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STRUCTURAL LANGUAGE ABILITIES IN CHILDREN WITH ATTENTION-DEFICIT/HYPERACTIVITY DISORDER AND THE POTENTIAL ROLE OF WORKING MEMORY

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The contributions of working memory to structural language have been well studied in the general population. Additionally, many studies have examined working memory in children with Attention-Deficit/Hyperactivity Disorder (ADHD). Although children with ADHD often present with difficulties in structural language, few studies have examined the relationship between the three areas: ADHD, structural language and working memory. Hence, the present review will examine the literature on the relationship between working memory and structural language within the context of ADHD and the accompanying symptom dimensions, thereby attempting to address this dearth in the literature. A greater understanding of this relationship may contribute to a more holistic understanding of language profiles in ADHD and inform future studies. It also may inform and facilitate the development of specialized interventions targeting structural language deficits by encouraging the field to consider working memory in its intervention work.

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HEADING 1

INTRODUCTION

Attention Deficit-Hyperactivity Disorder (ADHD) is a highly prevalent childhood behavioral disorder, affecting approximately five percent of children (APA, 2013). The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) specifies two symptom dimensions of ADHD: inattentive and hyperactive/impulsive. The combination of symptom dimensions may result in the predominantly inattentive, predominantly hyperactive/impulsive, or combined presentation of ADHD (APA, 2013). Many neurodevelopmental and/or psychiatric conditions may co-occur with ADHD, including conduct disorders, mood disorders, autism spectrum disorder (ASD), learning disorders, and language disorders (Ghirwati et al., 2017; Mayes et al., 2008; Pliszka, 2015; Zablotsky et al., 2018). In addition, the extant literature repeatedly has documented executive functioning (EF) deficits, especially working memory (WM), among youth with ADHD.

Working memory (WM) may be a core impairment in ADHD and has received considerable attention as an underlying cognitive construct associated with various higher-order cognitively and linguistically related functions (Sung et al., 2017). In general, individuals with deficiencies in WM processes are at moderate to high risk for a broad range of disadvantages, including lower academic performance and scholastic achievement, increased rates of mood and/or behavioral problems, social interaction deficits, and language problems (Agnes Brunnekreef et al., 2007; Rapport et al., 2008a). Regarding language problems, WM deficits may lead to the production of irrelevant utterances, word-finding problems, impaired sequencing at the word and propositional level, tangential language, and verbosity (McDonald et al., 2013).

Difficulties in both the formal learning and application of language structure are common in neurodevelopmental disorders such as ADHD (Gilmour et al., 2004; Green et al., 2013; Hawkins et al., 2016; Sciberras et al., 2014). Structural aspects of language include the sounds of language (phonology), vocabulary (semantics), grammar (syntax and morphosyntax), narrative discourse, and auditory verbal information processing. Specifically, children with ADHD exhibit delays and disorders in phonological, semantic, and syntactic development at the group-level (Love & Thompson, 1988). However, the structural language impairment research on youth with ADHD has largely focused on language abilities underlying basic reading disability, including phonological processing. Meanwhile, less is known about their semantic and syntactic language abilities.

Some researchers posited difficulties related to inattentive and hyperactive/impulsive symptoms may disrupt the ability to learn language and social skills, at least through formal methods of teaching (Parks et al, 2021). Other researchers posited linguistic deficits may be due to the EF deficits commonly seen in ADHD (Beitchman et al., 1987). In contrast, developmental theorists hypothesized that general language ability both relies on, and facilitates, cognitive processes, such as holding information in short-term memory and attention control (Gartstein et al., 2007; Marchman & Fernald, 2008). Taken together, the development of language structuring processes in childhood may depend heavily on attentional, executive, and short-term/working memory processes (Brites, 2020).

Within the ADHD literature, several studies investigated language as a mechanistic explanation for executive functioning (e.g., Kuhn et al., 2014; Petersen et al., 2013; Petersen et al., 2014), but few studies investigated EF as a mechanistic explanation for language. Given the postulated bi-directional relationship between WM and language, this lack of holistic study of structural language abilities and related executive processes in children with ADHD has created a critical gap in the literature. Understanding the structural language profiles in youth with ADHD, in addition to the role of WM in structural language, is critical considering the importance of language competence for successful social and academic functioning (Bashir & Scavullo, 1992). Further, this understanding would be useful for accurately identifying children in need of special intervention and to better inform clinicians on their client’s areas of deficit.

HEADING 2

REVIEW OF THE LITERATURE

Overview

The current review of literature will investigate structural language functioning in children with ADHD, looking specifically at semantic and syntactic language abilities. Further, this review of literature will examine the relationship between ADHD symptom dimensions, working memory (WM), and semantic and syntactic language abilities. The first section of the review of literature will focus on ADHD. The subsequent section will focus on WM and its relation to ADHD. Next, I will detail the expressive/receptive semantic and syntactic aspects of structural language, followed by a discussion on the relationship between WM and structural language, as well as semantic and syntactic language abilities in ADHD. Finally, the review will summarize research integrating ADHD, WM, and structural language.

Throughout the review of literature, the term working memory (WM) will be used when referring to the whole WM system, including all of its components. When referring to a specific component of Baddeley and Hitch's (1974) WM model, I will use the specific term (e.g., phonological loop). At times, I will refer to verbal and visuo-spatial WM separately. Verbal WM then involves verbal short-term memory (STM) and central executive (CE) components, whereas visuo-spatial WM involves visuo-spatial STM and CE components.

Attention-Deficit Hyperactivity Disorder (ADHD)

Attention-Deficit/Hyperactivity Disorder (ADHD) is a heterogeneous disorder and one of the most common neurodevelopmental disorders in childhood, affecting between two to seven percent of all school-aged children and adolescents (Sayal et al., 2018). ADHD is characterized by developmentally inappropriate inattentiveness, impulsivity, and/or hyperactivity. These core symptoms of ADHD can profoundly affect a child's cognitive, academic, behavioral, emotional, and social functioning across settings (e.g., at home, in school, and/or with friends; Visser et al., 2014; Wilens & Spencer, 2010; Wolraich et al., 2019). Further, children with ADHD are more vulnerable than children without ADHD for developing other psychiatric disorders with comorbidity rates around 60% (Sciberras et al., 2017).

The contemporary concept of ADHD, as defined by the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5, APA, 2013), estimates current prevalence rates to be at five percent in children. The DSM-5 specifies two symptom dimensions of ADHD in children: inattentive and hyperactive/impulsive. According to the DSM-5, the inattentive dimension encompasses symptoms related to poor attention to detail, poor organization and planning, distractibility, difficulty sustaining attention, selectively attending to detail, poor divided attention, and other related symptoms (APA, 2013). The hyperactive/impulsive dimension encompasses symptoms related to excessive motor activity and energy, feelings of restlessness, difficulty waiting, lack of goal directed behavior, and other related symptoms (APA, 2013). From these two dimensions, the DSM-5 identifies three types of presentations of ADHD: predominantly hyperactive/impulsive (ADHD-HI); predominantly inattentive (ADHD-PI); and combined presentation (ADHD-C). The combined presentation must meet the definitions for both the inattentive dimension and the hyperactive/impulsive dimension.

According to evidence from several worldwide studies, ADHD-PI was the most common presentation diagnosed, followed by ADHD-C and ADHD-HI (Ayano et al., 2020). Further, the two most prevalent and commonly researched presentations were ADHD-PI and ADHD-C. Given the lacking empirical support for the hyperactive/impulsive presentation and its rarity past preschool/early elementary (Lahey et al., 2005; Hurtig et al.,2007; Todd et al., 2008), the literature investigating ADHD-HI was sparse. Thus, this review of literature will focus primarily on ADHD-PI and ADHD-C.

To receive a diagnosis of ADHD, a child must present with at least six inattentive symptoms and/or hyperactive/impulsive symptoms prior to the age of twelve. These symptoms must be present for at least 6 months in two or more settings (APA, 2013). ADHD-C is diagnosed when symptom thresholds are met for both dimensions. For older adolescents (17+), the DSM-5 requires only five symptoms for a domain to be considered significant. Although the DSM-5 is the most current and comprehensive resource used by mental health clinicians and researchers, much of the research cited in this review of literature was based on the DSM-IV criteria. Thus, the current study utilizes the DSM-IV definition of ADHD.

The Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV, APA, 1994) and the Diagnostic and Statistical Manual for Mental Disorder, Fourth Edition – Text Revision (DSM-IV-TR, APA, 2000) defined ADHD as a repeated pattern of inattentive and/or hyperactive/impulsive symptoms. The DSM-IV divided impairing symptoms into inattentive and hyperactive/impulsive dimensions and defined three nominal subtypes: predominantly inattentive type (ADHD-I), predominantly hyperactive-impulsive type (ADHD-H), and combined type (ADHD-C). The ADHD-I type included individuals with at least six inattentive symptoms but fewer than the specified number of hyperactive/impulsive symptoms. The ADHD-H type included individuals with at least six hyperactive/impulsive symptoms but fewer than the specified number of inattentive symptoms. The ADHD-C type included individuals with six or more symptoms on both dimensions. With the publication of the DSM-IV, the term ADHD was retained from the Diagnostic and Statistical Manual for Mental

Disorder, Third Edition –Revision (DSM-III-R, APA, 1987), along with the introduction of the three specific subtypes, as discussed above.

The Diagnostic and Statistical Manual for Mental Disorder, Third Edition –Revision (DSM-III-R, APA, 1987) combined age-inappropriate hyperactive/impulsive and inattentive symptoms into a single symptom dimension with one cut-off score (Lange et al., 2010). As a result of this, the presentation was quite variable across individuals diagnosed with the disorder. The DSM-III-R also included an “undifferentiated attention deficit disorder (UADD)” category for children with inattention only (Morgan et al., 1996). Further, the DSM-III-R introduced the term “ADHD,” eliminating the term “Attention-Deficit Disorder (ADD) with or without hyperactivity.”

Prior to the name change of the disorder mentioned above, the Diagnostic and Statistical Manual of Mental Disorders, Third Edition (DSM-III; APA, 1980) characterized the disorder as primarily a problem of inattention and could occur in two types: with or without hyperactivity. The DSM-III developed three separate symptom lists for inattention, impulsivity, and hyperactivity, each with its own explicit numerical cutoff score and specific guidelines for age of onset and duration of symptoms (Barkley, 2006; Lange et al., 2010). ADD with hyperactivity was characterized by age-inappropriate inattention, hyperactivity, and impulsivity, whereas ADD without hyperactivity was described as meeting criteria primarily in the inattentive and impulsivity symptoms.

Age of Onset

Although the DSM-5 (APA, 2013) permits a reliable diagnosis of ADHD symptoms at the age of four, most children are not assessed for ADHD until they are of school age. The 2016 National Survey of Children’s Health (NSCH; United States Census Bureau, 2017) reported the average age of onset for ADHD was about seven years old, but children with more severe cases of ADHD were diagnosed earlier. Further, the median age of diagnosis was five years for children with severe ADHD, seven years for children with moderate ADHD, and eight years for children with mild ADHD (NSCH; United States Census Bureau, 2017).

An analysis of the DSM-IV field trials revealed differences in ages at onset according to ADHD subtype, with the inattentive group exhibiting a later onset (Applegate et al., 1997). While onset of symptoms of ADHD must occur in childhood, most children continue to display symptoms and impairments through adolescence and into adulthood (Wolraich et al., 2019). According to Barkley and colleagues (1990), as many as 50% to 80% of children with ADHD continue to meet diagnostic criteria in adolescence.

Prevalence Rates

Amongst studies in the United States, there was a lack of consensus regarding the definition and estimation of prevalence of ADHD. The diagnostic criteria for ADHD have evolved as research has advanced our understanding of the unique characteristics of the disorder. In addition to changes in diagnostic criteria, the reported prevalence of ADHD varies based on differences in research methodologies, age groups, application of diagnostic criteria, and study populations (Faraone et al., 2003; Holbrook et al., 2016). Thus, these confounding factors make it difficult to compare prevalence data for ADHD across studies both within the United States and across countries.

Community vs. Clinical Rates. Community prevalence represents the number of individuals with ADHD in a representative population sample according to predefined criteria (Saval et al., 2018). Clinical prevalence, on the other hand, represents the number of individuals with clinically diagnosed and/or reported ADHD as a proportion of the whole population (i.e., the prevalence of diagnoses made in practice; Saval et al., 2018). Collectively, Wilcutt's (2012) systematic review suggested that the pooled clinical prevalence estimate of ADHD in children and adolescents was 7.2%. When assessing community-based samples, researchers reported higher estimates of ADHD ranging from 8.7% to 15.5% (Rowland et al., 2015; Wolraich et al., 2014). With regard to sex differences in community-based samples, ADHD appeared to be higher in boys than girls, with male to female ratios ranging from 2:1 to 3:1 (APA, 2003; Wilcutt, 2012). This higher male to female ratio was consistently reflected in clinical prevalence studies as well.

Many studies have estimated clinical prevalence by using only prescription data. When based on prescription data alone, systematic reviews suggested that the clinical prevalence of ADHD ranges from 0.6% (in under 18-year old's in 1987; Olfson et al., 2002) to 10% (in 7-11 year old's in 1995-1996; LeFever et al., 1999). However, the use of pharmacological and non-pharmacological treatment options for ADHD varies greatly between and within countries given that several factors can influence both the prescription and uptake of medication treatments. Thus, studies that only reported prescription data are unlikely to reflect the true clinical prevalence. When based on ADHD diagnosis, systematic reviews suggested that the reported clinical prevalence ranges from 0.93% (in 2–5-year-olds in 2002; Fontanella et al., 2013) to 11.0% (in 4–17-year-olds in 2003 to 2011; Visser et al., 2014).

Co-occurring Language Problems

When compared to typically developing children, children with ADHD are at increased risk for several markers of language problems, including delayed onset of first words and word combinations, reduced performance on standardized language tests (vocabulary, syntax, reading fluency, and short-term memory), limited discourse for producing cohesive narrative, and reduced pragmatic language associated with inappropriate conversational participation (for a review, see WA, 2018). In addition, inattentive and hyperactive/impulsive symptoms of ADHD have been implicated in language abilities because successful communication depends on the ability to maintain attention, focus on others, and follow the rules of nonverbal interaction (Bruce et al., 2006; McInnes et al., 2003; Parks et al., 2021). As will be detailed later in the review, a robust body of research has consistently reported an elevated prevalence of receptive (comprehension) and/or expressive (production) language problems among children with ADHD in both clinical and community samples (see Korrel et al., 2017 for a review). Some of these linguistic deficits may be due to executive functioning deficits commonly seen in ADHD as opposed to a more 'pure' structural receptive and/or expressive language deficit.

Executive Functions

Executive functions (EF) refer to a family of top-down cognitive processes involved in organizing information, carrying out goal-directed behavior, and planning (Diamond, 2013; Friedman, 2017). They are an important correlate of children's mental and physical health; academic performance and school success; quality of life; and cognitive, social, and psychological development (for a review, see Diamond, 2013). Although ADHD is typically defined based on symptom dimensions that describe behavior, many researchers have suggested that weaknesses in executive functions are also integral features of ADHD (e.g., Adler et al., 2017; Barkley, 1997, 2011; Brown, 2005; Chan & Fugard, 2018).

As a group, children with ADHD often display weaknesses in executive functioning, yet tend to be quite heterogeneous in their EF profiles (Nigg, 2005). Findings from Kofler and colleagues (2019) reported 89% of children with ADHD exhibit deficits in at least one EF, with 62% having an impairment in working memory (WM), 27% having an impairment in inhibitory control, and 38% having an impairment in cognitive flexibility. Despite these differences, extant research identified inhibitory control and WM as two of the most promising EFs for explaining a wide array of ADHD symptoms. Specifically, meta-analytic studies found medium to large-level group effect sizes on tasks intended to assess WM and inhibitory control (Alderson et al., 2007; Kasper et al., 2012; Lijffijt et al., 2005; Martinusssen et al., 2005; Willcutt et al., 2005). Further, WM has received considerable attention as an underlying cognitive construct associated with various higher-order cognitively and linguistically related functions (Sung et al., 2017). Thus, this review will focus on WM in youth with ADHD. Evaluating other EFs is beyond the scope of this review.

Working Memory

In general, working memory (WM) has been defined as the capacity to actively maintain and manipulate information in one’s mind over a short period of time (Baddeley, 2012). It is a key function that underlies many cognitive tasks (i.e., remembering instructions and completing tasks), and it is implicated in practical applications such as academic learning, reasoning, and planning (Nigg, 2000). While several conceptualizations of the nature, structure, and function of WM exist, the predominant theoretical model of WM used in neuropsychology is Baddeley and Hitch’s (1974) multi-component model.

Baddeley’s functional model defines WM as a limited capacity system that allows for the temporary storage, rehearsal, and manipulation of internally held information for use in guiding behavior (Baddeley & Hitch, 1974). As will be detailed below, Baddeley and Hitch (1974) proposed three distinct components of WM: a central executive (CE) and two domain specific slave systems (the phonological loop and visuo-spatial sketchpad). Baddeley (2000) proposed a fourth component to his WM model referred to as the “episodic buffer.” This component will also be discussed.

Phonological Loop. The phonological loop rehearses and stores cognitively constructed speech/language information. This memory store has also been referred to as phonological or verbal STM in the multicomponent WM model. Further, this store is comprised of two subcomponents: the phonological store and the articulatory rehearsal process (Baddeley & Hitch, 1974). The phonological store is a storage component that receives information directly and automatically from speech (Baddeley, 1986). The articulatory rehearsal process is a maintenance component, analogous to inner speech, used to maintain material within the phonological subsystem. Phonological information can be held in the phonological store for approximately 1.5-2 seconds and decays if not actively refreshed and maintained by the articulatory rehearsal process (Baddeley, 1992; Schuchardt et al., 2011). Hence, the role of the articulatory rehearsal process is to counteract the decay by periodically refreshing the contents of the phonological store by way of subvocal rehearsal, or inner speech (Buchsbaum, 2013). The phonological loop is assumed to support performance on measures of phonological short-term memory (STM), such as forward digit and word span tasks, word list tasks, and nonword repetition tasks (Baddeley, 2003).

Visuo-Spatial Sketchpad. The visuo-spatial sketchpad parallels the phonological loop, acting as a subsystem for storage and manipulation of non-verbal visual and spatial information (e.g., shape, color, and location). The visuo-spatial sketchpad is a limited capacity storage component, able to hold approximately three to four items at a time (Baddeley, 1986). Further, it plays a key role in the generation and maintenance of mental images. This memory store has also been referred to as visuo-spatial STM in the multicomponent WM model. Measures of visuo-spatial STM include forward spatial span tasks and spatial learning tasks (Kibby & Cohen, 2008).

Central Executive. The central executive (CE) is not a memory system per se but instead monitors and coordinates the processes of the two subsystems of WM (Baddeley, 2000). Specifically, the CE is thought to be a domain-general resource primarily responsible for directing attention to relevant information; shifting attention between information used to perform tasks of planning and decision making; suppressing irrelevant information and inappropriate actions; and coordinating cognitive processes when more than one task is carried out at the same time (Fabio et al., 2019). It has been informally referred to as the "working" part of WM. The CE is also thought to act on information retrieved from long-term memory to support complex cognitive activities such as mental calculation, language and reading comprehension, and text generation (Engle, et al., 1999; Gathercole, 1999; Martinussen et al., 2005). It is typically measured through tasks that tap simultaneous process and storage of verbal and/or visuo-spatial information. Updating tasks, such as the n-back, are commonly used to measure the CE (Kirchner, 1958). Other CE tasks include backward and/or sequenced spatial and/or digit span tasks, mental arithmetic, complex verbal tasks and mental route following (Daneman & Carpenter, 1980; Peng et al., 2017).

Episodic Buffer. The episodic buffer was proposed as a limited capacity storage system responsible for integrating information from several sources to create a unified memory (Baddeley, 2000). The episodic buffer supposedly does this by "binding" information from the various subsystems of working memory (e.g., phonological loop, visuo-spatial sketchpad) and relevant activated long-term semantic and linguistic knowledge into a coherent whole (Henry & Winfield, 2010). Although some researchers assert the existence of the episodic buffer through support from dual-task paradigms (e.g., Baddeley, 2007; Morey, 2009; Was & Wolts, 2007), many researchers have raised concerns about its existence and functioning (Allen et al., 2006; Gathercole, 2008; Henry, 2010; Jefferies et al., 2004).

For instance, the boundaries between the episodic buffer and two subsystems of WM, as well as the boundaries between the episodic buffer and episodic long-term memory, are unclear (Baddeley, 2000). Given that the episodic buffer emphasizes the integration of information, clearer understanding about the role of executive processes in chunking may elucidate these boundaries (Baddeley, 2003). Moreover, research is needed to discern relatively automatic binding of properties of normal perception from the more active and attentionally demanding, integrative processes that are assumed to play a crucial role in the episodic buffer (Baddeley, 2017). Taken together, the episodic buffer has not been fully embraced by the neuropsychological literature, likely because it has been difficult to create valid tasks to measure its function. Hence, it will not be discussed further.

ADHD and Working Memory

Research has identified WM as one of the most impaired domains in individuals with ADHD when compared to healthy controls (Cockcroft & Alloway, 2012; Mayes & Calhoun, 2007; Moura et al., 2019; Theiling & Petermann, 2016). One meta-analytic study suggested that up to 80% of children with ADHD have a WM deficit (Kasper et al., 2012). Another meta-analytic study found a medium effect size of 0.56 when examining verbal WM deficits in youth with ADHD and compared to typically developing controls. Additionally, they found a medium effect size of 0.63 when examining visuo-spatial WM deficits. However, within that analysis there was a wide heterogeneity in effect size and impairment estimates across studies, suggesting that WM is not universally impaired in ADHD. Fosco and colleagues (2020) suggested that this heterogeneity may be due to an underappreciation of the multi-component nature of the WM construct, resulting in little consideration of the aspects of WM that were being evaluated. Nonetheless, converging evidence indicated that children with ADHD are impaired in all three components of Baddeley's WM model at the group level, with the largest/most common deficits found in the CE, followed by the visuo-spatial sketchpad and then the phonological loop (Fosco et al., 2020; Gibson et al., 2016; Kasper et al., 2012; Kofler et al., 2019; Kolterman et al., 2020; Martinussen et al., 2005; Martinussen & Tannock, 2006; Rapport et al., 2008a).

Central Executive

One complicating factor in WM research has been differences in defining WM constructs, resulting in inconclusive findings about WM in ADHD. Some WM theories differentiated between maintenance and manipulation, qualifying only manipulation as true WM, with maintenance as simple recall (Rapport et al., 2013). Other WM models considered both maintenance and manipulation as WM operations of varying complexity (D'Esposito et al., 1999; Jolles et al., 2011; Rypma et al., 2002). Baddeley proposed a 3-component system including 2 short-term stores and a domain-general central executive (CE), others have suggested the CE component of it should be updated to include a domain-specific system for easier CE tasks and a domain-general system only for very challenging tasks. For instance, Cornoldi and Vecchi (2003) suggested that WM functions on a continuum, in which the CE functions flexibly and assists in domain-specific WM tasks. According to this view, domain specificity is found when tasks have a lower CE demand (e.g., Digit Span Backward), whereas domain-generality is found when tasks have a high CE demand (e.g., effortful experimental tasks; Cornoldi & Vecchi, 2003; Kasper et al., 2012). As such, results regarding the CE can be domain-specific in nature.

Verbal Central Executive. Several studies have demonstrated difficulties in verbal CE in individuals with ADHD, most commonly measured with a digit span test, in individuals with ADHD (Alderson et al., 2014; Martinez et al., 2018; McInnes et al., 2003; Rohlf et al., 2021; Willcutt et al., 2005). Results from Ramos and colleagues' (2019) meta-analysis reinforced verbal WM as a key domain of cognitive dysfunction in ADHD. They found a medium effect size of 0.56 when examining verbal WM deficits in youth with ADHD and compared to typically developing controls. Martinussen and colleagues' (2005) meta-analysis yielded a modest effect size of 0.43 when examining verbal CE deficits in children with ADHD and compared to typically developing controls. In this meta-analytic study, measures of verbal CE included tasks that required both maintenance and manipulation of verbal stimuli. Similarly, Martinussen and Tannock (2006) found an effect size of 0.6 when examining verbal CE deficits in youth (7-13 years-old) with ADHD and compared to controls. Consistent with these findings of moderate effect sizes, verbal CE deficits are not found in some studies (Kibby et al., 2004, 2012; Kibby & Cohen, 2008, Sowerby et al., 2010; Pineau et al., 2019; Pallas, 2003; Rucklidge & Tannock, 2002; Willcutt et al., 2001).

Kibby & Cohen (2008) examined WM functioning in a clinic sample of children with ADHD and found that children with ADHD demonstrated intact CE when using verbal measures from the Children's Memory Scale (CMS; Cohen, 1997). Although the children with ADHD performed worse than controls on a measure of verbal WM, children with ADHD ultimately performed comparably to controls when problems with the phonological loop and focused attention were controlled. Based on these findings, they suggested that the CE is intact in ADHD and that verbal WM deficits, when they are found, are related to focused attention and potentially linguistic deficits (Kibby & Cohen, 2008).This proposition has been widely supported by a body of literature suggesting that verbal WM is intact in many individuals with ADHD (Kerns et al., 2001; Kuntsi et al., 2001; Pallas, 2003; Rucklidge and Tannock, 2002; Songua-Barke et al., 2008; Wilcutt et al., 2001; Pineau et al., 2019; Sowerby et al., 2010).

Visuo-Spatial Central Executive. In contrast with verbal CE, deficits with visual-spatial CE are more consistently found in children and adolescents with ADHD (Kibby & Cohen, 2008, Martinussen et al, 2005; Sowerby et al., 2010; Kasper et al., 2012; Kofler et al., 2019; Spronk et al., 2013). Martinussen and colleagues' (2005) meta-analysis yielded a large effect size of 1.06 when examining visuo-spatial CE impairments in children with ADHD compared to typically developing controls. In their meta-analytic study, measures of visuo-spatial CE included tasks that required both maintenance and manipulation of visuo-spatial stimuli. Results from Martinussen and Tannock (2006), as noted above, found an effect size of 1.1. Some researchers stated that there might be a developmental delay in visuo-spatial WM in individuals with ADHD. For instance, in a cross-sectional study, Sowerby and colleagues (2010) found visuo-spatial WM impairments in younger (6–7-year-olds) and older (8–12-year-olds) children with ADHD-C, compared to their typically developing peers. In another study, Westerberg and colleagues (2004) assessed visuo-spatial WM performance in boys (8-12 years old) with and without ADHD and found an effect size of 1.34, indicating that visuo-spatial WM deficits in children with ADHD were significantly worse than their typically developing peers. Further, these visuo-spatial WM deficits were the largest during adolescence (Westerberg et al., 2004).

Taken together, the research on the CE in ADHD is disparate, with some researchers finding it affected and others findings it spared, especially when the tasks utilized verbal material. Thus, CE functioning in youth with ADHD warrants further investigation. From a domain-general perspective, both verbal and visuo-spatial WM should be equally affected by CE deficits. However, some researchers depict something different. One possibility is that differing STM deficits are driving the varying WM deficits in ADHD. Hence, the extent to which ADHD is associated with impairments in the distinct phonological and visuo-spatial STM systems must be delineated.

Visuo-Spatial Sketchpad

Several researchers demonstrated that scores on spatial span tasks (as well as other visuo-spatial STM tasks) performed by children with ADHD were significantly lower than the scores of typically developing peers (e.g., Kasper et al., 2012; Narimoto et al., 2018; Westerberg et al., 2004; Wilcutt et al., 2005). Martinussen and colleagues' (2005) meta-analysis found an effect size of 0.85 when examining spatial storage deficits in children with ADHD. Martinussen and Tannock's (2006) study supported these findings. They found an effect size of 0.7 when examining visuo-spatial storage deficits in children with ADHD compared to typically developing youth. Nonetheless, some studies have found visuo-spatial STM to be intact in ADHD (e.g., Alloway & Gathercole, 2006; French et al., 2003; Karatekin, 2004).

These discrepancies may be related to the nature of the visuo-spatial sketchpad. Specifically, the visuo-spatial sketchpad has separable subcomponents for visual/non-spatial material and spatial material. Results from a study by Kibby and Cohen (2008), mentioned above, found that the visuo-spatial STM performance in children with ADHD was related to the type of material utilized (visual/non-spatial vs. visuo-spatial). They found that children with ADHD had mildly impaired visuo-spatial sketchpad when the task had low spatial demands, whereas their STM for visual/non-spatial material was intact (Kibby and Cohen, 2008). Results from this study suggested that deficits in nonverbal STM may be evident in children with ADHD when tasks contain a spatial component.

Phonological Loop

Regarding the phonological loop, several researchers have reported adequate performance in children with ADHD, particularly when they were focused on the task (e.g., Adams & Snowling, 2001; Kibby, 2012; Kofler et al., 2029; McInnes et al., 2003; Rucklidge & Tannock, 2002; Roodenrys, 2006). Specifically, Kibby and Cohen (2008) used select subtests from the Children's Memory Scale (CMS; Cohen, 1997) to assess verbal STM in children with ADHD. These subtests included Stories, Word Pairs, Word Lists, Numbers Backward, and Numbers Forward. Despite performing comparably to typically developing controls on most measures of verbal STM, children with ADHD had mild difficulties on Numbers Forward, which is often used to assess the functioning of the phonological loop. Based on this pattern of performance, Kibby and Cohen (2008) hypothesized that the phonological loop was intact in ADHD when tasks were more forgiving and allowed for brief fluctuations in attention. Not all studies agreed with these findings, however, suggesting that the phonological loop is impaired in children and adolescents with ADHD (e.g., Ackermann et al., 2018; Raiker et al., 2017; Rapport et al, 2008).

In an examination of the two primary components of the phonological STM subsystem, as described above, Bolden and colleagues (2012) found that both the phonological short-term store and the articulatory rehearsal were impaired or significantly underdeveloped in boys with ADHD relative to typically developing boys. Martinussen and colleagues' (2005) meta-analytic study found an effect size of 0.47 when examining verbal storage in children with ADHD. Similarly, Martinussen and Tannock (2006) found an effect size of 1.3 when examining phonological STM in children with ADHD and compared to their typically developing peers. Taken together, there remains a discrepancy in the research on STM deficits in ADHD, although deficits in visual-spatial STM are more commonly found than those in verbal STM. It is unknown how much of the verbal STM deficits that are found are due to inattention versus an encoding problem.

Dimensional Differences

In addition to separating the specific components of WM and examining their deficits in ADHD, it is also important to examine WM deficits and their associations with ADHD symptoms. Findings from many studies suggested that WM impairments are more strongly associated with the inattentive symptom dimension than with the hyperactive/impulsive symptom dimension of ADHD (Castellanos & Tannock, 2002; Elisa et al., 2016; Kasper et al., 2012; Klingberg et al., 2005; Kofler et al., 2009; Lui & Tannock, 2007; Martinussen et al., 2005; Martinussen & Tannock, 2006; Molavi et al., 2020; Mulder et al., 2011). Further, some researchers hypothesized that children with and without ADHD can attend equally well while engaged in activities that place minimal demands on WM but will exhibit higher rates of inattention during activities that require considerable CE resources (i.e., complex span tasks; Orban et al., 2017). Nonetheless, some studies reported deficits in children with ADHD on visuo-spatial STM tasks that required sustained attention over brief and/or extended periods of time (Holmes et al., 2010; Pasini et al., 2007; Solanto et al., 2007).

Regarding the hyperactive/impulsive symptom dimension, some researchers have investigated excess motor activity as a compensatory mechanism that facilitates neurocognitive functioning in children with ADHD. These researchers have found a significant, positive relationship between CE functioning and activity level in children with ADHD, suggesting that higher rates of activity level improve, but do not normalize, WM performance for children with ADHD (Rapport et al., 2008b; Sarver et al., 2015; Patros et al., 2017). In contrast, some ADHD models predict relatively stable and high activity levels for children with ADHD that is either unrelated cross-sectionally (Halperin & Schulz, 2006) or negatively related to deficits on tests of executive functions, such as working memory (Barkley, 1997; Campez et al., 2021; Hudec et al., 2015; Kofler et al., 2016; Patros et al., 2015; Raiker et al., 2012). Taken together, there is still a need to understand and empirically document the nature of WM impairment in relation to symptoms of ADHD.

Summary

Among youth with ADHD, performance on WM tasks is seemingly dependent on the modality of the WM measure (verbal vs. visuo-spatial) and the magnitude of the demands of the CE component. Youth with ADHD consistently demonstrate deficits with visuo-spatial STM and WM, whereas the literature on verbal STM and WM was disparate. Further, WM tasks with high demands on the CE component seemed most impaired in children with ADHD. These tasks included those that required examinees to remember stimuli and later recall them in a different pattern than the originally presented sequence, or those that required the examinee to compare a newly presented stimulus with a representation in WM and to update the representation (Kofler et al., 2020; Martinussen et al., 2005; Ortega et al., 2020). Additionally, many researchers have suggested that deficits in WM may be more strongly related to the inattentive symptom dimension of ADHD. In fact, Willcut and colleagues (2005) suggested that verbal and visuo-spatial STM and verbal CE contribute to the inattentive symptom dimension of ADHD.

Language

Language is often characterized as a dynamic, structured, and complex communication system which involves different types of information that are created according to certain rules (Chomsky, 2007). In brief, the language system encompasses how words are created and put together, the meaning of those words, and how to apply language in different contexts. Language and communicative competence provide critical tools for learning, engaging in social relationships, and behavior and emotion regulation (Cohen, 2005). Hence, the development of language skills is one of the most important achievements of early childhood.

Modes of Language

There are two primary language categories: receptive language or expressive language. Receptive language refers to a child's ability to understand what they see (i.e., movement, gestures, signs, and symbols) and/or what they hear (i.e., sounds and words). It encompasses word discrimination, vocabulary comprehension, and grammar comprehension (Frazier, 2011b). Expressive language refers to a child's ability to express specific wants and needs through verbal or nonverbal (i.e., gestures, signs, and symbols) communication. It encompasses word articulation, sentence imitation, and narrative production (Frazier, 2011a). While receptive language appears to play an important role in the development of expressive language, expressive language does not influence the development of receptive language to the same degree (Gibson et al., 2012). Throughout this review of literature, the term language comprehension will be used interchangeably with the term receptive language. Similarly, the term language production will be used interchangeably with the term expressive language.

Structural Language

According to Cohen (2005), two domains are typically considered by the language construct: structural language and pragmatic communication. Structural language refers to individual words and how these words are strung together into phrases and sentences. More specifically, the structural aspects of language include the use of morphology, phonology, semantics, and syntax. These skills are important for literacy development and for expressing and understanding language in communication (Cohen, 2005). As aforementioned, this review will focus primarily on syntax and semantics. Examining all aspects of structural language is beyond the scope of this review.

Syntax refers to the structure of phrases and sentences and how the words relate to each other within the phrase or sentence. The process of building syntactic structure (syntactic formulation) involves assigning grammatical functions (e.g., subject, object) to the selected lexical items, computing the relationships between grammatical constituents and their linear order, and assigning the appropriate morphology. Further, syntax involves following and understanding how the arrangement or combination of words affects the meaning of the sentence (Bock, 1990; Bock & Levelt, 1994). For instance, whereas most three-year-old's will know the individual words of the sentence, "The car hit the truck," correctly representing the sentence requires understanding of the importance of the sequence of words: 'car → hit → truck' not 'truck → hit → car' (Staffan and Etlinger, 2008). When assessing syntax, researchers typically assess two aspects of syntax: syntactic knowledge and syntactic awareness. Syntactic knowledge is the knowledge of how words can be combined into meaningful sentences, phrases, or utterances. Syntactic awareness is the ability to monitor the relationships among words in a sentence in order to understand what you are saying as you are saying it (Cain, 2007).

Semantic language refers to an understanding and appropriate use of meaning in single words, phrases, sentences, and even longer units. Semantics as a whole can be divided into two main fields: lexical semantics and phrasal semantics. Lexical semantics focuses on the meaning of individual words, whereas phrasal semantics focuses on how the meaning of a sentence is composed from the meaning of the constituent/individual words, and from extra meaning contained within the structural organization of the sentence itself (Riemer, 2010). Taken together, semantic language encompasses the ability to understand and state labels, recognize and name categorical labels, understand and use descriptive words (including adjectives and smaller parts of whole items), comprehend and state functions, and recognize words by their definition and define words (Paul & Norbury, 2012).

According to Lust (2006), infants can categorize types of words by their syntactic roles (e.g., nouns vs. verbs) soon after birth. Further, infants can parse the speech stream into the essential syntactic unit (the clause), long before they utter their first words. Meanwhile, children's semantic development is a gradual process that begins just before the child says their first word and will continue throughout life (Lust, 2006). Given these developmental differences in language acquisition, receptive and expressive language assessments will differ in complexity and skill base depending on the child's age and ability. However, the areas assessed (e.g., semantics, morphology, syntax) will remain constant.

Measuring Language

Tests of receptive language go from word level to sentence level, and often to paragraph level of comprehension. Typically, tests of simple receptive language require individuals to identify, typically via pointing to a picture or object, a word or words uttered by the tester (i.e., receptive vocabulary). Comprehensive receptive language assessments generally look at a range of areas, including the understanding of different words, instructions, range of sentence structures, and abstract language (Gibson et al., 2012). Tests of expressive language often require individuals to generate spoken word(s) when presented with an image or object, with the simplest being expressive vocabulary (when providing a one-word answer). Comprehensive expressive language assessments typically focus on evaluating semantics, morphology, and syntax. Thus, these tests typically include measures of expressive vocabulary, sentence formation, and may sometimes include measures that evaluate the individual's ability to construct prose, a form of language that has no formal metrical structure (Gibson et al., 2012). Common measures to assess oral language skills are detailed below.

The Children's Communication Checklist Second Edition (CCC-2; 2003) is a 70-item questionnaire used to assess different measures of language and communication skills in children (4–16-year-olds). More specifically, the CCC-2 is designed to identify structural and pragmatic language deficits that may be difficult to elicit in a test. It should be completed by an adult who knows the child well.

The Clinical Evaluation of Language Fundamentals, Revised (CELF-R; Semel-Mintz et al., 1989) is a standardized assessment tool that examines both receptive and expressive oral language skills in individuals (5-16 year-olds). It uses a variety of subtests that are designed to target specific aspects of language, including semantics and syntax. The CELF evaluates a broad range of language skills, such as recalling and formulating sentences, word classes, word definition, understanding spoken paragraphs, and semantic relationships. The CELF also contains measures of pragmatic language. The CELF-R was revised to the CELF-3 in 1995. It included changes to the test stimuli (e.g., color pictures, more updated and demographically diverse stimuli), minor and major revisions to subtests, the addition of new subtests, a change to age-specific start points, and an age range extension of the test (6–21-year-olds; Semel et al., 1995). The CELF-4 was published in 2003 and was designed to reflect the clinical decision-making process beginning with making a diagnosis and determining the severity of language disorder, identifying relative strengths and weaknesses, making recommendations regarding accommodations and intervention, and measuring efficacy of intervention (Paslawksi, 2005).

The Test of Language Development – Primary (TOLD-P; Hammill & Newcomer, 1982b) is an individual test of English language proficiency for children (4–8-year-olds). It measures various features of linguistic ability, including syntax, semantics, and phonology from both the receptive and expressive modalities. The TOLD-P subtests are organized into several composites, based on the different intersections between a linguistic feature (i.e., syntactic, semantic, or phonological) and a language domain (i.e., receptive or expressive language). These composites include syntax, semantics, speaking, listening, and overall spoken language. Results from the TOLD-P provide a comprehensive profile of children's specific abilities and disabilities in several areas of language development. The Test of Language Development – Intermediate (TOLD-I; Hammill & Newcomer, 1982a) assesses spoken language in intermediate-aged students (8–17-year-olds). Similar to the TOLD-P, it measures various aspects of oral language, including semantics and grammar, listening, organizing, speaking, and overall language ability.

Narratives have been widely used to measure communicative abilities in typically developing children and in children with developmental disorders. They are used to tap different aspects of language, including structural components, such as lexical diversity, syntactic complexity, and sentence length, to more pragmatic components (Botting, 2002). Further, narratives provide a direct measure of children's communicative abilities, which can be difficult to retrieve from parental questionnaires.

Language Processing

Language processing refers to the way humans use words to express thoughts and ideas, and how such communications are processed and understood (Hardy, 2015). Within the literature, there were a large number of hypotheses about the architecture and mechanisms of language processing, attempting to explain how language users convert sounds into meanings (receptive language) and how they convert meanings into sounds (expressive language). Yet, there is currently no single, all-inclusive model of language processing that can definitively characterize it as being entirely holistic (processing a whole phrase at a time) or componential (processing components of a phrase separately).

Language Comprehension. Language comprehension is a complex process that requires more than mere word recognition. During language comprehension, the listener must be able to extract individual words from a continuous speech signal and access a range of different kinds of information about each of those words from the mental lexicon (e.g., meaning and grammatical class). Additionally, they must compute the syntactic relationships among those elements, and integrate the syntax with the meanings of the words to arrive at an interpretation of the utterance (Fasold & Connor-Linton, 2015).

Semantic processing is at the heart of language comprehension and is the process by which the meaning of words, or their semantic representations, are activated as individual's hear them (Craik & Lockhart, 1972). It involves extracting meanings from recognized word strings and inferring user's dialogue acts or information goals based on recognized semantic concepts and preceding dialogue context (He & Young, 2005). Further, the listener must be able to determine an overall semantic representation of the sentence by fitting the meanings of individual words into the framework of the sentence (i.e., Who did what to whom and what are the implications of such; Humphries et al., 2006). Thus, listeners must use syntactic information, among other types of information, to determine the meaning of a sentence.

Syntactic processing involves combining the words in a particular way such that the listener can abstract meaning of sentences (Kaan & Swaab, 2002). A first step in syntactic comprehension, or breaking down a sentence into its component parts, involves analyzing relationships between individual words based on information such as lexical category and word order (Humphries et al., 2006). In this process, called phrase-level or constituent parsing, basic grammatical elements of the sentence (i.e., noun and verb phrases and their components, auxiliaries, modals, prepositions, etc.) are first represented (Humphries et al., 2006). Later stages of syntactic analysis are thought of involved processes related to linking together displaced syntactic elements, repairing and reanalyzing mis-parsed fragments, and representing syntactic information in WM (Caplan & Waters, 1999; Grodzinsky, 2000; Kaan & Swaab, 2002).

Language Production. Although it seems effortless and automatic in most situations, language production involves complex interactions among phonological, semantic, and syntactic information to produce meaningful speech and complex expressions (Dell et al., 1992; Levelt et al., 1999). Specifically, a word is selected from among all the words in the mental lexicon to communicate an intended message. This representation is then mapped on to the sound shape of the word, specifying its phonological form. Then, this abstract phonological representation is mapped on to the articulatory implementation processes which provide detailed information to the articulators about the ultimate phonetic realization of the word (Peramunage et al., 2011). While complex, the goal of communication is to express meaning to be understood by others.

Semantics permits the access to meaning of words, and thus, orientation in the surrounding world by means of language production (Sierpowska et al., 2019). Language production theories generally agree that when a speaker intends to produce a word, the meaning is activated at the conceptual (semantic) level and forwarded to the word's representation at the lexical level. Hence, during the initial planning stages of language production, one of the core tasks is to select a lexical representation that best expresses the meaning of an intended message with its semantic attributes and associations (Treiman et al., 2003). Meanwhile, the process of building syntactic structure (syntactic formulation) involves assigning grammatical functions (e.g., subject, object) to the selected lexical items, computing the relationships between grammatical constituents and their linear order, and assigning the appropriate morphology (Beck, 1990; Bock & Levelt, 1994; Treiman et al., 2003). Further, computing the relationship between grammatical constituents involves the construction of hierarchical representations, which is necessary since the structural relationships between sentence constituents are not always reflected in their linear order in an utterance (i.e., passive sentences; Treiman et al., 2003).

Summary

Taken together, language production and comprehension are complex processes that involve different levels of analysis. For instance, language comprehension involves a number of different processing levels, including acoustic, phonological, morpho-lexical, syntactic, semantic, and pragmatic (Jacquemot & Scott, 2006). During language production, speakers must conceptualize their intended message, select appropriate lexical items and build syntactic structure, activate the corresponding phonological and metrical structure, and finally engage in articulation (Levelt, 1989; Bock & Levelt, 1994). Further, the appropriate understanding of syntactic structure and the semantic relationships between words allows listeners to analyze heard information, comprehend the complex thoughts and intentions being conveyed by the sentence, and produce meaningful messages that match the speaker's internal goals (Treiman, 2003).

Language and Working Memory

More recently, researchers have suggested that cognitive characteristics predict language ability beyond environmental factors (i.e., parent-education and other child-level demographic variables; White et al., 2017; Archibald, 2015). In particular, WM appears to play an important role in language production and comprehension (Diamond, 2013). WM assists the speaker in analyzing effectively and efficiently what they hear and organizing thoughts and actions in accordance with internal goals (Ghazi & Ansaldo, 2017; Parker et al., 2005).

Language Comprehension

Language comprehension involves actively accessing, maintaining, and processing linguistic information. Thus, it has been one of the most studied areas in relation to WM abilities (Emmorey et al., 2017). As will be detailed below, verbal STM and WM were consistently and frequently associated with several language abilities, including vocabulary, morphology, syntax, and grammar. In contrast, research investigating the role of visuo-spatial STM and WM in spoken language comprehension was sparse.

Verbal Working Memory. Verbal WM has been postulated to play a crucial role in language comprehension because the intermediate products of narrative and sentence comprehension need to be kept active as the discourse is being processed to ensure coherence (Caplan & Waters, 1999; Friedmann & Givon, 2003). Specifically, the role of verbal CE in the comprehension of syntactically complex sentences has been well documented in the literature. Several findings indicated that a deficit or limitation in verbal CE may lead to a deficit in the comprehension of non-canonical, or atypical, sentences (Chow et al., 2020; Daneman & Hannon, 2007; Fedorenko et al., 2006; Gordon et al., 2006; Warren & Gibson, 2002; White, 2020). According to some researchers, these types of sentences tend to be more difficult to process, and thus, may demand more verbal CE resources. In contrast, increased experience or familiarity with syntactic structures (i.e., simple sentences) likely demand less CE and may lead to more efficient processing (Caplan et al., 2011; Ferreira et al., 1996; Wells et al., 2009).

Phonological STM. Given that the phonological loop facilitates the long-term learning of phonological structure, phonological STM has often been associated with vocabulary knowledge and word learning (Baddeley et al., 1998; Bree & Zee, 2020; Engel de Abreu et al., 2011; Michas & Henry, 1994; Ylinen et al., 2020). In addition, phonological loop deficits were linked to impairment in the comprehension of syntactically demanding and complex sentences (Adams et al., 1999; Friedrich et al., 1985; Lauro et al., 2010; Papagno et al., 2007; Verhagen et al., 2016). Lauro and colleagues (2010) further examined the role of the phonological loop in the comprehension of syntactically simple sentences by parsing out its subcomponents. Based on their findings, they proposed that the phonological short-term store, but not the articulatory rehearsal process, is involved in the comprehension of long, syntactically simple sentences (e.g., noun phrase coordination and sentential coordination). Nonetheless, even with a basic understanding of typical syntax, a listener must remain attentive and engage phonological STM in order to utilize the knowledge of syntax for proper comprehension (Lauro, 2010).

Visuo-Spatial Working Memory. In general, visuo-spatial WM resources have typically been studied in the context of nonverbal abilities. Nonetheless, findings from Emmorey and colleagues (2017) suggested that visuo-spatial WM is tapped when processing spatial language, regardless of whether the information is presented in written or spoken format. Spatial language refers to language that helps people explain where objects are in space (e.g., up, down, left, right; Emmorey et al., 2017). Findings from White's (2020) study supported the involvement of the visuo-spatial CE in the comprehension of non-spatial language, specifically the comprehension of complex syntactic structures. In addition, White (2020) postulated that the visuo-spatial CE is involved in the acquisition of vocabulary knowledge.

Visuo-Spatial STM. Regarding visuo-spatial STM, Yim and colleagues (2020) suggested that performance on tasks that tap the visuo-spatial STM are potential predictors of preschool children's narrative comprehension abilities. These findings were supported by research assessing visuo-spatial STM in children with developmental language delay (DLD). Finding from Vugs et al., (2013) meta-analysis indicated that children with DLD tend to perform below their typically developing peers in span tasks requiring visuospatial recall. Although this review focuses on the language profiles in children with ADHD, these findings are noteworthy when evaluating the relationship between WM and language.

Language Production

Language production and planning involves the maintenance and ordering of linguistic information. Further, this information ranges over multiple levels, including messages, several different points that the speaker plans to make, words within phrases, phrases within sentences, and articulatory gestures for executing the utterance (Acherson & MacDonald, 2010). Thus, it is reasonable to assume that WM is involved in holding all the elements of the utterance at different levels of planning, while the speaker is articulating (Ishkhanyan 2018). However, studies addressing the role of STM and WM in language production were scarce.

Verbal Working Memory. In addition to general language learning, links have been suggested between children's verbal WM and language production abilities. For instance, results from Versksa and colleagues' (2020) study suggested that a well-developed verbal WM may lead to lexically and grammatically more accurate language production in preschool children. Additionally, a study by Hartsuiker and Barkhuysen (2006) showed a link between verbal WM and syntactic planning and sentence construction. In their study, individuals with lower verbal WM capacity experienced more difficulties in planning the correct subject-verb agreement in spoken sentence completion (Hartsuiker & Barkhuysen, 2006). Taken together, verbal WM appears to play some role in language production; however, the strength and specificity of this role is not well documented.

Phonological STM. Within the literature, the phonological loop has been linked to several other language production skills, including word decoding, speech sound accuracy, number of different words, syntactic constructions, and number of utterances; Adams & Gathercole, 2000; Torrington Eaton & Ratner, 2016; Waring et al, 2016). More specifically, some researchers argued that utterance planning for speaking places large demands on the phonological loop because it requires serial ordering to assemble words into sentences and to assemble sub-word unties such as syllables and phonemes (MacDonald, 2016). Other findings indicated that the phonological loop is involved in the storage and processing of sentences in children. In these studies, children with good phonological STM were found to repeat spoken sentences more accurately than children with weak phonological STM abilities (Hanten & Martin, 2001; Willis & Gathercole, 2001).

Visuo-Spatial Working Memory/STM. The role of visuo-spatial WM and STM in language production has not been well-studied, perhaps due to the oral nature of expressive language abilities. In fact, no research was found on the role of visuo-spatial WM or STM in language production. However, there is some evidence for a link between visuo-spatial WM and written language production. For instance, Kellogg and colleagues (2007) found that visuo-spatial WM was selectively engaged when imaging the referents of concrete nouns during utterance planning. Further, these findings indicated that visuo-spatial WM is heavily loaded when defining concrete words that readily give rise to visual images of their referents in planning conceptual content (Kellogg et al., 2007). Although the present review focuses on WM in relation to spoken language production, these findings are noteworthy because both spoken and written language production requires planning of semantic content and linguistic encoding of such content (Bock & Levelt, 1994).

Summary

Taken together, several studies have linked WM with a variety of language abilities in young children, such as listening comprehension, vocabulary knowledge, word learning, and grammar (Gathercole & Baddeley, 2009). Within the literature, the role of verbal STM and WM in language comprehension has been well-studied. Specifically, the comprehension of syntactically complex sentences has been consistently linked with verbal CE and phonological STM. There also has been some evidence about the role of visuo-spatial STM and WM in the comprehension of narratives and spatial language. Regarding language production, less is known about the strength and specificity of the role of WM. Nonetheless, findings suggested that verbal WM and STM may support the development of complex linguistic skills and spoken language production abilities to a larger extent than visuo-spatial WM and STM.

ADHD and Language

A robust body of research has consistently reported an elevated prevalence of language problems among children with ADHD in both clinical and community samples. In a meta-analytic review assessing language problems in children with ADHD, findings showed that children with ADHD had poorer performance on measures of overall, expressive, receptive, and pragmatic language (for a review, see Korrel et al., 2017). More specifically, Love and Thompson (1988) identified 27.6% of clinic-referred youth with ADHD to have disorders in both receptive and expressive language, whereas 7.8% had only receptive language disorders, and

6.9% had only expressive language disorders. Further, youth with ADHD demonstrated deficits or disorders in phonological, semantic, and syntactic development (Love & Thompson, 1988).

It should be noted that it is difficult to generalize about the language skills of children with ADHD because of methodological differences across studies. Prior work has noted that linguistic tasks used to measure receptive and expressive language tend to differ across studies. In addition, few studies examining language outcomes in ADHD have included appropriate comparison groups (Redmond, 2016). Thus, differential findings across studies could be partially due to these distinct methodological differences.

Language Production

Several studies have found that school-age children with ADHD had significantly lower scores on expressive language tests than same-aged peers, especially in the domains of phonology, vocabulary knowledge, and sentence structure (e.g., Baixauli Fortea et al., 2018; Geuts & Embrechts, 2008; Kim & Lee, 2009; Love & Thompson, 1988; Purvis & Tannock, 1997; Stanford & Delage, 2020; Vaisanen et al., 2014). In particular, some researchers found that children with ADHD demonstrated poor sentence formulation and word structuring skills as a result of incorrect omission or insertion of function words and the improper specification of morphemes for verbs and nouns (Oram et al., 1999; Cohen et al., 2000; Kim & Kaiser, 2000). Findings from Kuijper and colleagues (2017) also indicated impairments on syntactic complexity and speech fluency in children with ADHD. When compared to their typically developing peers, children with ADHD used fewer complex clauses, made more morphosyntactic errors, and produced more repetitions, suggesting some deficits with self-monitoring for responses (Kuijper et al., 2017).

Researchers have also described an array of general, expressive language characteristics in the children with ADHD. These included excessive talkativeness, shorter utterances, and an overall inability to effectively modify language to accommodate changes in the specific demands of the task at hand (Barkley et al., 1983; DaParma et al. 2011; Kim & Kaiser, 2000; Mathers, 2006; Whalen et al., 1979). It should be noted that most researchers were unclear about possible coexisting language impairment in the children with ADHD that were included in their studies. Hence, these deficits may be due to comorbid language impairment. Nonetheless, the results can be interpreted as supporting the view that children with ADHD may respond differently than their typically developing peers in the ways they create and use language at a group level (Mathers, 2006).

Language Comprehension

Despite its functional importance in everyday social interactions and learning, studies that exclusively examined receptive language in children with ADHD were limited, and the findings were mixed. Some researchers suggested that receptive language is relatively intact in school-aged children with ADHD, with no noticeable problems with overarching comprehension skills (Cohen et al., 2000; Luo & Timler, 2008; Parigger, 2012; Redmond et al., 2011). In contrast, other researchers suggested that children with ADHD have difficulties with several aspects of story comprehension, specifically with understanding causal relations and monitoring ongoing comprehension (e.g. Bailey et al., 2011; Berthiaume et al., 2009; McInness et al., 2003; Lorch et al., 2009; Papaliou et al., 2012). Based on these findings, McIness and colleagues (2003) researchers hypothesized that children with ADHD can comprehend surface details adequately but have deficits on tasks that require relatively higher degrees of vigilance and attentional control.

Wassenberg and colleagues’ (2008) study focused more on the fundamental aspects of language comprehension, specifically the accuracy and speed of complex sentence comprehension in children (8-11-year-old) and adolescents (12-16-year-old) with ADHD-C. Although children with ADHD-C appeared to understand the complex sentences as accurately as typically developing controls, they needed considerably more time to provide accurate answers. Thus, Wassenberg and colleagues suggested that youth with ADHD may be slower/less efficient than their same-aged peers with regard to complex sentence comprehension (Wassenberg et al., 2008).

Dimensional Differences

Several studies identified a link between increased inattentive and hyperactive/impulsive symptoms and receptive and expressive language deficits (e.g., Gremillion & Martel, 2012; Gut et al., 2012; Hawkins et al., 2016; Hutchinson et al., 2012; Johnsdottir et al., 2005; Martinuessen & Tannock, 2006; McInnes et al., 2003). Given that inattentive and hyperactive/impulsive symptoms can produce different patterns of behaviors, they may differentially impact language outcomes (Parks et al., 2021). However, the research in this area is lacking and inconsistent.

A study by Mueller and Tomblin (2012) compared frequency of language impairment between youth with ADHD-I and ADHD-C. Unfortunately, there were not enough children in the ADHD-H group to examine comorbidity. Findings showed that the comorbidity of language impairment was higher in ADHD-I than ADHD-C. These findings suggested that inattentive symptoms, rather than hyperactive/impulsive symptoms, may be more strongly associated with language impairment in youth with ADHD. These findings were in accordance with other literature, suggesting a general link between attentional deficits and expressive and receptive language deficits (Baker & Cantwell, 1992; Cohen et al., 2021). Parks and colleagues (2021) also parsed out the distinct components of ADHD symptomology in order to delineate their relationships with language in young adults (16-21-year-old) with ADHD. They found both inattentive and hyperactive/impulsive symptoms were associated with lower receptive language abilities. However, there was no relationship with expressive language. One proposed explanation for these discrepant findings was that difficulties related to expressive language are more salient in younger groups with a clinical diagnosis of ADHD (Parks et al., 2021). It also may be that receptive language is more attention demanding.

In contrast to the above literature, some researchers find language symptoms to be related to the hyperactive-impulsive dimension specifically. Geurts and Embrechts (2008) investigated the role of ADHD symptomology on communication abilities in preschool aged children with ADHD (4-7-year-old). Findings indicated that impulsive symptoms, but not inattentive and hyperactive symptoms, predicted the presence of greater language difficulties. Findings from Geurts and Embrechts (2008) suggested that impulsive symptoms have an impact on structural language and may play an important role in the existence or development of language abilities. Further, the authors suggested that when children become older, their speech output, syntax, and coherence abilities improve. Some longitudinal studies also have demonstrated associations between early language difficulties and later hyperactive/impulsive symptoms during the preschool and school periods, even when prior levels of hyperactive/impulsive symptoms were accounted for (Aro et al., 2014; Lindsay et al., 2007; Petersen et al., 2013, 2014; Peyre et al., 2016; St Clair et al., 2011). Taken together, poor language and communication skills commonly observed in youth with ADHD symptomology may be associated with both dimensions of ADHD symptomology.

Summary

Compared to their typically developing peers, children with ADHD may exhibit difficulties in the ways they use and create language. Regarding expressive language, children with ADHD display significant weaknesses with vocabulary knowledge and sentence structure at the group level. In addition, there is some noteworthy evidence for difficulties with receptive language, specifically with the comprehension of narratives. Morphosyntactic weaknesses, in particular, were frequently associated with weak comprehension and poor construction of grammatical structures. In addition, inattentive and hyperactive/impulsive symptoms were frequently linked with language difficulties among youth with ADHD. However, it is unclear how ADHD symptomology, such as high levels of distractibility, interact with specific, structural aspects of language (Stanford & Delage, 2020).

Language and Working Memory in ADHD

Few studies have examined the contribution of WM to structural language deficits in youth with ADHD. Within the ADHD literature, the relationship between WM and language typically is studied in the context of pragmatic language (e.g., Ludlow et al., 2017) or in children with co-morbid reading disorders (e.g., Tiffin-Richards et al., 2007) and/or language disorders (e.g., Martinussen & Tannock, 2006; Miranda et al., 2013) However, even when researchers, such as Oram and colleagues (1999) controlled for comorbid language disorders, performance on standardized language tests was still below that of typically developing peers and appeared to vary according to the task’s cognitive demands. According to developmental theory, general language ability both relies on, and facilitates, cognitive processes, such as holding information in short-term memory and shaping attention (Marchman and Fernald, 2008). Thus, examining all aspects of WM in relation to structural language in youth with ADHD warrants a further investigation. The following studies represent the limited research available on the topic.

Language Comprehension

McInnes and colleagues (2003) found that verbal and visuo-spatial WM were significantly correlated with passage-level listening comprehension in children (9-12-years-old) with ADHD. The authors used two tasks to assess listening comprehension ability for expository passages. The first task assessed comprehension of facts and inferences, and the second task assessed the ability to self-monitor comprehension. The Numbers Backward subtest from the CMS (Cohen, 1997) was used to measure verbal WM. A novel backward administration of the Finger Windows subtest from the Wide Range Assessment of Memory and Learning (WRAML; Adams & Sheslow, 1990) was used to assess visuo-spatial WM.

Compared to typically developing controls, children with ADHD demonstrated significantly poorer performance on both the verbal and visuo-spatial WM tasks. In addition, children with ADHD correctly answered fewer inferential questions, and they had more difficulty with monitoring comprehension of instructions. Findings also indicated that inference scores were significantly associated with performance on verbal and visuo-spatial WM tasks (McInnes et al., 2003). These findings were in accordance with findings from the Papaeliou and colleagues' (2012) study.

Papaeliou and colleagues (2012) examined the role of WM in narrative comprehension in school-aged children with ADHD. The Working Memory Index (WMI) of the Weschler Intelligence Scale for Children – Fourth Edition (WISC-IV; Weschler, 2003) was used to assess WM; the Verbal IQ Test (VIQ; Stavrakaki & Tsmpli, 2000) was used to assess receptive and expressive language; and a story recall task was used to assess narrative comprehension.

Findings showed that children with ADHD exhibited deficiencies in verbal WM, grammar comprehension, and sentence recall. They also demonstrated poorer performance with answering factual and inferential questions related to the story. In addition, narrative comprehension was significantly positively correlated with WM. Taken together, findings from these studies suggested that problems with complex sentence comprehension and narrative comprehension may stem from underlying deficits in WM (Papaeliou et al., 2012).

Language Production

Findings from Papaeliou and colleagues (2012) study, as described above, also suggested that children with ADHD experience difficulties in aspects of expressive language that require WM, such as sentence recall. More specifically, the authors suggested that deficits in WM may impede an individual's ability to accurately construct and repeat complex morphosyntactic structure (Papaeliou et al., 2012). This observed link between WM and expressive language in children with ADHD was consistent with earlier reports. For example, Oram and colleagues (1999) compared the performance of children (7-11-year-old) with ADHD to children with ADHD and comorbid language impairment (ADHD+LI), and typically developing peers on the CELF-R. In general, the ADHD+LI group performed worse than the ADHD group and typically developing control group on all subtests of the CELF-R. However, children in the ADHD group consistently performed worse than their typically developing peers on three of the CELF-R subtests: Formulated Sentences, Word Structure, and Sentence Assembly. In particular, the Formulated Sentences subtest appeared substantially difficult for children in the ADHD group, whose mean fell more than one standard deviation below the mean of the typically developing control group. In general, this subtest places substantial demands on WM because individuals are required to remember a target word(s) while formulating a sentence and using an illustration as a reference. Thus, the authors suggested that poorer performance on the Formulated Sentences subtest was a result of underlying WM deficits (Oram et al., 1999).

Another study examined narrative abilities at the sentence level (syntactic complexity), discourse level (discourse pragmatics), and narrative level (verbal productivity) in children (6-12-year-old) with ADHD. In addition, the relationship between narrative abilities and WM, specifically the CE, was evaluated (Kuijper et al., 2017). Regarding narrative production, children with ADHD produced shorter sentences and more repetitions than typically developing peers. In addition, they used fewer complex clauses and made more morphosyntactic errors. Findings also showed that WM, measured by the n-back task, was associated with syntactic complexity and verbal productivity. Based on these findings, the authors concluded that children with lower WM capacity tend to produce shorter and simpler sentences and stories and are less able to establish a coherent and cohesive discourse (Kuijper et al., 2017). Taken together, these findings indicated that WM deficits may underly difficulties with certain aspects of expressive language among youth with ADHD.

Mechanistic Explanations for Language Problems

Several studies have investigated language skills as a mechanistic explanation for executive functioning (e.g., Kuhn et al., 2014; Petersen et al., 2013, 2015). However, few studies investigated executive functions as mechanistic explanations for the association between language skills and ADHD symptomology. One study examined the extent that EF deficits functioned as mediators in the relation between ADHD and functional impairment, specifically academic achievement (Siowall & Thorell, 2014). In this study, Sjowall & Thorell (2014) compared the performance of children (7-13-year-olds) with ADHD to typically developing controls on measures of inhibition, shifting, delay aversion, and working memory. To measure academic achievement, the author's asked parents and teachers to rate the child's school performance with mathematics and language skills in relation to same-aged peers. Ratings were made on a scale from 1 (much below average) to 5 (much above average; Sjowall & Thorell, 2014). It should be noted that the authors did not specify the types of linguistic abilities evaluated.

In line with previous work, children with ADHD performed worse than typically developing controls on all tests of executive functioning and were rated lower on academic achievement (Siowall & Thorell, 2014). Further, EF deficits were related to poor academic achievement. Regarding language skills, simple mediation effects were found for WM (collapsed across auditory-verbal and visual-spatial tasks). In addition, multiple mediation analyses were conducted to obtain estimates of the total indirect effect, as well as the independent contribution of each mediator. Results indicated that WM partially mediated the relation between ADHD status and parent- and teacher-ratings of children's language skills (Sjowall & Thorell, 2014).

Gremellion and colleagues (2017) investigated verbal WM as a potential mechanism of the association between poor vocabulary skills and ADHD symptoms in a community sample of children (3-6-year-olds) at risk for ADHD. ADHD symptoms were measured via parent- and teacher-ratings on the Disruptive Behavior Rating Scale (DBRS; Barkley and Murphy, 2006), and via the Kiddie Disruptive Behavior Disorders Schedule (K-DBDS; Leblanc et al., 2008). Receptive skills were measured using the Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4; Dunn & Dunn, 2007), and expressive skills were measured using the Expressive Vocabulary Test-2 (EVT-2; Williams, 2007). Because receptive and expressive vocabulary were highly correlated, a language composite using standard scores from the PPVT-4 and EVT-2 was calculated in SPSS. Finally, verbal WM was measured using the Digit Span Backward (DSB) subtest of the WISC-IV (Weschler, 2003). Findings indicated that worse ADHD symptoms were significantly correlated with poorer vocabulary skills and verbal WM. Further, they found that verbal WM significantly meditated the association between vocabulary skills and ADHD symptoms. The authors also evaluated longitudinal mediation effects and found that their results largely held at one-year follow up (Gremellion et al., 2017).

Summary

As illustrated above, limited research has examined the relationships between distinct components of WM and structural language functioning in children with ADHD. In general, there was some evidence for an association between WM and structural language among youth with ADHD. Further, some findings indicated that WM may be a mechanism by which poor language skills, particularly vocabulary, are related to ADHD symptoms. However, the relationship between WM and specific aspects of structural language skills remains unclear, and further research is needed in this area. This is particularly true as much of the research on ADHD and language does not control for comorbid language impairment. Hence, relationships found could be due to language impairment instead of ADHD specifically.

HEADING 3

CONCLUDING SUMMARY

Few studies have examined the relationship between ADHD, WM, and structural language concurrently. Nevertheless, there is a wealth of literature addressing the relationship between these factors in various combinations (e.g., ADHD and WM, ADHD and structural language, WM and structural language). It has been demonstrated, for example, that WM is affected in ADHD, and WM is related to structural language functioning in the general population. Thus, further research is needed to better understand how WM may influence structural language functioning in youth with ADHD. Additional research is needed on the structural language profiles in youth with ADHD as well. As aforementioned, the studies examining structural language profiles in youth with ADHD may have been disparate because of methodological differences across studies (Redmond, 2016), as well as inconsistently controlling for comorbid language impairment. Nonetheless, youth with ADHD may experience difficulties with semantic and syntactic aspects of language based upon the research overall. Additionally, the inattentive and hyperactive/impulsive symptom dimensions may be differentially associated with performance on syntactic and semantic measures of language. Further, these linguistic difficulties may be related to executive functions, such as working memory (Cohen et al., 2000).

Finally, a paucity of literature has addressed the relationship between ADHD, WM, and structural language, despite literature suggesting WM is related to language functioning and children with ADHD frequently have WM and language deficits, as noted above. Although a few studies have indicated a link between WM deficits and structural language problems in youth with ADHD (e.g., Gremellion et al., 2017), the specificity and strengths of these relationships were unclear. Understanding these relationships may contribute to a more holistic understanding of language profiles in ADHD and to the development of specialized interventions targeting working memory and structural language deficits.

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