AN INVESTIGATION OF THE COMPONENTS OF WORKING MEMORY IN CHILDREN WITH LEARNING DISABILITY

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JULY 2024

CERTIFICATE

This is to certify that this dissertation entitled **"An Investigation of the Components of Working Memory in Children with Learning Disability"** is a bonafide work submitted in partial fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student Registration Number: P01II22S123041. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"An Investigation of the Components of Working Memory in Children with Learning Disability"** is a bonafide work submitted in partial fulfilment for the degree of Master of Science (Speech-Language Pathology) of the student Registration Number: P01II21S0010. This has been carried out under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to anyother University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"An Investigation of the Components of Working Memory in Children with Learning Disability"** is the result of my own study under the guidance of Dr. Priya M. B., Assistant Professor, Centre for Speech and Language Disorders in Children, Adults and Senior Citizens, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CHAPTER 1

INTRODUCTION

The term "learning disabilities" (LD) refer to a range of disorders that affect the acquisition, retention, comprehension, organization, or use of verbal and/or non-verbal knowledge (Learning Disabilities Association of Ontario, LDAO, 2001). These disorders are the result of average thinking and reasoning skills combined with deficiencies in one or more learning-related psychological processes. Learning difficulties are different from intellectual disabilities since they are specific, not general deficits.

LD are differentiated from intellectual impairments by both the LDAO definition of LD and the DSM 5 criteria for specific learning disorders. The Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition (DSM 5), (American Psychiatric Association, 2013) recognizes a specific learning disorder as a single, comprehensive diagnosis that includes deficiencies affecting academic performance. The exclusionary criterion D, which states that "intellectual disabilities is not a better explanation for the learning difficulties," is part of the DSM 5 diagnosis.

Individuals with LD are often reported to have memory deficits, particularly the working memory. The more active component of the human processing system is referred to as working memory (Newell, 1973). Miller et al. coined the term working memory in the year 1960, and since then, researchers have defined the term in many different ways. Working memory is used for performing calculations, understanding written material, carrying out complicated instructions, or combining data from several sources to make decisions (Vandenbrouckea et al., 2018). It is the psychophysiological concept of temporarily retaining and modifying pertinent sensory information units (Baddeley, 2007). Working memory is also considered as the limited capacity mechanism that allows a person to process and retain information in the mind while carrying out cognitive tasks (Cabbage et al., 2017). It can also be defined as the mechanism by which behavior is guided by the remembered stimulus, in the absence of external cues (Goldman-Rakic, 1996).

It is assumed that working memory serves both processing and storing purposes. It serves as a site for the execution of processes and storing their products (Baddeley & Hitch, 1974; LaBerge & Samuels, 1974). Cognitive skills like reasoning, planning, and problem solving rely primarily on working memory. Working memory helps an individual to access alternatives, update knowledge and take new information into account, derive general principles, determine connection between concepts, and also perform critical reasoning (Diamond, 2013). The development of working memory is partially dependent on the maturation of prefrontal cortex (Anderson, 2002) and is considered as an important prerequisite for phonological development (Adams & Gathercole, 1995) and literacy skills (Alloway et al., 2005; Vandenbrouckea et al., 2018).

Individual variances in working memory have an impact on the academic, professional, and cognitive performance in both children and adults (Cowan, 2017). The concept of working memory has been approached from various theoretical perspectives, leading to differing views. Theories like Baddeley's model, proposed in 1974 and later refined in 2000, emphasize the existence of distinct components within working memory, including, phonological loop, and visuospatial sketchpad and central executive. The model makes a distinction between different working memory components, each of which are specialized for processing different types of information. The episodic buffer is another recent contribution to the working memory model, that is believed to serve as a brief and constrained storage space to combine working memory slave systems and long-term memory. Contrary to this, some theories propose a holistic view of working memory, suggesting that it might not be as segregated into distinct components but rather operates as a more cohesive system influenced by attentional mechanisms (Engle, 2002).

There is variability in how specific components of working memory relate to LD. While there are consistent evidences for phonological working memory deficits in children with LD, the evidence for deficits in central executive function and visuospatial processing is more mixed (Gray et al., 2019; Jeffries & Everatt, 2004; Menghini et al., 2011; Schuchardt et al., 2013). The phonological loop consistently emerges as crucial in understanding difficulties in phonological processing. The visuospatial sketchpad appears to have more relevance in tasks involving visual-spatial processing and possibly in specific academic domains such as spelling and numerical operations. These insights underscore the complexity of working memory and its implications for understanding and addressing LD.

1.1 Need for the study

The role of working memory in language learning and different cognitive tasks has been well established in both typically developing children as well as children with language and literacy-based difficulties. Working memory is often viewed as a single construct although specific functions are delineated for each of the different components of working memory. The same notion is also reflected in the assessments and intervention of working memory. However, recent investigations have focussed on studying the individual components of working memory using specific tasks (Cabbage et al., 2017; Gray et al., 2019). The findings of these studies indicate that different components of working memory are affected in dyslexia and developmental language disorders thereby highlighting the importance of profiling working memory deficits in these populations (Gray et al., 2019).

Specific tasks related to each component of working memory are not included in most of the existing studies. Considering this, it is necessary to conduct a comprehensive study to determine distinct working memory profiles in children with typical development and children with various developmental disorders. This will help in the identification and comparison of potential differences in working memory components in these populations. Further, it is important to gain better understanding about working memory and its impact on different cognitive tasks, especially in children with varying developmental profiles. Description of specific tasks related to each component of working memory will facilitate precise identification of the differences in performance.

In view of the fact that working memory deficits are consistently reported in children and adolescents with LD, investigating distinct working memory profiles between typically developing children and those with LD can provide valuable insights into tailor made interventions to support children based on their specific working memory deficits. For instance, techniques that concentrate on enhancing the phonological component could prove beneficial for children with phonological working memory deficits. Similarly, interventions targeting visuospatial memory or central executive functions separately might be more effective for children with deficits in these areas. This tailored approach can significantly impact educational and clinical interventions, reshaping how we approach and support children with diverse working memory profiles.

1.2 Aim of the study

The study aimed to investigate the components of working memory (central executive, phonological memory, and visuospatial memory) in children with LD in grades 5 to 7 in comparison with their typically developing peers.

1.3 Objectives of the study

The specific objectives were:

1) To compare the score of N back visual task between children with LD and their typically developing peers.
2) To compare the scores of (a) Digit span forward (audio) (b) Digit span backward (audio) task between children with LD and their typically developing peers.

3) To compare the scores of (a) Visual forward span (figures) (b) Visual backward span (figures) between children with LD and their typically developing peers.

1.4 Hypotheses of the study

Null hypotheses were assumed to achieve the objectives of the study as follows

1) There is no significant difference between the scores of children with LD and their typically developing peers in N back visual task.

2) There is no significant difference between the scores of children with LD and their typically developing peers in (a) digit span forward (audio) and (b) digit span backward (audio) tasks.

3) There is no significant difference between the scores of children with LD and their typically developing peers in (a) Visual forward span (figures) and (b) visual backward span (figures) tasks.

CHAPTER 2

REVIEW OF LITERATURE

The National Joint Committee on Learning Disability (1991) states that learning disability (LD) refers to a broad spectrum of conditions characterized by significant difficulties in acquiring and applying speaking, listening, reading, writing, thinking, and math skills. Each person has a different set of disorders, believed to be caused by disturbances in the central nervous system and can occur at any time. Self-regulation, social perception, and social interaction issues are related to learning difficulties but are not always signs of LD. Even though extrinsic factors like cultural differences or inadequate or inappropriate instruction can have an impact, LD does not directly result from these factors; they may occur concurrently with other conditions like intellectual disability, sensory impairment, or severe emotional disturbance.

2.1 Prevalence of LD

The DSM-5 reports that the prevalence of specific learning disorder among school-aged children from diverse languages and cultures is between 5–15%. The prevalence of specific learning disorder was reported to be 8% in a meta-analysis of investigations carried out in India (Scaria et al., 2023) A prevalence study conducted among school-age children in Kerala's Ernakulum district found that 16.49% of them had LD; of these, 12.57% were linked to difficulties with reading, 15.6% to difficulties with writing, and 9.93% to difficulties with math (Chacko & Vidhukumar, 2020). The lifetime prevalence of LD in children was reported to 9.7%, according to a study done in the

United States of America (Altarac & Saroha, 2007). Another study carried out in Brazil found that the prevalence was 7.6% (Fortes et al., 2016).

2.2 Cognitive deficits in LD

Children with LD face a range of challenges in memory function and metacognitive abilities. It is generally accepted that most people with LD also struggle with one or more cognitive functions, including perception, attention, memory, or metacognition (Swanson, 1996). Meta-memory, working memory, and short-term memory are all clearly affected in these children. Numerous studies have found that children with LD experience varying degrees of difficulty when it comes to analyzing task requirements, choosing appropriate strategies, allocating learning time, monitoring, and controlling the learning process, evaluating outcomes, and other related areas. According to a review of recent empirical research, children with LD were reported to perform poorly on working memory tasks. Compared to controls, children with severe, mild, moderate, borderline, or specific LD are less capable to complete immediate memory tasks (Li & Liang, 2021). Even when children are matched with controls for general mental ability, linguistic proficiency, and nonverbal competence, the same overall picture appears to hold true (Masoura, 2006).

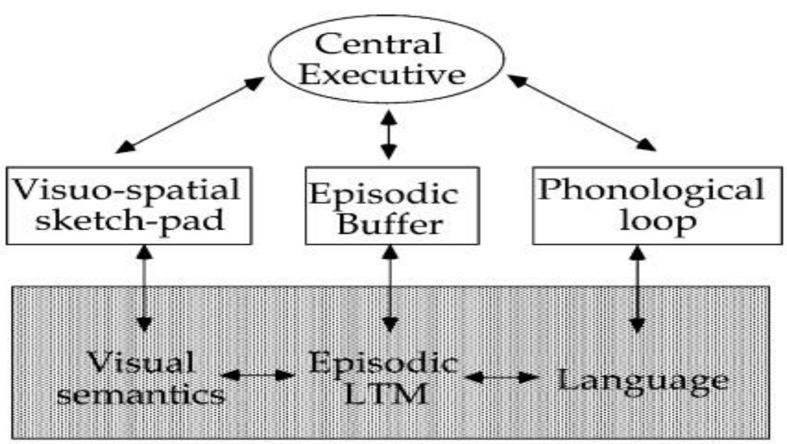
2.3 Working Memory

The temporary storing and manipulation of data that is thought to be required for a variety of complex cognitive tasks is known as working memory (Baddley, 2003). It is considered as a system with a limited capacity that stores and processes temporal information.

Baddeley (2000, 2007) proposed that working memory could be basically divided into three subsystems: the phonological loop, which deals with verbal and auditory information; the visuospatial sketchpad, which provides its visual equivalent; and the central executive, the attentionally limited control system. The phonological loop and visuospatial sketchpad are dependent on the central executive. A fourth subsystem was also included namely, the episodic buffer that integrates short- and long-term memory, thereby improving storage and retrieval. The different components of the working memory model are represented in the figure 2.1.

Figure 2.1

The Baddeley's working memory model



Source: Baddeley, A. (2003). Working memory and language: An overview. *Journal of communication disorders*, p.196. *36*(3), 189-208

2.4 Components of working memory

The components of working memory, as described by Baddley (2000, 2007), include:

1) ***Central executive***: The central executive, which regulates the encoding and retrieval of sensory stimuli and keeps track of attention changes, has been conceptualized as the core component of the tripartite working memory model (Baddeley, 1996). Likely, one of the critical factors influencing individual variances in working memory span is executive processes (Daneman & Carpenter, 1980). It is an attentional mechanism utilized for maintaining current task goals, analyzing incoming information, and blocking internal (such as other unrelated long-term memory units) and external (such as environmental distractions) interference (Engle, 2000).

Baddeley (2007) suggests that the central executive acts more like a system regulating attention processes than a memory bank. It links working and long-term memory, figuring out how to use the storage components strategically, and is essential for focusing, switching, and dividing attention. The central executive manages data stored in two slave systems: a phonological loop for sound-based input and a visuospatial sketchpad for visual and spatial input. Though visual and spatial data were initially said to be processed by a single visuospatial sketchpad system, they were eventually divided into two distinct components (Della et al., 1999; Logie, 1995; Logie & Pearson, 1997). The central executive develops later than the two slave systems, the phonological loop and visuospatial sketchpad (Davidson et al., 2006; Garon et al., 2008). The dorsolateral prefrontal cortex plays a significant role in central executive functions (Mottaghy, 2006).

2) ***Phonological loop***: Information based on acoustics and speech is mentally stored and manipulated by phonological working memory (Cabbage et al., 2017). Supporting the developing language processing system is one of the primary purposes of phonological working memory (Crain et al., 1990; Gathercole & Baddeley, 1993; Shank-weiler & Crain, 1986). Over the past decade, much research has proven the critical link between young children's phonological memory skills and at least three significant components of language development, which includes vocabulary acquisition (Gathercole & Baddeley, 1989; Gathercole et al., 1992; Service, 1992), comprehension of language (Smith et al., 2003) and development of reading (Wagner & Torgesen, 1987). It facilitates the retention of "speech-based" information presented by visual or auditory means (Baddley, 2003).

The two distinct parts of the phonological loop are the phonological store and the subvocal rehearsal process. The phonological input store is accessible to both visual and auditory information. However, this information decays quickly and therefore, an active, frequent subvocal articulatory rehearsal must enhance and replenish it. It is essential for language learning because it processes verbal information received (Gray et al., 2019). It has been stated that children have a shorter attention span when it comes to words, figures, and nonwords that are presented acoustically. The idea of distinct storage and rehearsal systems is supported by neuroimaging studies and research on individuals whose lesions result in phonological loop deficits The cortical region associated with storing is Brodmann area 44, whereas Broca's area (Brodmann areas 6 and 40) seems to be associated with subvocal rehearsal (Baddeley, 2003).

3) ***Visuospatial sketchpad***: This working memory component combines visual, kinesthetic, and spatial information into a single, modifiable, and temporarily retained representation (Baddeley, 2003). It is essential for helping us be aware of our location and other objects around us (Baddeley, 1997). The visuospatial sketch pad, according to Logie (1995), is made up of two components, namely the visual cache (stores information on colour and form) and the inner scribe (processes information about movement and space in the visual cache and sends information from visual cache to central executive).

4) ***Episodic buffer:*** It is the fourth subsystem that has been suggested lately. It is considered as a system with limited capacity that primarily relies on executive processing; nevertheless, it is not the same as the central executive in that, its main function is information storage, not attentional management. The term "episodic" refers to its ability to bind together data from several sources into segments or episodes. In this respect, it functions as a buffer, allowing data from

various modalities to be combined into a single, multifaceted code. Lastly, it is thought to support our capacity for conscious awareness (Baddley, 2000).

2.5 Language and working memory

According to recent research, language and the working memory system have strong connections and are essential to language acquisition (Baddeley et al., 1998). Disorders in working memory can have an impact on language processes (Baddeley, 2002). Research suggests a connection between language and the verbal aspects of working memory, but the evidence supporting the relation between the visuospatial component and language is weaker (Gray et al., 2019). The phonological loop has more primary relevance to language disorders than the visuospatial sketchpad (Baddeley, 2003). Numerous findings from research point to a connection between working memory impairments and specific learning disabilities (Alloway & Gathercole, 2006; Pickering, 2023). Children who struggle to learn but are not diagnosed may suffer from working memory deficits (Archibald & Gathercole, 2006).

One of the most common reasons for academic failure is learning disorders. Children with learning disorders, such as dyslexia may struggle significantly very early on in school, to master the fundamentals of reading and writing. Throughout a student's schooling, these challenges often continue or get worse. Impaired perception, thought, memory, or learning processes are the root cause of learning disorders.

2.6 Assessment of working memory

Different tasks related to working memory are used to assess the components of working memory. Several researchers have used variations of the "n back" procedure (Gevins & Cutillo, 1993) to investigate the neural bases of the central executive component of working memory. A series of visual stimuli, represented by numbers, was presented one after the other in each trial, and the complete list of stimuli appeared at the end. The individual was asked to memorize and choose the final stimuli for each trial. Online monitoring, updating, and modification of recalled information are necessary for the task. Therefore, it is believed to place significant demands on several essential working memory functions.

The nonword repetition test was created to evaluate children's phonological memory skills during preschool (Gathercole & Adams, 1994). According to research, the nonword repetition test is a sensitive measure that activates several short-term memory functions, including processing, retrieval, and storing (Gathercole & Baddeley, 1990). However, the use of nonword repetition as a working memory test was opposed by several researchers who argued that it is a part of a language test (Snowling et al., 1996).

Complex memory paradigms that require simultaneous processing and storing of information are frequently used to evaluate individual variances in the central executive capacity. Serial memory tasks containing arbitrary verbal elements, like words or numbers, are commonly used to evaluate the phonological loop capacity (Pickering & Gathercole, 2004). Schulze et al. (2018) used the digit recall test to measure phonological working memory. A visual span test was used to access the visuospatial sketchpad (Cabbage et al., 2017) wherein, the participant was shown a series of geometric shapes on the screen and asked to pick the same order of shapes as presented from the list provided at the end.

2.7 LD and working memory deficits

Numerous studies on children with LD have demonstrated the variability of the condition with respect to traits, etiology, and co-occurring deficits. A prospective study of children provided preliminary evidence that children with significant learning difficulties have working memory deficits (Gathercole & Pickering, 2001). Researchers have found deficits in working memory, as well as several phonological information processing components, including phonological awareness, as potential causative factors that underlie learning disorders (Eisenmajer et al., 2005; Nithart et al., 2009).

It has been found that children who do not show progress in the literacy domains tend to have relatively low capacities to store material over short periods (de Jong, 1998; Gathercole & Pickering, 2001; Gathercole et al., 2004; Swanson, 1994). Jeffries and Everatt (2003) found a connection between working memory deficits and specific learning difficulties. In their study, adults with dyslexia or dyspraxia were assessed, and their results were compared with those of the adult control group, who had no history of learning difficulties, on tasks intended to evaluate how well the phonological loop and visuospatial sketch pad function. The findings revealed that people with dyspraxia showed impairments in tests involving the visuospatial sketch pad, whereas people with dyslexia showed deficits in phonological loop recall tasks. Pickering and Gathercole (2001) found that fifteen dyslexic children performed worse than chronologically age-matched children on three tests, each relying on a single working memory component from their prototype, Children's Working Memory Assessment Battery (WMTB-C). The co-occurrence of dyslexia and dyscalculia has been shown by several epidemiological research (Badian, 1983; Lewis et al., 2004; Ramaa & Gowramma, 2002; Hasselhorn & Schuchardt, 2008). The high rate of co-occurring LD may explain the heterogeneity in findings regarding the specific kind of working memory impairments in this population.

Though the findings are inconsistent, recent research suggests that distinct working memory components may be differently associated with specific academic domains, such as reading, spelling, and mathematics (Vandenbrouckea et al., 2018). A study by Meyer et al. (2012) states that solving mathematical word problems uses all working memory components. However, the visuospatial sketchpad was the only one related to the precision of numerical operations. Similarly, the phonological loop and central executive are crucial for word reading, while the visuospatial sketchpad is not (Zheng et al., 2011). A study conducted by Brandenburg et al. (2015) indicated that visuospatial sketchpad is associated with spelling.

2.7.1 LD and Central executive function

In addition to identifying deficits in complex abilities like text comprehension, several research on dyslexia have also identified deficits in central-executive working memory functioning (Palmer, 2000; Schuchardt et al., 2008; Siegel & Ryan, 1989).

Studies on children with LD showed mixed evidence of deficits in central executive function (Gray et al., 2019). Numerous pieces of evidence point to the possibility that not all working memory components exhibit the same types of deficits. Instead, the central executive appears to be significantly compromised (Geary et al., 2000; Hitch & McAuley, 1991;).

The central executive capacity test, which requires the child to simultaneously process incoming material and store previously learned knowledge, shows significant deficits in children experiencing difficulties in learning (Gathercole & Pickering, 2003). Schuchardt et al. (2013) observed that 9-year-old children with typical development did noticeably better in counting and backward digit span tasks than those with dyslexia. However, the author remarked that the central executive tasks required phonological information processing (e.g., digits). Thus, deficits in phonological loops may affect the outcome. Similarly, Jeffries and Everatt (2004) observed that 8-year-old typically developing children scored noticeably higher for auditory recall and backward digit recall tests than children with dyslexia, suggesting children with dyslexia had abnormalities in central executive function. Another study conducted by Van der Sluis et al. (2005) indicated abnormality only in the central executive subsystem.

2.7.2 LD and Phonological working memory

There is strong evidence for phonological working memory deficits in children with dyslexia (Gray et al., 2019). Research indicates that children diagnosed with dyslexia experience difficulties with phonological processing and storage (Schuchardt et al., 2008). Children with dyslexia scored significantly less than their typically developing peers on verbal span tasks (Menghini et al., 2011), forward digit recall (Jeffries & Everatt, 2004; Schuchardt et al., 2013), word recall (Schuchardt et al., 2013), and nonword repetition tasks (Jeffries & Everatt, 2004; Schuchardt et al., 2013).

2.7.3 LD and Visual-spatial sketchpad

There are barely any reliable associations between dyslexia and visual-spatial sketchpad functioning (Eden & Stein, 1995; Howes et al., 2003; Pickering, 20023). When children between the ages of 8 and 14 were divided into groups for primary school (grades three through five) and middle school (grades five through seven) by Menghini et al. (2011), it was found that children with dyslexia exhibited considerably poorer scores on visual-spatial and visual-object span assessments in both age groups when compared to the typically developing group. Contrary to this, Jeffries and Everatt (2004) found no differences in the performance of 8-year-olds with dyslexia and typical development in block recall or maze memory tasks. In another study, the author indicates that working memory impairments can also affect visual processing in children with dyslexia (Gray et al., 2019).

In summary, the review of literature indicates that children with LD often exhibit deficits in working memory, which in turn could affect outcomes in domains such as phonological processing, visual processing, language, and literacy skills. It is also evident that the different components of working memory contribute uniquely to different skills indicating the need to consider working memory as being more than a unitary entity.

Understanding the relationship between LD and working memory deficits with respect to specific components is crucial for developing effective interventions and support strategies tailored to the specific cognitive challenges faced by individuals with LD. Thus, the current study was taken up to investigate the different components of working memory in children with LD compared to their typically developing peers.

CHAPTER 3
METHOD

The study aimed at investigating the components of working memory (central executive, phonological memory, and visuospatial memory) in children with learning disability (LD) in comparison with their typically developing peers.

3.1 Objectives of the study

The specific objectives of the study are:

4) to compare the score of N back visual task between children with LD and typically developing peers.
5) to compare the scores of a) Digit span forward (audio) b) Digit span backward (audio) task between children with LD and typically developing peers.
6) to compare the scores of a) Visual forward span (figures) b) Visual backward span (figures) between children with LD and typically developing peers.

3.2 Research design

Standard group comparison was used to investigate the components of working memory (central executive, phonological memory, and visuospatial memory) in children with LD in comparison with their typically developing peers.

3.3 Participants

A total of 38 children (20 boys; 18 girls) with typical development (control group) and 13 children (8 boys; 5 girls) with LD (clinical group) from grades 5 to 7 (age range –10-12 years) were included in the study. The details of the participants are given in Table 3.1.

Table 3.1

Details on the participants' grades and gender distribution in the study

Grade	TDC	LD
5	15	4
	(7 B; 8 G)	(1 B; 3 G)
6	11	5
	(6 B; 5 G)	(4 B; 1 G)
7	12	4
	(7 B; 5 G)	(3 B; 1 G)
Total	**38**	**13**
	(20 B; 18 G)	**(8 B; 5 G)**

Note: B – Boys, G – Girls, TDC – Typically Developing Children, LD – Learning Disability

3.3.1 Participant selection criteria

The criteria for selection of participants of the study are as follows:

- All participants were native speakers of Kannada residing in the urban ambient environment of Mysore.
- They were studying in schools with English as the medium of instruction without a history of change in medium of instruction/repeating any grades.
- All participants had normal hearing as assessed through hearing screening.
- All participants had normal or corrected vision.

- Typically developing participants were screened to ensure normal speech, language and hearing abilities using the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) checklist (WHO, 2004).
- Participants in the clinical group had a clinical diagnosis of LD based on evaluations by a multidisciplinary team including Speech Language Pathologist, Clinical Psychologist and Special Educator. Participants with history of neuropsychiatric disorders, or co-morbid conditions such as ADHD or autism spectrum disorder were excluded.

3.4 Ethical Clearence and Informed Consent

The procedures of the study adhered to the AIISH ethical guidelines for Bio-behavioural research involving human subjects (Venkatesan 2009). Parents/caretakers of all the participants provided a written consent prior to their inclusion in the study.

3.5 Test Environment

The participants of the study were tested in a quiet, distraction-free setting with sufficient lighting, ventilation, and comfortable sitting arrangements. Each task was administered individually for every participant in the clinical group as well as the control group.

3.6 Stimuli

The stimuli used in the study to assess different components of working memory were presented using a custom designed software named Smrithi-Shravan 3.0 (Maruthy & Kumar, 2013). The different modules in the software were carefully selected and designed based on established cognitive and theoretical frameworks to provide a comprehensive assessment of working memory abilities. Different tasks in the software were used to assesses different components of working memory such as phonological working memory (to assess working memory while minimizing the influence of lexical knowledge), visual-spatial working memory (the ability to temporarily modify and retain spatial and visual data) and central executive (to assess both storage and manipulation of information with visual or auditory stimuli).

This software consists of two modules Smriti - I and Smriti - II. Smriti - I contains Auditory Stimulus and Visual Stimulus. Smriti – II contains N-Back Auditory Stimulus, N-Back Visual Stimulus, Math Span Stimulus, Operating Span Stimulus, Reading Span Stimulus, Listening Span Stimulus and Running Span Stimulus. Auditory and Visual Stimulus from the module Smriti - I and N-Back Visual Stimulus from the module Smriti- II were used as stimuli for the present study.

3.7 Procedure

The participants were seated at a comfortable viewing distance in front of a personal laptop in which the Smrithi Shravan 3.0 software (Maruthy & Kumar, 2013) was installed. The examiner monitored the participant's attention during the tasks by sitting next to them while the test was administered. Each task took an average of five minutes to complete and the order of tasks was randomised across participants.

Three practice trials were given per task before the actual assessment to ensure familiarization with stimulus presentation and response modality. During the practice trials, feedback on the accuracy of the responses were also given. While calculating the scores, the practice trials were excluded. One-up-one-down method was applied in the presentation of stimulus for each task, as used by Jagadeesh and Kumar (2019). The software has been set to begin each task with a sequence of three stimuli. A series of random stimuli were displayed with a one-second gap between each stimulus. Following the presentation of the sequence's final stimulus, a new window was opened, allowing the examiner to enter the sequence using the laptop's keyboard in the same order as indicated by the participant. The participants were given a maximum of thirty seconds to provide their responses. In the following sequence, the span length was increased by one for each correct response and decreased by one for each wrong response. The details of the tasks included in the study are described in the following sections.

3.7.1 Task for central executive

1. *N back Visual*: The test was conducted using N back span module of the software.

   Stimuli: A sequence of visual stimuli (number strings including numbers from 0-9).

   Instruction: Each trial included a sequence of visual stimuli (numbers) presented one after the other in a random order and the entire list (of stimuli) was displayed at the end. The participant was instructed to memorize the sequence and select the last nth stimuli (n=2, second last stimuli) for each trial.

In the present study, the value of ‘n’ was set to 2 and the participants were instructed to select the second last stimuli in the presented sequence.

Scoring: A score of ‘1’ was given for each correct response and ‘0’ for each incorrect response. The total score was calculated by the software by summing up the scores obtained in each trial.

3.7.2 Tasks for Phonological memory

Two tasks, namely the digit span forward (audio) and digit span backward (audio) were used to assess phonological memory, using the digit span module of the software.

1. *Digit span forward (audio)*

   Stimuli: A sequence of numbers from 1 to 9 excluding 7 presented at comfortable hearing level.

   Instruction: A sequence of numbers was presented auditorily through in-built speakers of the laptop and the participant was asked to repeat the numbers in the same order as presented. The examiner typed in the response of the participant.

   Scoring: Analysis and scoring were done in accordance with the test's original instructions. Accuracy score and midpoint value for each response were given in the report section of the software. A score of "1" was given for accuracy if every test item was repeated in the same order (for instance, if the stimulus was 8342 and the answer 8342, then “1” was the score). A score of "0" was given if the test items were not repeated in the correct order.

2. *Digit span backward (audio)*

The stimuli and instructions given were same as that of digit span forward (audio) task except that the participant was asked to repeat the sequence of numbers presented in the reverse order.

Scoring: Analysis and scoring were done in accordance with the test's original instructions. Accuracy score and midpoint value for each response were given in the report section of the software. A score of "1" was given for accuracy if every test item was repeated in the proper reverse order (for instance, if the stimulus was 8342 and the answer 2438, then "1" was the score). A score of "0" was given if the test items were not repeated in the correct reverse order.

3.7.3 Tasks for visual- spatial working memory

The visuo-spatial working memory was assessed through two tasks, namely the visual forward span, and visual backward span for figures, using the visual span module of the software.

1. *Visual forward span (figures)*

Stimuli: A sequence of geometrical shapes including square, triangle, circle, rectangle, and cone.

Instruction: A sequence of geometrical shapes was presented on the screen and the participants were asked to select the same order of shapes from the list given at the end.

Scoring: Accuracy score and midpoint value were calculated in the same way as that of digit span forward task.

2. *Visual backward span (figures)*

The stimuli and instructions given were same as that of visual forward span (figures) task except that the participant was asked to select the sequence of figures presented in the reverse order.

Scoring: Accuracy score and midpoint value were calculated in the same way as that of digit span backward task.

3.8 Scoring and Analysis

The scores of individual participants in both the groups, that is, typically developing children and children with LD were generated as an analytical report by the software. Of the different scores generated, the midpoint value and the accuracy score for digit span forward (audio), digit span backward (audio), visual span forward and visual span backward tasks were considered and tabulated for further analysis. The accuracy score for each task for individual participants was obtained by adding the scores obtained in each trial of the task. Similarly, total score out of 13 was calculated by the software for N back visual task. The scores thus obtained for each individual participant, were compiled separately for each task to obtain the data for the two groups.

3.9 Statistical Analyses

Data were analyzed using SPSS (Statistical Package for Social Sciences) software (version 26). Initial analysis was carried out to check for the distribution of data using Shapiro Wilk test of normality. As the data did not follow normal distribution, further analyses were done using non-parametric tests. Descriptive statistics was used to compute the mean, median, standard deviation and interquartile ranges for the scores obtained by typically developing children and children with LD on each of the working memory tasks.

Mann Whitney U Test was used to compare the scores between clinical and control groups in each of the task included in the study. Correlation between the scores obtained in N back visual, digit span forward (audio), digit span backward (audio), visual forward span, and visual backward span tasks were assessed using Spearman’s correlation coefficient in each group of participants.

CHAPTER 4

RESULTS

The study aimed to investigate the components of working memory (central executive, phonological memory, and visuospatial memory) in children with learning disability (LD) compared to their typically developing peers. The specific objectives of the study were to compare the scores of the following tasks between the two groups: 1) N back visual task, 2a) Digit span forward (audio), 2b) Digit span backward (audio), 3a) Visual forward span (figures), 3b) Visual backward span (figures). Thirty-eight typically developing children (TDC) and thirteen children with LD across grades 5-7 participated in the study.

Data were analyzed using SPSS (Statistical Package for Social Sciences) software (version 26). Initial analyses were carried out to check for the distribution of data using the Shapiro-Wilk test of normality. As most of the data did not follow normal distribution ($p < 0.05$), further analyses were done using non-parametric tests. Descriptive statistics was used to compute the means, medians, standard deviations and interquartile ranges for the scores obtained by TDC and children with LD on each of the working memory tasks.

The results of the study are described under the following sections:

4.1 Comparison of working memory tasks between TDC and children with LD.

4.2 Correlation between different working memory tasks in TDC and in children with LD.

4.1 Comparison of working memory tasks between TDC and children with LD

The means, medians, standard deviations, and interquartile ranges of the scores obtained by TDC and children with LD for each of the working memory tasks included in the study are presented in Table 4.1.

Table 4.1

Means, Medians, Standard Deviations (SD) and Interquartile ranges (IQR) of the scores obtained by TDC and children with LD on the working memory tasks

Group		NBS	DSF Mid	DSF Acc	DSB Mid	DSB Acc	VFS Mid	VFS Acc	VBS Mid	VBS Acc
TDC (N= 38)	Mean	11.32	3.46	8.45	1.97	6.16	1.90	5.11	1.09	3.97
	Median	12.00	3.33	8.50	2.15	7.00	2.00	6.00	1.50	3.00
	S.D.	1.90	1.02	1.62	0.82	2.58	0.90	2.75	0.99	3.23
	IQR	2	1.4	3	0.9	2	1.0	5	1.80	5
LD (N= 13)	Mean	10.38	2.95	7.54	1.59	4.54	1.14	3.69	0.60	1.54
	Median	11.00	3.10	8	1.50	5.00	1.50	5.00	0.00	1.00
	S.D.	2.10	1.29	2.14	1.13	3.30	1.03	2.81	0.79	1.45
	IQR	4	1.2	3	1.4	7	1.8	5	1.50	3

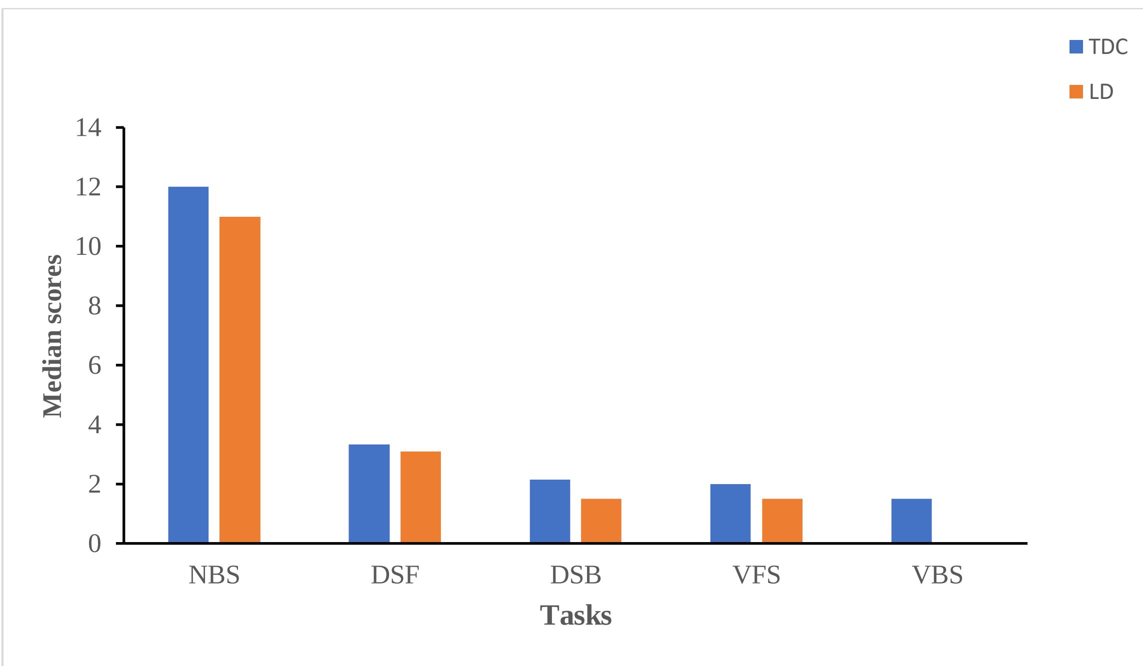
Note: TDC – Typically Developing Children; LD – Learning Disability; NBS- N back span visual; DSF – digit span forward(audio); DSB – digit span backward (audio); VFS – visual forward span; VBS – visual backward span; Acc- Accuracy score; Mid- Midpoint value

From Table 4.1, it can be observed that the median scores obtained by TDC were slightly higher when compared to children with LD for all the given tasks, including N back visual task, digit span forward (audio), digit span backward (audio), visual forward span and visual backward span tasks. This was found to be true for both midpoint value and accuracy scores. Further, in each group, the median scores obtained were slightly higher for the auditory tasks when compared to visual tasks. Within each modality, the median scores obtained were slightly higher for the forward-span tasks when compared to the backward-span tasks.

To verify the trend observed in descriptive statistics, the Mann-Whitney U test was carried out to compare the scores between TDC and children with LD. The results of the analyses are given in the following subsections.

Figure 4.1

Median of the midpoint value obtained by TDC and children with LD on different working memory tasks



NBS- N back span visual; DSF digit span forward (audio); DSB – digit span backward (audio); VFS – visual forward span; VBS – visual backward span; TDC-typically developing children, LD – Learning disability (group).

4.1.1 Comparison of N-back visual task scores between TDC and children with LD

The results presented in this section addresses the objective 1. The Mann-Whitney U test was used to compare the N-back visual task scores between TDC and children with LD. The results revealed no significant difference (|z|=1.55, p=0.119) between the scores obtained by the two groups.

4.1.2 Comparison of digit span forward (audio) and digit span backward (audio) tasks scores between TDC and children with LD

This section addresses objectives 2(a) and 2(b). Accuracy scores and midpoint values for each task were obtained. Results of Mann-Whitney U test revealed no significant difference between TDC and children with LD for either midpoint value (|z|=1.125, p=0.260) or accuracy scores (|z|=1.253, p=0.210) of digit span forward (audio) task. Similarly, no significant difference was obtained between the two groups for either midpoint value (|z|=1.783, p=0.075) or accuracy scores (|z|=1.654, p=0.098) of the digit span backward (audio) task.

4.1.3 Comparison of scores of visual forward span and visual backward span tasks between TDC and children with LD

This section addresses objectives 3(a) and 3(b). Accuracy scores and midpoint values for each task were obtained. The Mann-Whitney U test was used to compare the scores between TDC and children with LD and the results revealed a significant difference for the midpoint value (|z|=2.474, p=0.013) of the visual forward span task but not for the accuracy score (|z|=1.922, p=0.055). Similarly, a significant difference between the two groups were revealed for the accuracy score (|z|=2.453, p=0.014) of the visual backward span task but not for the mid-point value (|z|=1.801, p=0.072).

4.2 Correlation between working memory tasks in TDC and in children with LD

Correlation analyses were carried out separately in the two groups of participants, and the results of the analyses are given in the following subsections:

4.2.1 Correlation between different working memory tasks in TDC

Spearman's Correlation analysis was done to find the correlation between different working memory tasks, including N back span visual, digit span forward (audio), digit span backward (audio), visual forward span and visual backward span tasks in TDC, and the results are presented in Table 4.2.

From Table 4.2, it can be observed that there is a significant positive correlation ($p<0.01$) between the midpoint value of digit span forward (audio) and midpoint values of digit span backward (audio), visual forward span, and visual backward span. Similar results were observed for correlation analyses for the accuracy scores of digit span forward (audio) task. The digit span backward (audio) task was also found to have a significant positive correlation with that of visual forward span task with respect to both midpoint value ($p<0.01$) and accuracy scores ($p<0.05$). Correlation was found to be significant between the visual forward and visual backward span tasks for midpoint value ($p<0.05$) but not for accuracy ($p>0.05$). However, there was no significant correlation ($p>0.05$) between the N back visual task and any other task of working memory considered in the study in the group of TDC.

Table 4.2

Results of correlation analyses between different working memory tasks in TDC

		DSF		DSB		VFS		VBS		N
		Mid	Acc	Mid	Acc	Mid	Acc	Mid	Acc	**back**
DSF	Mid	1.00	-	0.489**	-	0.579**	-	0.470**	-	0.061
	Acc	-	1.00	-	0.396*	-	0.527**	-	0.499**	0.183
DSB	Mid	-	-	1.00	-	0.441**	-	0.194	-	0.137
	Acc	-	-	-	1.00	-	0.396*	-	0.295	0.017
VSF	Mid	-	-	-	-	1.00	-	0.367*	-	0.062
	Acc	-	-	-	-	-	1.00	-	0.266	0.017
VSB	Mid	-	-	-	-	-	-	1.00	-	0.172
	Acc	-	-	-	-	-	-	-	1.00	0.166
N back		-	-	-	-	-	-	-	-	1.00

Note: **- Significant correlation (p<0.01); *- significant correlation (p<0.05); NBS- N back span visual; DSF- digit span forward(audio); DSF- digit span backward (audio); VFS– visual forward span; VBS- visual backward span; Mid- midpoint; Acc- accuracy score.

4.2.2 Correlation between different working memory tasks in children with LD

The results of Spearman's correlation analyses were carried out to find the correlation between different working memory tasks, namely the N back visual task, digit span forward (audio), digit span backward (audio), visual forward span and visual backward span tasks in children with LD are given in Table 4.3. The results showed that the correlation was not significant (p>0.05) between any of the tasks in children with LD.

Table 4.3

Results of correlation analyses between different working memory tasks in children with LD

		FSA		BSA		VSF		VSB		N back
		Mid	Acc	Mid	Acc	Mid	Acc	Mid	Acc	
FSA	Mid	1.00	-	0.530	-	0.542	-	0.198	-	0.394
	Acc	-	1.00	-	0.498	-	0.088	-	-0.091	0.325
BSA	Mid	-	-	1.00	-	0.549	-	0.101	-	-0.001
	Acc	-	-	-	1.00	-	0.434	-	0.476	-0.080
VSF	Mid	-	-	-	-	1.00	-	0.197	-	-0.013
	Acc	-	-	-	-	-	1.00	-	0.263	-0.309
VSB	Mid	-	-	-	-	-	-	1.00	-	0.318
	Acc	-	-	-	-	-	-	-	1.00	0.123
N back		-	-	-	-	-	-	-	-	1.00

Note: **- Significant correlation ($p<0.01$); *- significant correlation ($p<0.05$); NBS- N back span visual; DSF- digit span forward(audio); DSF- digit span backward (audio); VFS– visual forward span; VBS- visual backward span; Mid- midpoint; Acc- accuracy score.

In summary, the comparison of working memory tasks between TDC and children with LD revealed a significant difference ($p<0.05$) for the midpoint value of visual forward span and accuracy scores of visual backward span tasks. There was no significant difference ($p>0.05$) between the two groups for the N-back visual task, and similarly, no significant difference for either mid-point value or accuracy scores of digit span forward (audio) and digit span backward (audio). There was a significant correlation between a few working memory tasks in TDC. In contrast, there was no significant correlation between any working memory tasks in children with LD.

CHAPTER 5

DISCUSSION

The study aimed to investigate the components of working memory (central executive, phonological memory, and visuospatial memory) in children with learning disability (LD) compared to typically developing children (TDC) studying in grades 5 to 7. Data provides significant findings regarding the components of working memory in both groups.

The results of the study are discussed under the following subsections:

5.1 Comparison of N-back visual task scores between TDC and children with LD

5.2 Comparison of digit span forward (audio) and digit span backward (audio) tasks scores between TDC and children with LD

5.3 Comparison of scores of visual forward span and visual backward span tasks between TDC and children with LD

5.4 Correlation between different working memory tasks in TDC and in children with LD

5.1 Comparison of N-back visual task scores between TDC and children with LD

The study results indicated no significant difference between the scores obtained by TDC and children with LD for the N-back visual task. The absence of a significant difference suggests that children with LD performed similar to their typically developing peers in the cognitive task that require the central executive component of working memory. This finding contradicts previous studies that reported consistent poor performance by children with LD on tasks requiring a central executive component of working memory, such as the N-back visual task (Gathercole & Pickering, 2003; Palmer, 2000; Siegel & Ryan, 1989; Swanson,1993; Schuchardt et al., 2008;). These differences could possibly be attributed to the differences in participant age and sample size between the studies. While the current study included 13 children with LD between 10 to 12 years of age, some of the reported studies included participants of younger ages in relatively large numbers. In the study done by Gathercole and Pickering (2003), there were 54 children with a mean age of 4.11 years. Similarly, in the study conducted by Schuchardt et al. (2008) included 97 participants within the age range of 7-10 years.

It can also be speculated that some children with LD may have a compensatory mechanism that allows them to perform similar to TDC on specific cognitive tasks. The compensatory strategies may include techniques like overt rehearsal which are actively used by older children, including those with LD to complete the tasks. Furthermore, the finding underscores the complexity of assessing cognitive abilities in children with LD. While the N-back task is a widely used measure of working memory and executive function, it is just one of many tasks that contribute to a comprehensive understanding of cognitive functioning.

5.2 Comparison of digit span forward (audio) and digit span backward (audio) tasks scores between TDC and children with LD

The findings of the study indicate that there is little to no significant difference between TDC and children with LD in terms of the midpoint values and accuracy scores for both digit span forward and backward tasks. This again contradicts the strong evidence for phonological working memory deficits in children with LD (Gray et al., 2019). Literature shows that children with LD scored significantly less than their typically developing peers on verbal span tasks (Jeffries & Everatt, 2004; Menghini et al., 2011), word recall (Schuchardt et al., 2013), and nonword repetition tasks (Jeffries & Everatt, 2004; Schuchardt et al., 2013).

The results of current study pertain specifically to digit span tasks (forward and backward) and cannot be directly compared to earlier studies reporting phonological memory deficits based on word recall and nonword repetition tasks. Compared to studies that used stimulus similar to that of the present study (e.g.: Jeffries & Everatt, 2004), the difference could be attributed to sample size and age-related differences between the two studies. Further, there are reported evidences stating that despite children having LD, the peripheral systems of the phonological loop (responsible for processing and storing verbal information) and the visuospatial sketchpad (responsible for processing and storing visual and spatial information) were relatively intact in these children (Swanson et al., 1990). This aligns with the findings of the current study.

5.3 Comparison of scores of visual forward span and visual backward span tasks between TDC and children with LD

The current study revealed mixed findings for the comparison of visual span tasks between TDC and children with LD. A significant difference in midpoint values was obtained between the two groups **for the visual forward span task,** but not for accuracy scores. In contrast, for the visual backward span task, there is a significant difference in accuracy scores but not in midpoint values.

A vast majority of the earlier studies in this direction barely indicate any reliable associations between dyslexia and visual-spatial sketchpad functioning (Eden & Stein, 1995; Howes et al., 2003; Kibby et al., 2004; Pickering, 2006b). Further, Jeffries and Everatt (2004) found no differences in the performance of 8-year-olds with dyslexia and typical development in block recall or maze memory tasks, suggesting variability in task-specific findings related to visual processing in LD. However, there are also reports supporting the notion of deficits in visual-spatial skills in children with dyslexia. In a study conducted by Menghini et al. (2011), it was found that children with dyslexia exhibited considerably poorer scores on visual-spatial and visual-object span assessments when compared to the typically developing group. These findings are supported by that observed in the current study wherein significant differences were obtained between children with LD and TDC for visual span tasks.

Overall, the findings of the current study suggest that while there may not be consistent associations between LD and visual-spatial functioning across all studies, there are specific instances, such as visual-span tasks, where differences in performance are evident. These differences underline the importance of considering task-specific cognitive assessments when evaluating children with LD.

5.4 Correlation between different working memory tasks in TDC and in children with LD

The findings of the correlation analyses in TDC suggest that children who score well on digit span tasks (both forward and backward) tend to perform similarly well on visual span forward task. The significant correlation ($p < 0.01$) between mid-point values of digit span tasks and visual forward span task indicates a strong relationship between these pairs of tasks. This is further emphasized by the significant correlation ($p<0.01$) observed between accuracy scores of digit span forward and visual forward span tasks.

In contrast, the results of correlation analyses in children with LD did not reveal any significant correlations between any of the working memory tasks. The lack of significant correlations between working memory tasks in children with LD suggests that the scores obtained on one type of span task (auditory or visual) may not be related to the other. There is no reported literature particularly with regard to correlation between different components of working memory in TDC or LD. Nevertheless, the disparity between TDC and children with LD observed in this direction indicates differences in the functioning of different working memory components in the two groups. While TDC showed a strong correlation between auditory and visual span tasks pertaining to phonological memory and visual-spatial sketchpad, children with LD exhibited a lack of such relationship between these components.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The primary focus of the current study was to investigate the components of working memory (central executive, phonological memory, and visuospatial memory) in children with learning disability (LD) in grades 5 to 7 compared to their typically developing peers.

A total of 38 children (20 boys; 18 girls) with typical development (control group) and 13 children (8 boys; 5 girls) with LD (clinical group) from grades 5 - 7 (age range –10-12 years) were included in the study. Participants were tested individually for different working memory tasks, including N back visual, digit span forward (audio), digit span backward (audio), visual forward span, and visual backward span tasks using various modules of Smrithi Shravan software.

The results of the study for comparison of working memory tasks between typically developing children (TDC) and children with LD revealed a significant difference ($p<0.05$) for the midpoint values of visual forward span and accuracy scores of visual backward span tasks. However, there was no significant difference ($p>0.05$) between the two groups for the N-back visual task. Similarly, no significant differences were obtained between the groups for either midpoint value or accuracy scores of digit span forward (audio) and digit span backward (audio) tasks. These results underscore the heterogeneity of working memory components in both groups of children, thereby supporting the need to assess individual components of working memory, particularly in the clinical group.

Spearman's correlation analysis was done to find the correlation between different working memory tasks in TDC and in children with LD. The results indicated a significant correlation between a few working memory tasks in TDC. In contrast, there was no significant correlation between any working memory tasks in children with LD. This contrast between TDC and children with LD indicates differences in the functioning of different working memory components in the two groups. While TDC showed a strong correlation between auditory and visual span tasks, children with LD exhibited a lack of such correlations, indicating potential dissociation between different working memory components in this population.

6.1 Implications of the study

- The results of the study offer deeper insights into the profile of working memory abilities in children with LD in comparison to their typical peers.
- The tasks used in the study can be utilized for assessments of specific component of working memory, where required.
- The findings can be utilized to customise clinical interventions with respect to specific components of working memory rather than considering it as a single construct.

6.2 Limitations of the study

- Generalization of the findings of the study is limited owing to the smaller participant number, particularly in the LD group.
- Although specific tasks were considered to evaluate each component of working memory, it may not be possible to rule out the influence/interaction between the components.

6.3 Future Directions

- Further investigation with a larger sample size and a wider age range is necessary for comprehensive understanding of potential differences in components of working memory abilities between TDC and children with LD.
- A protocol to assess each working memory component can be developed for routine use in a clinical/research set up.
- Conducting a similar study in children with other language disorders, such as specific language impairment/developmental language disorder, autism spectrum disorders and attention deficit hyperactivity disorder, could yield valuable insights into the nature of working memory functioning in these groups.

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