Comprehension
List A, Trial 1	-0.01	0.21**
List A, Trial 5	0.11	0.27***
List B	0.13	0.36***
Short-delay free recall	0.13	0.23**
Short-delay cued recall	0.08	0.26**
Long-delay free recall	0.06	0.24**
Long-delay cued recall	0.05	0.25**
Semantic Clustering	0.08	0.01
Middle Region recall	0.08	0.14
Recall Consistency	0.02	0.11
Total Intrusions	-0.08	-0.18*
Recognition Hits	0.17	0.24**
Recognition False Positives	-0.19*	-0.26**
SRI-2 Passage Comprehension	0.31***	---

Notes: *p<.05; **p<.01; ***p<.001

Although the CVLT-C 3-factor structure retained through the EFA did not appear to improve significantly upon the fit or parsimony of CFA models, we nonetheless explored the relationship between these factors and performance on the SRI-2 (Table 13). Passage Comprehension was significantly positively related to Attention & Verbal Learning and Executive Functioning, while it was significantly negatively related to Inaccurate Recall. Word Reading Accuracy was not significantly related to any of the CVLT-C factors.

Table 13
Correlations among 3 factors determined by exploratory factor analysis (EFA) of the California Verbal Learning Test – Children's Version (CVLT-C) and Standardized Reading Inventory, Second Edition (SRI-2) performance scores

CVLT-C Factors	SRI-2 Word Reading Accuracy	SRI-2 Passage Comprehension
Factor 1: Attention & Verbal Memory	0.09	0.25**
Factor 2: Executive Functioning	0.10	0.22**
Factor 3: Inaccurate Recall	-0.12	-0.30***

Notes: **p* < .05; ***p* < .01; ****p* < .001

5 DISCUSSION

This study examined the fit of six previously proposed models of verbal learning and memory, as measured by the CVLT-C, on data collected from a group of 155 elementary school children who met criteria for DD. Given the limited fit of these six models revealed by CFA, a post-hoc EFA was conducted to investigate whether a different structure was present that would better explain the internal structure of the CVLT-C in this sample. This exploratory analysis revealed a 3-factor model that did not significantly improve upon the previously proposed models from either a statistical or a theoretical standpoint. That being said, this retained 3-factor EFA model provides insights into the potential structure of verbal learning and memory within this population that differ from previously studied clinical and typically developing groups. Specifically, while the retained EFA model aligns in several ways with previous literature and theoretical conceptualizations of verbal learning and memory (and therefore with the previously proposed models tested via CFA), it also contains several characteristics that are inconsistent with previous research.

The second aim of this study was to explore the relationship between reading outcomes, as measured by word reading accuracy and passage comprehension, and verbal learning and memory. This relationship was described by the individual variables from the CVLT-C, as well as by the 3-factor model retained via the EFA. These analyses revealed that verbal learning and memory performance was more strongly related to passage comprehension than to word reading accuracy, although even these relationships were moderate. This pattern provides support for the higher-order language and executive functioning demands of both tasks and has meaningful implications for interpretation of CVLT-C performance in this population.

5.1 Confirmatory Factor Analyses

Regarding the first aim of this study, CFA results did not support our hypothesis that the best fitting proposed model for these data would be Model 6, which conceptualized that the key CVLT-C variables would best be explained by five factors (Attention Span, Learning Efficiency, Free Delay Recall, Cued Delay Recall, and Inaccurate Recall). In fact, results showed that, contrary to many previous studies of verbal learning and memory among clinical and non-clinical groups, none of the previously identified theory-derived models met a priori criteria for fit and parsimony and thus did not adequately represent the present data. Despite abundant previous literature supporting these models (see above for review), the original 1st hypothesis was rejected and, further, Models 1-6 were rejected for this sample.

5.2 Ancillary Exploratory Factor Analysis

Given the null findings regarding fit of the proposed models revealed via CFA, we conducted a post-hoc EFA. A 3-factor internal structure was retained through this analysis. From a statistical standpoint, this 3-factor model did not provide a clear advantage over the previously proposed, theory-derived models evaluated via CFA. More specifically, this EFA-derived model

did not demonstrate better fit or parsimony for these data. A comparison of the CFA and EFA models appeared to indicate that all models were picking up on the same general trends within the dataset. This suggests that no clear, parsimonious solution or model describes these data. Therefore, even the best model identified within the post-hoc EFA, the 3-factor model, did not appear to improve substantially upon the theory-driven CFA models from a statistical perspective.

Despite the limited fit of the EFA-derived model, the discrepancies observed in the factor indications of this model when compared to the previously proposed models provided insights into differences in CVLT-C performance in this population. From a theoretical perspective, the internal factor structure in the retained 3-factor EFA model was largely in line with previous literature and conceptualizations of verbal learning and memory, although several anomalies were noted. Here, we discuss these discrepancies as a means of exploring potential cognitive-linguistic differences among children with DD as compared to typically developing children.

5.2.1 EFA – Patterns consistent with previous literature

Across the 3-factor model retained via EFA, several CVLT-C variable pattern coefficients were largely consistent with the previous theoretical conceptualization of their function as well as with previous empirical findings among clinical and non-clinical groups. To reiterate the structure of this EFA model (Table 11): Factor 1, which we labeled Attention & Verbal Memory, had primary indications of: Short Delay Free Recall, Short Delay Cued Recall, Long Delay Free Recall, Long Delay Cued Recall, Middle Region Recall, Recall Consistency and Recognition Hits. The second factor, labeled Executive Functioning, had primary indications of: List A-Trial 5, Short Delay Free Recall, and Recall Consistency. Factor 3, labeled Inaccurate Recall, had primary indications from the Total Intrusions and Recognition False Positives

variables. First, we describe the elements of these indications that are consistent with previous theoretical and empirical literature.

5.2.1.1 Factor 1

First, all of the CVLT-C delayed recall variables (i.e., Short Delay Free & Cued Recall, Long Delay Free & Cued Recall, and Recognition Hits) significantly indicated Factor 1. These scores reflect a child's ability to recall words from the original word list after both short and long delays, under free recall and cued recall conditions. The contribution of all the delayed recall variables, regardless of delay duration or presence of cues, to the same factor is in line with the conceptualization of the unified Delayed Recall factor proposed in theory-based Model 3 (Donders, 1999). Model 3 proposed a verbal learning and memory structure consisting of three factors: Learning Efficiency, Delayed Recall, and Inaccurate Recall (Atkinson & Shriffin, 1968; Donders, 1999; Malmberg, Raaijmakers, & Shiffrin, 2019). The Delayed Recall factor in proposed Model 3 consists only of indications from these five variables, which reflects both theoretical foundations as well as empirical support differentiating between initial learning and delayed memory performance among healthy adults (Burton, Mittenberg, & Burton, 1993), adults with epilepsy (Banos et al., 2004), and child clinical samples (Burton, Mittenberg, Gold, & Drabman, 1999). Further, even when delayed recall performance variables were divided into two factors (Free Recall and Cued Recall) in Model 6, the most supported model across studies, researchers found that these factors shared approximately 90% of common variance (Donders, 1999). This coefficient pattern on Factor 1 is consistent with conceptualizations of strength of verbal learning and memory performance being fundamentally supported by depth of encoding. Thus, this result that all the delayed recall scores contribute to a shared factor is in line with previous literature across the standardization sample and clinical groups.

The Middle Region recall variable also significantly indicates Factor 1 of this EFA-derived model. This score reflects a child’s ability to learn and recall words from the middle portion of the original word list. Due to the relative difficulty of learning words from this portion of the list (as compared to those at the beginning and end of the list, due to primacy and recency effects), this score is traditionally interpreted as an indication of executive and attentional functioning (Donders, 1999). In the theory-derived models, this score is conceptualized to indicate the Learning Efficiency construct in Model 3 and upon the Attention construct in Models 4-6 (Donders, 1999). This indication is also in line with findings from the standardization sample’s best fitting Model 6, which illustrated that Learning Efficiency was strongly correlated with Free Delayed Recall (Donders, 1999; Malmberg et al., 2019; Rudner et al., 2013). Similarly, the present results indicate that this variable is positively associated with performance on delayed recall trials. This suggests that, as with typically developing children, recall from the middle portion of the target list may indeed be reflective of different levels of attention during learning trials among children with DD.

5.2.1.2 Factor 2

Interestingly, the only variable that primarily indicated Factor 2 and no other is List A-Trial 5. This score reflects the number of words a child is able to recall freely after being presented with the original word list five times. List A-Trial 5 is hypothesized to be related to a Learning Efficiency construct across previously proposed Models 4 – 6 (Donders, 1999). Performance on this final learning trial, in particular, is supported by both the child’s ability to retain and recall words, as well as her executive and attentional functioning skills, which enable independent organization of that verbal information (Atkinson & Shriffin, 1968; Donders, 1999; Malmberg, Raaijmakers, & Shiffrin, 2019).

Recall Consistency also significantly, although not solely, indicated Factor 2 (Executive Functioning) in this EFA-defined model of CVLT-C performance among children with DD. Recall Consistency is hypothesized to related to learning efficiency, as in proposed Models 3-6 (Donders, 1999). Thus, the indication of Recall Consistency on Factor 2 is in line with conceptualizations of executive functioning supporting increased verbal learning across trials.

5.2.1.3 Factor 3

Factor 3 was the only factor that was entirely consistent with previous theoretically and empirically supported models. This factor indicates children's errors in recall and recognition (i.e., intrusions and false positives) were not only strongly tied to one another, but also were negatively correlated with all scores reflecting accurate performance (Donders, 1999). In previously proposed Model 2, as well as all subsequent theory-derived models (i.e., Models 3-6), constructs distinguishing between accurate and inaccurate recall performance on the CVLT are defined. The Inaccurate Recall factor in those models aligns perfectly with Factor 3 (which we named the same) in the present model and includes the number of intrusion errors made during the free and cued recall trials as well as the number of false positive errors made during the recognition trial. These errors have been shown to negatively correlate with successful performance on the CVLT-C (Roman et al., 2002; Yeates et al., 1995). Further, more recent factor analysis has suggested that the inclusion of a distinct Inaccurate Recall factor significantly improves CVLT-II model fit among adults with epilepsy (Banos et al., 2004). Thus, this factor is fully consistent with previous literature and suggests that patterns of accurate and inaccurate performance within this sample of children with DD are in line with the patterns observed in clinical and non-clinical groups.

5.2.2 EFA – Patterns inconsistent with previous literature

Several elements of this factor structure were inconsistent with previous theoretical formulations and empirical findings. These characteristics are discussed in detail below.

5.2.2.1 Factor 1

First, while the indications of all delayed recall variables on one factor (Factor 1) was in line with previous findings, that these variables were not the only indications upon Factor 1 in the present EFA-derived model stands in contrast to previous theoretical and empirical evidence. This suggests less differentiation among CVLT-C variables than is predicted by previously supported models across multiple groups (e.g., Donders, 1999). That these traditionally uniquely tied variables (i.e., all delayed recall scores) are here strongly associated with several other variables suggests that within this sample, performance across these scores does not reflect constructs that function in the same way as among other clinical and non-clinical groups. In other words, performance on these CVLT-C components may be systematically different from that of other groups. It is possible that the relatively large number of variables indicating upon Factor 1, and the range of theoretical constructs they traditionally represent (i.e., attention and broad verbal memory) suggests less differentiated skill sets than would be predicted based upon previous theoretical conceptualizations and empirical findings.

Second, in addition to the significant positive indication on Factor 2, Recall Consistency performance also significantly indicated Factor 1. Interestingly, this indication was negative and functionally suggests that a child’s ability to consistently recall the same words across learning trials is conversely related to her delayed recall and ability to recall words from the middle of the list. This finding is inconsistent with previous literature and conceptualizations of verbal learning and memory (e.g., Atkinson & Shriffin, 1968; Donders, 1999; Malmberg, Raaijmakers, &

Shiffrin, 2019). In the context of the previously proposed Models 3 – 6, Recall Consistency is hypothesized to indicate the Learning Efficiency construct, along with List A, Trial 5 and Semantic Clustering performances (Donders, 1999). Based on previous research, we would expect that Recall Consistency would be only associated with Factor 2. It is unclear why this variable is negatively related to Factor 2, or what the implication is for this pattern within this sample of children with DD.

5.2.2.2 Overlapping indications

Notably, two of the three variables associated with Factor 2 also significantly indicated Factor 1. In addition to Recall Consistency, in which indications were in opposite directions for the two factors such that it was negatively related to Factor 1 and positively related to Factor 2, Short Delay Free Recall was noted to have practically equal indicating upon Factors 1 and 2. Short Delay Free Recall represents a child's ability to independently recall verbal information following a delay with interference, without the help of a semantic cue. As previously discussed, across the theory-derived models this variable is hypothesized to indicate only delayed recall constructs (Donders, 1999). It has been reported, however, that executive and attentional functioning skills supporting learning are strongly correlated with free delayed recall performance (Donders, 1999), which is in line with verbal learning and memory theory that suggests the elaborative rehearsal strategy use leads to stronger overall memory performance (Malmberg et al., 2019; Rudner et al., 2013). The present EFA suggests that, within this sample of children with DD, performance on Short Delay Free Recall is indeed tied equally with indicators of attention and verbal memory (i.e., Factor 1) as well as with those of executive functioning (i.e., Factor 2). This may be related to the Short Delayed Free Recall trial in children with DD being more impacted by the interference effects of List B recall, which would be related

to their attentional and executive functioning abilities. The shared indications of these two variables across two factors further contribute to a larger picture of this data as representing potentially poorly differentiated skills or constructs associated with verbal learning and memory in this population.

5.2.2.3 Non-indicating variables

Three of the CVLT-C variables were not found to significantly indicate any of the factors: List A-Trial 1, List B, and Semantic Clustering. This pattern does not reflect the previous studies describing the internal structure of verbal learning and memory, or the broader theoretical conceptualization of verbal learning and memory (Atkinson & Shriffin, 1968; Donders, 1999; Malmberg, Raaijmakers, & Shiffrin, 2019). Indeed, List A-Trial 1 and List B, which both reflect the child's ability to initiate new learning and to recall words after just one presentation of a word list, are hypothesized to relate to a Learning Efficiency construct (Model 3) or to an Attention construct (Models 4-6) in the theory-derived models (Donders, 1999). These conceptualizations are supported by empirical evidence (Banos et al., 2004; Burton et al., 1999; Burton et al., 1993; Burton et al., 1996; Donders, 1999; Griffiths et al., 2006). Therefore, it is surprising that in the present sample these scores do not significantly indicate either the Attention & Verbal Memory or the Executive Functioning factors (Factors 1 and 2, respectively), as would be expected. Functionally, this pattern may suggest that children with DD approach initial verbal learning in a substantively different way, which does not relate to traditional conceptualizations of learning efficiency, than previously studied groups.

Similarly, Semantic Clustering, which describes a child's tendency to recall semantically related words consecutively during recall, is traditionally thought to relate to executive functioning, as it requires conceptual reorganization of the word list. In theory-derived Models 3-

6, this variable was hypothesized to indicate the Learning Efficiency construct (Donders, 1999). However, here, this score is not significantly associated with the Executive Functioning factor, as we would expect. Functionally, this may indicate that these children with DD are somehow approaching the recall task in a significantly different way than other clinical and non-clinical groups. In other words, it is possible that these children's utilization of semantic strategies is the result of uneven executive functioning, language functioning, or both, resulting in a profile in which this metric does not relate to other indicators of successful verbal encoding, retention, and retrieval.

Notably, all of three of the variables that are not captured by this 3-factor EFA-derived model are theoretically related to a child's attention and executive functioning abilities, and more specifically, to their apparent inability to develop an organized strategy, especially initially, to assist in their learning like other clinical groups. It is possible that these larger constructs function differently in this sample than they do in the standardization sample and in other clinical groups (e.g., Banos et al., 2004; Burton et al., 1999; Burton et al., 1993; Burton et al., 1996; Donders, 1999; Griffiths et al., 2006). Given the high base rate of co-morbidity between DD and ADHD (Sexton, Gelhorn, Bell, & Classi, 2012), it is possible that these results reflects a unique pattern of neurocognitive differences related to executive functioning present within this sample that has not been observed in other clinical and non-clinical groups. More likely, it is possible that a subgroup of children within this sample meets criteria for both DD and ADHD, while another subgroup does not exhibit this co-morbidity. This possible subgrouping may serve to increase the noise in this sample because the two groups scores vary systematically different from one another, thereby limiting our ability to detect a parsimonious internal structure. At any rate, the present model, which does not include significant indications from three key CVLT-C

variables, is not supported by pervious literature and it remains surprising that these variables do not align with other scores or with each other.

5.3 Aim 1: Limitations (CFA & EFA)

Several issues arose in addressing the first aim of this study. First, the presence substantial overlap of variables indicating multiple factors within the EFA model (i.e., the 2 variables that significantly indicate Factors 1 and 2, described above). This suggests that, at least within this sample, there is no simple, parsimonious structure, which is supported by the limited incremental value added when comparing across models via CFA and EFA. Additionally, several variables were not associated with the retained, best fitting EFA model, suggesting this model not only inadequately describes the data, but also does not align well with the theoretical foundations of the task and decades of empirical evidence supporting these conceptualizations.

There are several possible explanations for the limited fit of CFA and EFA models to these data. First, the sample is somewhat small for these types of analyses. The present sample was composed of data from 155 participants. This sample size meets recommendations for CFA, which state that sample size needs to be at least 100 and at least 10x the number of variables (Yong & Pearce, 2013). However, we are aware that this study is on the smaller end of sample size that would be preferred for such an analysis, which may result in a quirk or unknown bias within the dataset having an outsized effect on the overall model. Indeed, similar studies utilized samples of 175 participants (Mottram & Donders, 2005), 205 participants (Carlew et al., 2018), 223 participants (Dejong & Donders, 2009), 289 participants (Griffiths et al., 2006) and 388 participants (Banos et al., 2004). Notably, each of these studies utilized the same approach, CFA, and identified a best fitting model among the same six models we tested here.

Beyond complications arising from sample size, it is possible that the skills tapped by these CVLT-C variables are poorly differentiated within this sample. In particular, given the high level of co-morbidity of language and attentional difficulties among children who meet criteria for DD (i.e., Language Impairment and Attention Deficit/Hyperactivity Disorder), it is possible that challenges with higher-order language and/or executive and attentional functioning skills within subgroups of this sample may be contaminating or altering the structure indications described within these models. It is likely that both language skills and attention/executive functioning skills underlie all aspects of CVLT-C performance. An uneven profile of skills and deficits across these foundational domains may be present in this small sample that would complicate and potentially contaminate estimated patterns.

5.4 Aim 2

Given the limited fit revealed by CFA of the six previously proposed models, and subsequent the rejection of our first hypothesis, we were not able to directly evaluate the relationship of a best-fitting model to reading performance. Instead, we first explored how individual CVLT-C scores related to reading performance at the level of word decoding and passage comprehension. Additionally, we evaluated the relationship between factors from the CVLT-C 3-factor model retained through the EFA and reading performance on the SRI-2.

5.4.1 CVLT-C z-score correlations

Correlations among all individual study-relevant CVLT-C z-scores and the SRI-2 scores highlighted three main findings. First, Passage Comprehension performance was significantly correlated with all CVLT-C scores, except Semantic Clustering, Middle Region recall and Recall Consistency. It was significantly negatively correlated with the error variables. In other words, these results indicate passage comprehension performance is strongly tied to broad aspects of

verbal learning, particularly scores that reflect attention, learning efficiency, and delayed recall. This pattern is consistent with previous research indicating that reading fluency and passage comprehension are tied directly to verbal learning and memory (Pham & Hasson, 2014; Roch et al., 2012).

Second, Word Reading Accuracy was only significantly correlated with CVLT-C Recognition of False Positives performance. While this is somewhat unexpected given the extensive evidence linking word reading skills to verbal learning and memory abilities (Kibby, 2009; Littlefield & Klein, 2005; Perez et al., 2012), it may be the case that the core deficit in decoding that characterizes this clinical DD sample impacts performance on these two tasks (CVLT-C and SRI-2 Word Reading Accuracy) and/or that the relationship between these two constructs (verbal learning and word reading) differently than it does among typically developing peers.

Third, this correlational analysis confirmed that, as expected, the components of the SRI-2 are significantly correlated with each other in this sample. This finding is encouraging as it is expected that these scores would be interrelated and further supports the nuanced finding that CVLT-C performance differentially relates to Passage Comprehension, despite the strong association with Word Reading Accuracy.

5.4.2 CVLT-C factor correlations

Despite the limited fit of the 3-factor structure retained from the EFA, we nonetheless conducted a follow-up correlational analysis of the relationship among these factors and reading performance at the word reading and passage comprehension levels.

Consistent with the correlational findings from the individual CVLT-C scores, Attention and Verbal Learning (Factor 1) and Executive Functioning (Factor 2) were significantly

positively related to Passage Comprehension. These results suggest that even though this model does not capture or explain all of the variables adequately, the CVLT-C framework does align with functional outcomes (i.e., higher-level reading performance). Further, this finding supports the conceptualization that multiple components of verbal learning and memory processes relate to reading comprehension. These results align with previous research demonstrating that short-term verbal learning and memory (Cain et al., 2004; Spooner et al., 2006), and higher-level executive functioning (Landi & Ryherd, 2017; Locascio et al., 2010) contribute to reading comprehension across development.

Inaccurate Recall (Factor 3) was negatively correlated with Passage Comprehension. This result is also in line with the results of the correlational analyses described above. In other words, despite the inadequacies of this model, results indicate it does relate to functional outcomes in a manner consistent with expectations based upon individual scores. Additionally, the negative relationship between errors in verbal learning and memory was expected based upon previous research suggesting stronger performance in verbal learning and memory predicts more successful passage comprehension skills (Pham & Hasson, 2014; Roch et al., 2012).

Finally, Word Reading Accuracy on the SRI-2 was not significantly related to any of the CVLT-C factors defined by the EFA model. This is again somewhat surprising from a theoretical standpoint, although it aligns with the pattern observed from the correlations of the individual CVLT-C z-scores. Indeed, reading comprehension is a multi-factorial skill that is supported by multiple concurrent abilities and processes: children must efficiently and accurately identify phonemes with their visually symbolic representations, connect these word forms with semantic meaning, and hold these individual words in mind while integrating them with larger syntactic

information in order to comprehend complex sentences and even longer texts (e.g., Cain, Oakhill, & Bryant, 2004).

Taken together, results from Aim 2 correlational analyses suggest that verbal learning and memory performance is associated with passage comprehension performance but not with word reading accuracy. While it is somewhat surprising that, at least within this sample, verbal learning does not appear to strongly relate to decoding abilities but instead appears closely tied to passage comprehension, this association may be explained by the shared demands on complex executive functioning and language skills. While substantial evidence supports the link between verbal learning and memory and reading at all levels, the high-level complexity of the CVLT-C is in line with higher-order demands of passage comprehension (i.e., requires working memory & executive functioning over and above pure decoding). Indeed, both successful word list learning and memory and successful text reading comprehension involve a child integrating multiple perceptual and cognitive processes including attention, auditory and visual processing, short-term storage (or working memory), executive functioning, and language comprehension. It is possible that children in this sample, who are known to exhibit core deficits in decoding (i.e., word reading accuracy), may have a different pattern of language abilities or have a different relationship between word reading and passage comprehension than typically developing children. It is also likely that a subset of these participants meet criteria for co-morbid Language Impairment and/or Attention Deficit/Hyperactivity Disorder, which may differentially impact the relationship between verbal learning and memory performance and reading outcomes. Unfortunately, we do not have a large enough sample to further explore that subset possibility.

6 CONCLUSIONS

None of the proposed models, derived from theoretical research on verbal learning and memory, fit well the data within this sample. Further, exploratory factor analysis did not reveal an alternative internal structure that better explained the CVLT-C data from either a statistical or theoretical standpoint. Several possible reasons for the limited fit of these confirmatory and exploratory CVLT-C models include: the relatively limited sample size, the lack of a simple, parsimonious structure (perhaps due to poorly differentiated or uneven language and/or executive functioning skills among these participants), and the potential that a subset of children within this sample also meet criteria for Language Impairment and/or Attention Deficit/Hyperactivity Disorder, which may contribute to and interact with the previously mentioned complications.

Despite these limitations, the present study highlighted the stronger relationship between verbal learning and memory skills, as measured by the CVLT-C, and passage comprehension relative to word reading accuracy, as measured by the SRI-2. This finding is important for functional interpretation of the widely used CVLT-C. Especially in the context of the global COVD-19 pandemic, which increases the need for remote and/or socially distanced neuropsychological evaluation, it is critical that neuropsychologists identify tests that are easily administered under such conditions and interpret them accurately. This study contributes to an understanding of the CVLT-C as well as its relationship with key academic outcomes, namely word reading accuracy and passage comprehension, within the particularly vulnerable population of children with DD.

In conclusion, the internal structure of CVLT-C performance among children with DD, as well as the nature of its relationship with reading, remains an outstanding question with

important implications for interpreting neuropsychological assessment data and prediction of academic performance. It is possible that among children who meet criteria for DD, these hypothesized CVLT-C factors are present or functioning differently than they do among typically developing children. This is important to understand in order to promote valid neuropsychological testing and interpretation.

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APPENDICES

Appendix A

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Scree Plot of Eigenvalues
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     ,                     4    5
   0 ˆ                              6    7    8    9
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         0    1    2    3    4    5    6    7    8    9    10    11    12    13

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