COMPARISON OF WORKING MEMORY ABILITIES ACROSS MODALITIES IN SCHOOL- AGE CHILDREN WHO STUTTER AND CHILDREN WHO DO NOT STUTTER

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CERTIFICATE

This is to certify that this dissertation entitled **"Comparison of Working Memory abilities across Modalities in School-age Children who Stutter and Children who do not Stutter"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science (Speech Language Pathology) of the student with Registration Number P01II24S123018. 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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This is to certify that this dissertation entitled **"Comparison of Working Memory abilities across Modalities in School-age Children who Stutter and Children who do not Stutter"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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ABSTRACT

Background. *Stuttering is a multifactorial disorder associated with disruptions in speech motor control, linguistic processing, and cognitive functioning. Among the cognitive domains implicated in stuttering, working memory (WM) has received considerable research attention, with prior studies consistently documenting deficits in phonological WM among children who stutter (CWS). However, evidence on WM across different modalities - auditory, visual, and spatial domains remains limited and inconsistent. Comprehensive cross-modal investigations are essential to understand the nature and extent of WM deficits in CWS, as modality-specific impairments may have broader implications for academic performance and speech-language intervention.*

Aim. *The present study aimed to compare WM abilities across auditory, visual, and spatial modalities between CWS and age- and gender-matched children who do not stutter (CWNS).*

Method. *Thirty-eight participants (36 boys, 2 girls) in the age range of 7–12 years were recruited for the study: 19 CWS and 19 age- and CWNS. All participants were native Kannada speakers from urban Mysuru, attending regular English-medium schools. WM was assessed using the backward span tasks — auditory, visual, and spatial from the Smriti-Shravan Version 1.0 software.*

Results. *The Mann-Whitney U test revealed statistically significant differences for both the backward span auditory and backward span visual tasks with CWNS outperforming CWS. No significant difference was observed between the groups on the backward span spatial task. Comparisons within group revealed no statistically significant difference in performance across the three modalities for either CWS or CWNS. However, in both groups, the visual modality yielded the highest mean rank, indicating a consistent but non-significant trend favouring visual modality performance.*

Conclusion. *The findings indicate that WM deficits in CWS extend beyond the well-documented phonological loop component, suggesting a global reduction in WM capacity rather than a selective, modality-specific impairment. These findings contribute to the growing body of evidence on cross-modal cognitive deficits in CWS and have implications for targeted cognitive assessment, training, and individualized therapeutic planning for school-age CWS.*

Keywords: *children who stutter, working memory, backward span, auditory, visual, spatial*

CHAPTER 1

INTRODUCTION

"Stuttering is a complex, multifactorial disorder characterized by atypical disruptions in the forward flow of speech" (Smith et al., 2017), which can affect a child's social and psychological well-being and quality of life (Rocha et al., 2020). Stuttering is considered a multifaceted condition because its onset and progression arise from the dynamic and non-linear interactions of motor, linguistic, and emotional factors rather than from a single underlying cause (Smith et al., 2017). Numerous theories and models have tried to explain the underlying mechanisms of stuttering which are suggested to range across psychosocial, biologic, behavioral, and learning theories (Ambrose, 2004). One of the perspectives is *neuropsycholinguistic function in stuttering* that explains stuttering as a breakdown in the interaction between linguistic and motor processes under time-pressure, suggesting that stuttering extends beyond a disruption in speech fluency and encompasses broader cognitive and linguistic processing demands during real-time communication (Perkins et al., 1991).

Cognitive functions refer to the mental processes that enable individuals to carry out goal-directed actions across diverse situations. The three key abilities included in Executive Function (EF) are: working memory (WM), cognitive flexibility (CF), and inhibitory control (IC). Reduced working memory capacity, limited cognitive flexibility, and weaker inhibitory control are said to increase cognitive demands during speech planning and production in individuals who stutter (Ofoe et al., 2018). Cognitive functions such as attention, executive functioning, processing speed, inhibition, and working memory are believed to contribute to speech planning and execution. Difficulties in these domains may interfere with efficient linguistic processing and fluent speech production. Research investigating cognitive differences between adults who stutter and those who do not has provided valuable insights into the role of cognitive functions in stuttering. Experimental findings indicate that individuals who stutter encode semantic information more slowly than their fluent peers (Bosshardt, 2006). In a recent investigation, performance on the Stanford-Binet Intelligence Scales, Fifth Edition - SB5 (Pomplun & Custer, 2005), demonstrated that working memory is one of the weakest EF components in children who stutter (CWS) and is significantly associated with stuttering severity, while nonverbal intelligence does not differ significantly between groups (Sami et al., 2025). Previously, Anderson and Wagovich (2010) reported that CWS exhibited reduced verbal working memory capacity, which may hinder fluent speech production.

Jones et al. (2017) noticed that preschool CWS performed poorly on tasks that required flexible thinking, suggesting difficulties adapting to changing task demands. In another investigation, Ofoe et al. (2018) reported that both parent questionnaires and behavioral tests consistently showed weaknesses in inhibition among young CWS. These difficulties may make it harder for them to juggle between language and thinking demands while speaking. In the case of verbal short-term memory (VSTM), some studies have found that preschool and school-aged CWS may have weaker VSTM skills than children who do not stutter (CWNS) (Anderson, Wagovich, & Hall, 2006; Anderson, Wagovich, & Hill, 2014; Hakim & Ratner, 2004), while a few others report no significant differences (Bakhtiar et al., 2007; Smith et al,2012). Devaraju and colleagues (2019) examined behavioral and neural correlates of auditory working memory tasks in adults with stuttering and suggested that inefficient allocation of cognitive resources may influence auditory working memory performance in persons who stutter. These findings support the possibility that cognitive-linguistic deficits may contribute to the speech difficulties observed in stuttering.

A cognitive function that has received relatively greater attention from researchers working in the field of stuttering is phonological working memory. Numerous studies have explored this skill in CWS and have consistently demonstrated poor phonological working memory abilities in CWS (Anderson & Wagovich, 2010; Hakim & Bernstein-Ratner, 2004; Yaruss 2014, 2016; Sugathan & Maruthy, 2020). Pelczarski & Yaruss (2016) further showed that even when controlling for broader language abilities, these phonological memory differences remain, suggesting a specific memory impairment. Further, parent-report measures indicated that CWS had significantly lower inhibition skills compared to CWNS. In contrast, behavioral tasks assessing inhibition yielded a low and non-significant difference between the two groups (Ofoe et al., 2018). Parent reports also suggest that CWS have slightly poorer attentional focus and persistence, but these differences may be subclinical, and behavioral data do not support a clear group difference in attention (Ofoe et al., 2018).

Working memory (WM) is widely acknowledged as a neurocognitive system responsible for the temporary storage and manipulation of incoming information (Oyoun et al., 2010). Working memory is the limited capacity mechanism that allows an individual to consciously retain and manage incoming information while doing cognitive activities (Cabbage et al., 2017). Working memory (WM) plays a vital role in cognitive and linguistic development in children, serves as a foundational system that supports the temporary storage and manipulation of information necessary for complex cognitive tasks such as learning, language comprehension, and reasoning (Baddeley, 2000). Each of these components is modality-specific, processing verbal and non-verbal (e.g., visual or spatial) information differently.

Among the various cognitive processes implicated in stuttering, working memory - particularly phonological working memory and central executive components - have received considerable attention from researchers investigating developmental stuttering. It has been found that CWS repeated nonwords less accurately than the CWNS, suggesting difficulty with phonological working memory (Hakim and Ratner, 2004., Anderson et al., Anderson and Wagovich., 2010) for a nonword repetition task. Another investigation indicated that CWS had a higher mean percentage of errors in non-word repetition compared to normal children, but this difference was not statistically significant (Vahab et al., 2014).

Further, Oyoun et al., (2010) also showed that CWS generally exhibit poorer performance in the picture-number recall test, which places higher demands on mental and recall abilities under time pressure. However, in other recall tasks, such as word set recall, digit span, and letter-sequence tests, no significant differences were observed between the two groups. Both groups showed better performance with shorter words and dissimilar word sequences, consistent with well-established effects on working memory. Additionally, CWS demonstrated longer reaction times and produced more phonological errors during nonword repetition tasks, indicating potential deficits in phonological encoding linked to working memory processes.

The results of a study done in Kannada-speaking children revealed that CWS performed significantly worse than CWNS on a nonword repetition task wherein CWS were less accurate in their initial attempts to repeat nonwords, especially as the syllable length increased. Further, CWS identified fewer target nonwords correctly in the silent identification task compared to CWNS. It was also noted that CWS took more trials and had lower initial accuracy, indicating challenges in phonological processing and retrieval (Sugathan & Maruthy, 2020). In a study by Sasisekaran and Weathers (2019), it was reported that school-aged CWS demonstrated more disfluencies and phonological revisions during nonword repetition tasks.

1.1 Need for the Study

Theories of stuttering have long recognized the potential contribution of cognitive processes to both onset and persistence of the disorder (Kolk et al., 1991; Smith & Weber, 2017). Researchers have also shown a keen interest in exploring the cognitive skills of individuals who stutter. Previous studies indicate subtle deficits in working memory (particularly phonological working memory), attention, inhibition, and cognitive flexibility in CWS when compared to typically developing peers. However, there are inconsistencies in these findings (Anderson & Ofoe, 2019; Ofoe et al., 2018; Paphiti & Eggers, 2022; Rocha et al., 2019).

It is noted that among various cognitive processes, working memory has intrigued most researchers. Studies have indicated that CWS may demonstrate reduced performance on tasks involving phonological encoding, nonword repetition, and working memory recall when compared to typically developing children (Oyoun et al, 2010). Previous findings suggest poor working memory in CWS (Anderson & Wagovich, 2010; Kaganovich et al., 2010). The most common aspect of working memory investigated among CWS is the phonological working memory typically assessed using tasks such as nonword repetition, phonological encoding, and phoneme monitoring. Irrespective of the task, evidence suggests that CWS exhibit significant deficits in phonological working memory (Anderson & Wagovich, 2010; Hakim & Bernstein Ratner, 2004; Pelczarski & Yaruss, 2014, 2016; Sugathan & Maruthy, 2020). A few other tasks that have been used to assess working memory abilities in those who stutter include the N-back task (Devaraju et al. 2019), reading span test (Arongna et al., 2020), and unscramble letter strings (McGill et al., 2016). However, findings on these other tasks have been inconsistent.

Despite these findings, relatively little is known about how working memory deficits manifest across different modalities, such as auditory, visual, and spatial domains. While some evidence suggests modality-specific effects—such as reduced auditory working memory capacity in CWS (Ofoe et al., 2018)—comprehensive cross-modal investigations remain limited. Understanding these differences is essential, as modality-specific working memory skills may differentially affect not only fluency but also broader academic outcomes, including reading, problem-solving, and classroom learning (Jones et al., 2017). Variations in participant characteristics, task demands, age ranges, and assessment methods may account for the inconsistencies in these findings.

Working memory capacity undergoes substantial development during the school-age years, with significant gains observed in phonological loop capacity, visuospatial working memory, and central executive functioning between the ages of 6 and 12 years (Gathercole et al., 2004). Given that school-going children are in a critical period of academic and linguistic development, understanding the nature and extent of their working memory capacities across modalities is essential. Such knowledge can provide deeper insights into the cognitive-linguistic profile of CWS and guide the development of more comprehensive and individualized therapeutic interventions.

1.2 Aim of the Study

The study aimed to compare working memory abilities across modalities - auditory, visual and spatial between school-age children who stutter (CWS) and children who do not stutter (CWNS).

1.3 Objectives of the Study

1. To evaluate and compare the performance of CWS and CWNS on the backward span auditory task.

2. To evaluate and compare the performance of CWS and CWNS on the backward span visual task.
3. To evaluate and compare the performance of CWS and CWNS on the backward span spatial task.
4. To analyze and compare the relative performance of CWS and CWNS across auditory, visual, and spatial backward span tasks.

1.4 Null hypotheses

The following null hypotheses were assumed to achieve the objectives of the study:

1. There is no significant difference in the performance of CWS and CWNS on the backward span auditory task.
2. There is no significant difference in the performance of CWS and CWNS on the backward span visual task.
3. There is no significant difference in the performance of CWS and CWNS on the backward span spatial task.
4. There is no significant difference in the relative performance of CWS and CWNS across auditory, visual, and spatial backward span tasks.

CHAPTER 2

REVIEW OF LITERATURE

Stuttering has been widely investigated across developmental stages, from early childhood through adolescence (Bloodstein & Bernstein Ratner, 2021). Research has identified several contributing factors, including linguistic abilities, emotional and temperamental characteristics, and speech motor control, highlighting the multifactorial nature of the disorder (De Nil,2004; Guitar, 2006; Smith, 1999; Walden et al., 2012).

Studies conducted in India indicate that approximately 0.4% of individuals in urban areas exhibit stuttering (Pachigar et al., 2011). Among school-going children, the prevalence is estimated to be about 1%, with a male-to-female ratio ranging from 2.2:1 to 5.3:1 (Mansson, 2000). Globally, the literature reports a lifetime incidence of approximately 5% and a prevalence of about 1% in the school population (Bloodstein & Ratner, 2008).

Within the linguistic domain, various theories have emphasized the role of deficits in phonological encoding as a potential underlying factor in stuttering. Several theoretical models support the involvement of phonological encoding difficulties in stuttering, including the Faultline Hypothesis (Wingate, 1988), the Neuropsycholinguistic Theory (Perkins et al., 1991), the Covert Repair Hypothesis (Postma & Kolk, 1993), and the EXPLAN model (Howell & Au-Yeung, 2002). Among these, Perkins et al. (1991) proposed the neuropsycholinguistic framework, which attributes stuttering to a failure in the timely synchronization of linguistic and paralinguistic components during speech production, particularly under conditions of time pressure. Stuttering has increasingly been associated with deficits in cognitive functioning.

Cognitive Skills in Individuals Who Stutter

Stuttering has increasingly been associated with underlying cognitive-linguistic deficits, particularly in areas related to speech planning, attention, and phonological processing. Neuroimaging research has provided important insights into the neurological basis of these deficits, with differences in gray matter and white matter development observed in children with persistent stuttering (Chow et al., 2023). These structural differences in speech-language networks suggest that cognitive deficits in stuttering may be linked to atypical brain development, extending beyond the observable disruptions in speech fluency.

Attention has been identified as one of the primary cognitive domains implicated in stuttering. Theoretical frameworks suggest that attentional resources play a regulatory role in speech planning and production, such that disruptions in attentional control may precipitate or exacerbate fluency failures (Perkins et al., 1991). In adults who stutter (AWS), several studies have documented difficulties in sustaining and directing attention during speech and non-speech tasks. A meta-analytic review by Doneva (2020) examined attentional abilities across 21 studies of adults who stutter (AWS) and adults who do not stutter (AWNS) and reported significant group differences in general attention, suggesting that attentional difficulties may play a role in the persistence of stuttering in adulthood. The findings of Devaraju et al. (2019) revealed poorer performance of AWS in comparison to AWNS on a 2-back task suggesting that AWS may experience increased attentional demands during more challenging tasks, such as the 2-back task when compared to 1 back and no back conditions.

Among children who stutter (CWS), attentional differences have also been documented, though findings are more variable. Ofoe et al. (2018), in a meta-analytic review of executive function in young CWS, reported that parents of CWS rated their children as having weaker attentional focus and persistence compared to children who do not stutter (CWNS). However, behavioral measures of attention did not consistently reveal significant group differences, indicating that subtle attentional weaknesses in CWS may be more evident in naturalistic settings than in controlled experimental conditions. More recent research by Eichorn and Pirutinsky (2021) suggests that attentional difficulties seen in younger CWS may persist into the school-age years, particularly under conditions of increased cognitive or linguistic demand.

Nonword repetition tasks, which tap phonological memory by requiring participants to repeat nonwords, have revealed that both children and adults who stutter demonstrate reduced accuracy and slower acquisition compared to their fluent peers, indicating deficits in phonological storage and retrieval (Bajaj, 2007; Anderson & Wagovich, 2010). In adults, Byrd et al. (2012) and Coalson and Byrd (2017) demonstrated that individuals who stutter showed reduced accuracy on nonword repetition tasks, particularly for longer and more phonologically complex stimuli, suggesting specific difficulties with phonological working memory encoding under increased processing demands.

In CWS, phonological memory difficulties have been documented across multiple studies. Anderson et al. (2006), Hakim and Ratner (2004), and Pelczarski and Yaruss (2016) found that CWS performed more poorly than CWNS on nonword repetition tasks, particularly at longer syllable lengths. Ofoe et al. (2018) further reported that CWS scored lower than CWNS on behavioral measures of phonological and verbal short-term memory. Oyoun et al. (2010) reported that CWS demonstrated significantly slower repetition of 2- and 3-syllable non words and produced a greater number of phonological errors compared to CWNS. Digit span performance was significantly reduced in CWS relative to their typically fluent peers, collectively indicating deficits in verbal short-term memory capacity among CWS.

Executive function (EF) is a comprehensive term including working memory, inhibition, and cognitive flexibility (Miyake et al., 2000, Ofoe et al, 2018). A meta-analytic review of executive function in AWS identified significant group differences in phonological working memory and general attention across multiple studies, though overall effect sizes were variable depending on the task demands and modality (Eichorn et al., 2023). In children, Ofoe et al. (2018) concluded from their meta-analysis that CWS show weaker executive function abilities than CWNS in two primary areas: behavioral measures of phonological and verbal short-term memory, and parent-reported measures of inhibitory control. Findings from more recent studies suggest that these weaknesses in executive functioning may continue beyond the preschool years (Eichorn & Pirutinsky, 2021; Paphiti & Eggers, 2022). These findings underscore the importance of examining cognitive functioning, and in particular working memory, as a key area of difficulty in individuals who stutter.

Working Memory in individuals who stutter

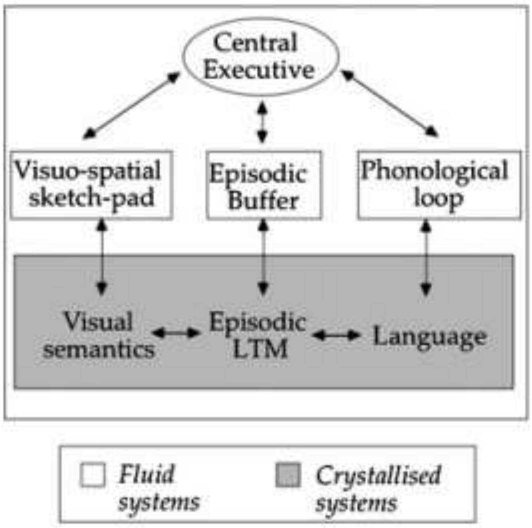
Working memory (WM) is broadly defined as a limited-capacity cognitive system responsible for the temporary storage and active manipulation of information during the performance of complex cognitive tasks (Baddeley, 2003; 2012). Baddeley (2012) described it as a system that not only holds information momentarily but also allows the individual to work with that information, distinguishing it from passive short-term memory storage.

The most widely cited and empirically supported framework for understanding working memory is the multicomponent model proposed by Baddeley and Hitch (1974) and subsequently refined by Baddeley (2000). The original model comprised three components: (1) the *central executive*, (2) the *phonological loop*, and (3) the *visuospatial sketchpad*. The central executive functions as an attentional control system of limited capacity, responsible for coordinating and directing the flow of information between the subsidiary systems, regulating attention, and managing complex cognitive tasks (Baddeley & Hitch, 1974). The phonological loop processes and temporarily maintains speech-based and auditory information through two subcomponents: the phonological store, which holds verbal information for a limited period, and the articulatory rehearsal process, which refreshes this information through subvocal repetition (Baddeley, 1986). The visuospatial sketchpad, in contrast, is responsible for the temporary storage and manipulation of visual and spatial information (Baddeley & Hitch, 1974).

Later in the year 2000, a fourth component was included in the model – the episodic buffer (Baddeley, 2003). The episodic buffer is conceived as a limited-capacity storage system that binds together information from these multiple sources, facilitating coherent cognitive representations that support language comprehension, learning, and reasoning (Baddeley, 2000). These four elements work together to form an adaptable and dynamic system that supports a wide variety of intricate cognitive processes.

Figure 2.1

Baddley's multicomponent working memory model



Source: Baddeley, A. D. (2012). Working memory: Theories, models, and controversies. Annual Review of Psychology, 63, 1–29.

Among the various cognitive domains examined in stuttering research, working memory has been extensively studied, largely because of its central role in speech and language processing. Since working memory has limited neural capacity, it is hypothesized that in individuals who stutter, the neural resources required for speech production may compete with those needed for working memory processing. This competition may reduce the individual's capacity for processing and retaining auditory or visual information in real time, thereby increasing the likelihood of fluency disruption (Baddeley, 2003). The relationship between working memory and stuttering has been investigated across multiple modalities — auditory, visual, and spatial for both children and adult populations (Eichorn et al., 2023; Bowers et al., 2018).

Digit Span Tasks: The digit span task is one of the most widely used measures of verbal working memory. In the forward digit span, participants listen to a sequence of numbers and repeat them in the same order, primarily assessing auditory attention and phonological storage. In the backward digit span, participants must repeat the numbers in reverse order, which additionally engages executive control and information manipulation processes, making it a more robust measure of working memory capacity (Baddeley, 2012). The backward digit span is considered a complex span task because it requires both storage and the active mental manipulation of information held in the phonological loop (Giofrè et al., 2016). Prior research on stuttering has revealed mixed findings using digit span tasks - while some studies have reported no significant group differences between CWS and CWNS on digit span measures (Oyoun et al., 2010; Pelczarski & Yaruss, 2016; Sasisekaran & Byrd, 2013), others have found subtle deficits, particularly when linguistic complexity is increased (Byrd et al., 2012). Shankar et al. (2025) reported that individuals who stutter showed poorer working memory scores on backward span tasks compared to their fluent peers. Recall accuracy was significantly lower among CWS compared to their fluent peers across verbal and written response conditions. These findings indicate that CWS may have reduced short-term memory capacity, independent of the mode of response (Reilly and Donaher, 2005).

Nonword Repetition Tasks: Nonword repetition tasks are widely employed to assess phonological working memory by requiring participants to repeat non-meaningful words. Although nonword repetition is primarily considered a measure of the phonological loop (Baddeley, 2003; Bowers et al., 2018), it also draws upon the phonological planning and encoding processes implicated in fluency. Numerous studies have demonstrated that CWS perform more poorly than CWNS on nonword repetition tasks, particularly at longer syllable lengths (Anderson et al., 2006; Anderson & Wagovich, 2010; Hakim & Ratner, 2004; Pelczarski & Yaruss, 2016; Spencer & Weber-Fox, 2014). In adults, Byrd et al. (2012), Coalson and Byrd (2017), and Sasisekaran and Weisberg (2014) also found reduced nonword repetition accuracy in AWS, particularly for phonologically complex stimuli.

Visuospatial Span Tasks: Visuospatial working memory tasks, such as the Corsi Block-Tapping Test and computerized spatial span paradigms, require participants to observe and reproduce sequences of highlighted spatial locations, either in forward or backward order. These tasks primarily assess the visuospatial sketchpad component of Baddeley's model (Baddeley & Hitch, 1974). Gkalitsiou and Byrd (2021) investigated visual and verbal working memory in AWS and AWNS using the visual N-back task with phonologically similar and dissimilar stimuli. There was no significant difference in accuracy between the two groups. The lack of accuracy differences across N-back levels led the authors to conclude that AWS do not demonstrate global working memory deficits, rather the difficulties may be selective to specific processes such as subvocal rehearsal and phonological encoding.

While verbal working memory deficits in CWS have been more consistently documented, research has increasingly highlighted the importance of examining visuospatial working memory as well. Oyoun et al. (2010) indicated that school-age CWS performed more poorly than CWNS on picture – number test, which assesses the visuospatial component of working memory. The test comprised of graded levels ranging from 3 to 10 picture-number tests, presented visually for sixty seconds, following which the child will be required to recall the numbers associated with previously presented pictures. The authors attribute this poor scores to the increased pressure and demands on the mental and recall abilities due to time pressure during the task. Wagowich et al. (2020) examined visual short-term memory (STM) in preschool-age CWS and age and gender-matched CWNS. Results revealed lower accuracy scores in CWS than CWNS, unveiling potential deficits in visual STM. The authors interpreted these findings based on Baddeley's (1986, 2003) working memory framework, attributing poor performance to deficits in the visuospatial sketchpad, and argued that the results point to domain-general rather than modality-specific cognitive deficits in CWS.

The backward span spatial task, which requires participants to recall highlighted spatial sequences in reverse order, places additional demands on executive control, making it a particularly sensitive measure of working memory beyond simple storage (Corsi, 1972; Baddeley, 2012). Although a variety of tasks have been used to explore phonological working memory in people who stutter, the most commonly employed have been nonword repetition and digit span tasks (Bowers et al., 2018).

There is some evidence of modality-specific deficits, such as reduced auditory working memory capacity, but comprehensive cross-modal comparisons are lacking (Ofoe et al, 2018) and prior research has mainly focused on phonological aspects, using tasks like nonword repetition and phonological encoding, while studies on other working memory domains (auditory, visual, spatial) are limited and yield mixed results (Anderson and Wagovich., 2010; Hakim and Ratner, 2004; Sugathan & Maruthy, 2020) and hence the need for the study**.**

CHAPTER 3

METHOD

The study followed the Ethical Guidelines of Bio-Behavioral Research involving Human Subjects version 2.0 (AIISH, 2023). The parents/caregivers of the participants were explained about the objectives and procedure of the study, following which informed written consent was obtained. Verbal assent was also taken from all participants.

Study Design

The study followed a standard group comparison research design wherein children who stutter (CWS) formed the clinical group and age- and gender-matched typically developing children who do not stutter (CWNS) served as the control group.

Participants

A non-purposive convenience sampling was done to recruit participants for the current study. A total of 38 participants (36 boys and 2 girls) in the age range of 7–12 years were recruited and distributed into clinical (19 CWS —18 boys; 1 girl; Mean Age: 9.74 years, *SD*: 1.73) and control (19 CWNS — 18 boys & 1 girl; Mean Age: 9.74, *SD*:1.73) groups. The participants in the clinical group (CWS) were recruited from the tertiary clinic at the investigator's university after a confirmed diagnosis of Developmental Speech Fluency Disorder by a certified Speech Language Pathologist (SLP) using Stuttering Severity Instrument – 4th Edition (SSI-4; Riley, 2009). Those in the control group (CWNS) were selected from local schools and neighbourhoods in urban Mysuru after they were age- and gender-matched with the clinical group.

All participants were native speakers of Kannada language and resided in the urban regions of Mysuru. Further, all participants attended regular schools with English as the medium of instruction. Handedness for all participants was determined using the Edinburgh Inventory for Assessment of Handedness (Oldfield, 1971). All 38 participants (19 CWS & 19 CWNS) were right-handed. They were screened for hearing sensitivity in both ears using the Android-based Hearing test app (developed by e-audiologia.pl), an app freely available in the Google Play Store. Masalski et al (2018), reported that the app has good sensitivity and specificity making it suitable for large scale hearing screening. In addition, the Screening Checklist for Auditory Processing (SCAP) developed by Yathiraj and Mascarenhas (2002) was administered to screen the auditory processing abilities of the participants. It was also ensured that all participants had normal or corrected vision. In addition, Raven's Standard Progressive Matrices (John and Raven, 2003) was administered to assess the non-verbal intellectual functioning of the participants. All participants demonstrated age-appropriate non-verbal cognitive abilities.

All participants were screened for any history of sensory, motor, neurological, language, or speech impairment (except stuttering for CWS) using the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) checklist (WHO, 2007). It was also ensured that there is no history of emotional, social, or psychiatric disturbances. Furthermore, it was ensured that none of the participants were under any medication that could potentially influence performance on the tasks in the current research. The demographic details of the participants in the clinical group are given in Table 3.1.

Table 3.1

Demographic Details of CWS

Participant No.	Age (in years; months)	Gender	Grade	Severity	Family history of stuttering
Participant 1	10;4	Male	5	Moderate	Negative

Participant 2	12;1	Male	5	Mild	Negative
Participant 3	10;2	Male	5	Moderate	Negative
Participant 4	8;1	Male	3	Moderate	Negative
Participant 5	11;2	Female	4	Moderate	Negative
Participant 6	7;11	Male	3	Moderate	Negative
Participant 7	9;2	Male	4	Moderate	Positive
Participant 8	8;3	Male	2	Moderate	Positive
Participant 9	11;3	Male	6	Moderate	Positive
Participant 10	7;4	Male	1	Moderate	Negative
Participant 11	11;5	Male	4	Moderate	Negative
Participant 12	7;5	Male	1	Moderate	Negative
Participant 13	10;3	Male	5	Moderate	Positive
Participant 14	9;4	Male	2	Moderate	Negative
Participant 15	11;11	Male	6	Moderate	Positive
Participant 16	12;0	Male	5	Moderate	Negative
Participant 17	8;1	Male	2	Moderate	Negative
Participant 18	11;10	Male	5	Moderate	Negative
Participant 19	10;1	Male	4	Moderate	Positive

Stimuli and Material

A custom-designed software named Smrithi-Shravan Ver.1.0 (Maruthy & Kumar, 2013) was used to evaluate the working memory abilities. It is an auditory and cognitive testing and training module. The cognitive training module consists of training on working memory (WM) skills in auditory, visual as well as spatial domains. This module has a set of working memory tasks grouped as simple and complex. The software consists of two modules Smriti-I and Smriti-II. In version 1.0, Smriti-I has auditory, visual, and spatial stimulus.

For the purpose of the current research, the *Backward-span task* was used to assess working memory abilities across three modalities — *auditory, visual*, and *spatial*. In the backward span task, digits/highlighted blocks with increasing levels of difficulty were presented, and the participants had to arrange them in reverse order. For the auditory and visual backward span tasks, the stimuli were Arabic numerals from one to nine excluding seven, whereas for the backward span spatial task, the stimuli were highlighted/coloured blocks. Every task included five practice trials for familiarization before the actual testing.

The software was installed on the investigator's personal laptop, and the same was used for test administration. The backward span auditory task was administered using a calibrated headphone.

Test Environment

All tasks were administered in a quiet, distraction-free setting with adequate lighting, ventilation, and comfortable seating. A comfortable viewing distance was maintained between the seating position and the laptop. The researcher sat next to the participant to monitor attention throughout the task.

Procedure

A pilot study was conducted prior to the study with two children (one each — CWS & CWNS) to check for the attention span and fatigue among participants when the three tasks were administered continuously. Based on the performance of participants in the pilot study, a decision was made to give a 1-minute break between the presentation of the three tasks, and the order of tasks was randomized across participants.

For the main experiment, the demographic details and case history of all participants were obtained through parent/caregiver interviews. The test was administered individually to each participant in both groups. As mentioned earlier, participants were seated at a comfortable viewing distance from the laptop on which the Smriti Shravan software was installed. Instructions for each task were provided orally by the researcher in Kannada prior to the respective task. The instructions for each test were also displayed in English on the laptop screen before the beginning of each test.

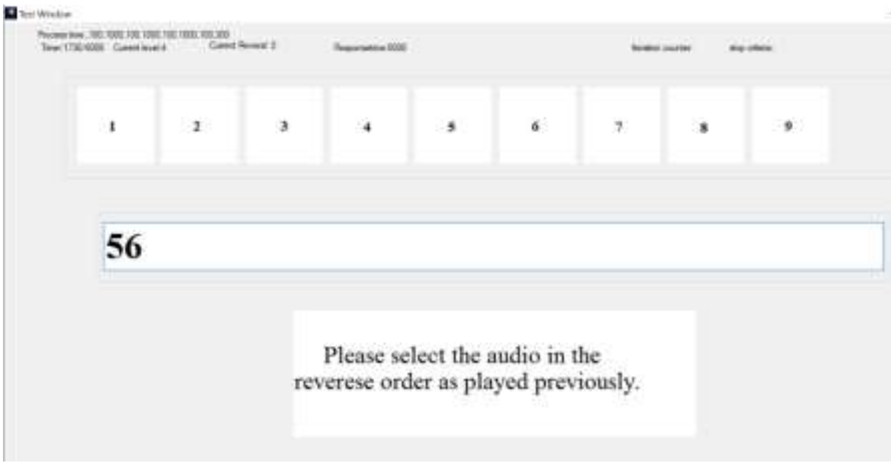
For all participants, the starting level was set as 3, indicating that the number of digits/sequence of highlighted blocks to be memorized was initially three. In the subsequent sequence, each correct answer resulted in one additional digit being played/displayed in the next attempt, whereas each incorrect answer led to one fewer digit being played/displayed. The maximum response time provided was 30 seconds for each sequence. The inter-stimulus interval was set at 500 milliseconds. Number of reversals was set to 3 and reversal discard as zero. A reversal occurred upon every change in response. The backward digit spans were calculated as the mean of the midpoint of the last four reversal points. For example, if a person remembered six digits correctly and gave an incorrect response when seven digits were presented, a reversal would occur, the mid-point of which would be 6.5.

Backward Span-Auditory Task

The stimuli were presented binaurally through Sennheiser HDA 200 circumaural headphones connected to the ASUS laptop with an Intel core i5 processor. The headphones used for stimulus presentation were calibrated to an output intensity level of 65 dB SPL, with the laptop volume maintained at 40% throughout the testing procedure. A series of digits was played auditorily with an interstimulus interval of 500 milliseconds, and the participants were instructed to type the digits on the keyboard in the reverse order of presentation. The stimuli consisted of digits from one to nine (except seven). The number of digits in the sequence presented auditorily varied according to prior responses. Figure 3.1 below is an example of a test trial for the backward span auditory task.

Figure 3.1

Screenshot of the Backward Span - Auditory Task



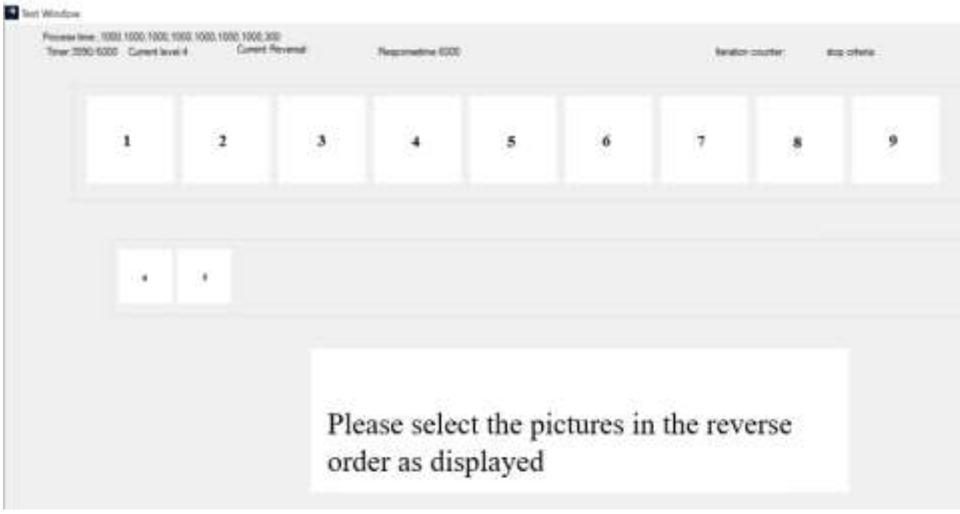
Instruction: "You will hear a sequence of numbers one after another. After the sequence ends, type the same numbers on the keyboard in the reverse order. For example: If you hear '3 – 8 – 1', you must type '1 8 3.' Remember, always repeat the numbers backwards, not in the same order as you hear."

Backward Span-Visual Task

In this task, Arabic numerals were displayed sequentially on the laptop screen. The participants were instructed to type the digits on the keyboard in the reverse order of presentation. Each digit was displayed on the screen for 2 seconds, followed by a 1-second gap (white screen) before the next digit was presented. The stimuli consisted of digits from one to nine (except seven). Figure 3.2 below is an example of the test trial for the backward span visual task.

Figure 3.2

Screenshot of the Backward Span Visual Task



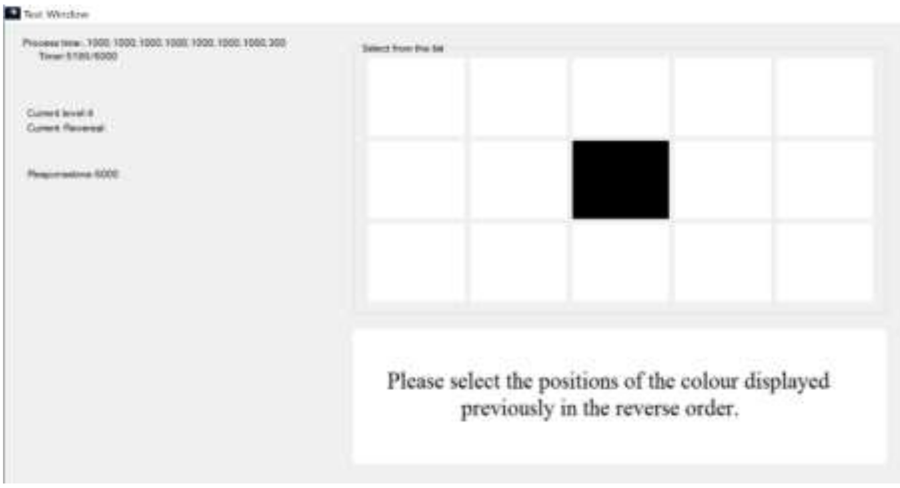
Instruction: "You will see a sequence of numbers on the screen, one after another. After the sequence ends, type the same numbers in the reverse order on the keyboard. For example: If you see '5 – 2 – 7', you must type '7 2 5'."

Backward Span-Spatial Task

During this task, the screen displayed a 4×4 grid containing 16 blocks. Different blocks on the grid were highlighted sequentially one after another. Each block was highlighted for 2 seconds, followed by a one-second pause before the onset of the next block. Participants were instructed to memorize the sequence in which the squares lit up and subsequently arrange them in backward sequential order. The number of highlighted blocks adapted according to previous responses. The mean calculated from the maximum number of correctly recalled blocks in backward order was averaged over three reversals and used as the index of working memory. Figure 3.3 below is an example of the test trial for the backward span spatial task.

Figure 3.3

Screenshot of the Backward Span Spatial Task



Instruction: "You will see boxes on the screen light up in a sequence. After the sequence ends, you must click on the boxes in the reverse highlighted order."

Scoring

The three parameters auto-analysed by the software are: (1) maximum value, which is the maximum length of sequence answered correctly by the individual for that particular task; (2) mid-point, which is the average score obtained for each task; and (3) response time (in milliseconds), which shows the time taken by the individual to type the digits in a specific order for a particular task, displayed graphically. Accuracy score is obtained from the report section of the software. A score of "1" is given for accuracy for each test item repeated correctly in reverse order, and a score of "0" is given if not repeated in the correct reverse order. In the present study, the midpoint value was considered (Spandita & Jain, 2026). In both the auditory and visual modalities, the maximum number of digits correctly recalled in reverse sequence was averaged across three reversal trials and midpoint value was computed. Similarly, the mid-point value was computed for spatial modality, by averaging the maximum number of highlighted blocks recalled in the exact reverse order of their presentation across three reversal trials.

Statistical Analyses

All statistical analyses were performed using IBM Statistical Package for the Social Sciences Statistics software (SPSS Version 26.0). Descriptive statistics, including mean, median, standard deviation, and interquartile range, were computed for the auditory, visual, and backward span spatial task scores for both CWS and CWNS. The Shapiro-Wilk’s test was used to assess the normality of the data distribution for each variable in both groups. Based on the results of test of normality, appropriate inferential statistics were performed for the between- and within-group comparisons. The level of statistical significance was set at $p < .05$ for all analyses.

CHAPTER 4

RESULTS

The study aimed to compare working memory abilities across auditory, visual, and spatial modalities between school-age children who stutter (CWS) and age- and gender-matched children who do not stutter (CWNS). The objectives of the study were to: (1) evaluate and compare CWS and CWNS on the backward span - auditory task (2) evaluate and compare CWS and CWNS on the backward span - visual task, (3) evaluate and compare CWS and CWNS on the backward span - spatial, and (4) analyze and compare the within-group performance of CWS and CWNS across auditory, visual, and backward span spatial tasks. A total of 38 participants (CWS = 19; CWNS = 19) were included in the study.

Data were analyzed using IBM Statistical Package for Social Sciences (SPSS; version 26.0) software. Initial analyses were carried out to check for the distribution of data using the Shapiro-Wilk test of normality. Results showed that 3 out of 6 variables had a non-normal distribution ($p < 0.05$). Hence, non-parametric inferential statistics were performed for between- and within-group comparisons. Descriptive statistics were used to compute the mean, median, standard deviation, and interquartile range for the scores obtained by CWS and CWNS on each of the three backward span tasks as shown in Table 4.1 below.

Table 4.1

Descriptive statistics for the midpoint values obtained by CWS and CWNS across backward span tasks

Group	**Tests**	**Mean**	**Median**	**SD**	**IQR Q1-Q3**
CWS	**BSA**	2.37	2.67	0.53	2.00 - 2.67
(N = 19)	**BSV**	3.18	2.67	1.24	2.33 – 3.33
	BSS	2.76	2.67	0.62	2.00 – 2.67
CWNS	**BSA**	3.38	3.00	0.97	2.50 – 4.00
(N = 19)	**BSV**	2.51	2.67	0.53	2.67 – 4.33
	BSS	2.79	2.67	0.46	2.67 – 3.00

Note. CWS – Children Who Stutter; CWNS – Children Who Do Not Stutter; BSA – Backward Span Auditory; BSV - Backward Span Visual; BSS – Backward Span Spatial; SD – Standard Deviation; IQR – Interquartile Range

From Table 4.1, it may be observed that CWNS demonstrated a higher median score on the backward span auditory task (Median = 3.00) compared to CWS (Median = 2.67). Further, for the backward span visual task, both CWNS and CWS obtained the same median score (Median = 2.67). The backward span spatial scores were comparable between the two groups, with both groups obtaining a median of 2.67.

Comparison of Working Memory Performance Between CWS and CWNS Across Modality

The Mann-Whitney U test was used to examine whether there were statistically significant differences between CWS and CWNS in working memory performance across the three modalities — auditory, visual, and spatial. The results revealed a significant difference between the two groups for the *auditory backward span tasks* (U = 109.50, $|z|$ = 2.145, p =

.032, r = 0.348) and *visual backward span tasks* (U = 108.50, $|z|$ = 2.132, p = .033, r = 0.346). In the backward span – auditory task, both the mean and median values were higher for CWNS than CWS (see Table 4.1). In case of the backward span - visual task, CWNS had higher mean values; however, median was same for both groups (see Table 4.1). In contrast to the above task, there was no statistically significant difference between the two groups (U = 116.00, |z| = 1.937, p = .053) for the *backward span – spatial task.*

Comparison of the Working Memory Performance Between Modalities for CWS and CWNS

The Friedman test was used to compare within-group performance of CWS and CWNS across the three backward span modalities — auditory, visual, and spatial. The results of the same are summarized below.

Working Memory Performance of CWS Across Modalities

The results of the Friedman test revealed no statistically significant difference in performance across the three backward span tasks (χ^2 = 3.207, df = 2, p = .201) for CWS. The mean ranks indicated that CWS performed best on the backward span - visual (Mean Rank = 2.29), followed by the spatial (Mean Rank = 1.89) and auditory (Mean Rank = 1.82) tasks.

Working Memory Performance of CWNS Across Modalities

In case of the CWNS, the results of the Friedman test revealed no statistically significant difference in performance across the three backward span tasks (χ^2 = 4.594, df = 2, p = .101). The mean ranks indicated that CWNS performed best on the backward span - visual (Mean Rank = 2.34), followed by the auditory (Mean Rank = 1.95) and spatial (Rank = 1.71) tasks.

CHAPTER 5

DISCUSSION

The present study investigated working memory (WM) abilities across three sensory modalities in school-age children who stutter (CWS) and age- and gender-matched children who do not stutter (CWNS) with typical development, using backward span tasks. The findings of the study are discussed hereunder.

Comparison of WM Performance Between CWS and CWNS

Backward Span - Auditory (BSA)

The findings of the present study revealed a statistically significant difference between CWS and CWNS on the BSA task. The CWNS demonstrated higher scores than CWS. The effect size was medium, indicating that the difference was not only statistically significant but also clinically meaningful. The BSA task places demands on both the phonological loop, for temporary storage of digit sequences, and the central executive, for active manipulation of the stored sequence in reverse order (Baddeley, 2012).

The reduced performance of CWS on this task, therefore, suggests inefficiencies in both the storage and manipulation components of verbal working memory. The present findings are consistent with previous research demonstrating weaknesses in phonological working memory among CWS. Anderson and Wagovich (2010), who examined the relationship among linguistic processing speed, phonological WM, and attention in preschool CWS and CWNS reported that CWS performed significantly worse than CWNS on nonword repetition, particularly for two- and three-syllable nonwords, even after controlling for chronological age. Importantly, Anderson and Wagovich found that, only for CWS, there was a significant negative relationship between phonological WM and linguistic processing speed — that is, CWS with poorer nonword repetition scores tended to be slower in picture naming. This pattern was not observed in CWNS, suggesting that the interaction between phonological WM and language processing operates differently in CWS compared to their fluent peers. Similar deficits in nonword repetition have been reported by several researchers (Anderson et al., 2006; Hakim & Bernstein Ratner, 2004; Pelczarski & Yaruss, 2016; Sugathan & Maruthy, 2020), supporting the view that CWS experience difficulties in storing, encoding, and retrieving phonological information, particularly when task complexity increases.

Though nonword repetition has been the most common task used to assess verbal/phonological working memory in CWS, a few researchers have also utilized the span tasks (Anderson et al., 2019; Kaganovich et al., 2010; Oyoun et al., 2010; Pelczarski & Yaruss, 2016; Sasisekaran & Byrd, 2013). While studies by Anderson et al. (2019) and Kakuta and Kawasaki (2025) reported poorer verbal span performance in CWS, others found no significant group differences (Kaganovich et al., 2010; Sasisekaran & Byrd, 2013a, 2013b; Sasisekaran et al., 2013; Sasisekaran & Basu, 2017). These conflicting findings have been attributed to the relatively lower cognitive and articulatory demands of digit span tasks compared to nonword repetition tasks. Nevertheless, a meta-analysis by Ofoe et al. (2018) reported robust differences between CWS and CWNS on measures of verbal short-term memory, suggesting weaker verbal memory abilities in children who stutter.

Overall, there is strong evidence for poor verbal short-term memory among CWS. In the context of span tasks, there are mixed findings reported. The current study, in accordance with existing literature indicated poorer performance in CWS. Hence, the null hypothesis that *there is no significant difference in the backward span – auditory task performance between CWS and CWNS* is *rejected*.

Backward Span – Visual (BSA)

The findings of the study revealed a significant difference in BSV task between CWS and CWNS, reflecting poorer WM in CWS. The backward span visual task in the present study required participants to observe a sequentially presented series of Arabic numerals on a screen and subsequently type them in reverse order. This task requires the visuospatial sketchpad for the temporary storage and mental representation of the visual digit sequence, and the central executive for the manipulation and reversal of the stored sequence (Baddeley & Hitch, 1974; Baddeley, 2012). Reduced midpoint scores in CWS on this task indicate either of the following two possibilities. First, the recall of digits may involve silent rehearsal, which in turn would involve the phonological loop. As discussed in the previous section, deficits in phonological WM among CWS are well documented. The second possibility is poor performance in the visual modality among CWS owing to a general WM deficit, one that is not restricted to any particular domain/modality. This may therefore reflect broader deficits in executive control and information manipulation in CWS, over and above the phonological processing difficulties.

While most prior research has focused on verbal or phonological WM in CWS, a growing body of evidence suggests that visuospatial WM may also be affected. Oyoun et al. (2010) assessed the visual WM among school-age CWS and CWNS using a paired-association task and results showed significantly poorer performance (recall abilities) in CWS than CWNS. Investigators concluded that WM deficits observed in CWS may not be domain-specific but rather a general one. A recent investigation by Kakuta & Kawasaki (2025), reported significantly poorer scores in CWS than CWNS on a visual memory task, along with poorer scores on a verbal WM task. The researchers suggest that low scores on WM tasks across modalities may reflect a deficit beyond the phonological loop and visuospatial sketchpad, one that represents deficits at a broader level such as central executive system. However, they cautioned regarding such an interpretation owing to absence of between group differences for inhibition and cognitive flexibility tasks. In an earlier investigation on cognitive flexibility (visual attention shifting) in school-age CWS when compared to CWNS, slower switching performance observed in CWS (Eichorn & Pirutinsky, 2021). This was attributed to reduced efficiency of executive functions, particularly attentional control, WM, and inhibitory control, which are considered foundational processes for cognitive flexibility.

The findings of the current study are in consensus with the existing literature (Eichorn & Pirutinsky, 2021; Kakuta & Kawasaki, 2025; Oyoun et al., 2010), indicating the possibility of a domain-general working memory deficit. Thus, the null hypothesis that *there is no significant difference in backward span – visual task performance between CWS and CWNS* is *rejected*. However, the use of digits in the visual task hints the possibility of silent rehearsals during recall, and hence the involvement of phonological loop cannot be ruled out completely. This aspect warrants further investigation.

Backward Span - Spatial (BSS)

In contrast to the auditory and visual modalities, no significant difference was noted between CWS and CWNS for the BSS task. Unlike the backward span auditory and visual tasks, the backward span spatial task, employed a non-linguistic stimuli (shapes) wherein participants had to observe and reproduce sequences of highlighted spatial blocks on a 4×4 grid in reverse order. This task primarily assesses the visuospatial sketchpad component of WM, specifically the spatial subcomponent, which is responsible for encoding and maintaining information about locations and spatial sequences (Baddeley & Hitch, 1974; Corsi, 1972; Baddeley, 2012).

While the researchers have been continuously exploring various aspects of phonological WM in CWS, there is limited evidence on spatial WM skills of these children. Wagovich et al. (2020) compared the visual attention and visual memory skills between preschool CWS and CWNS using visual tracking and recall task. CWS exhibited lower accuracy scores (both for visual tracking and memory) in comparison to CWNS. They concluded that preschool CWS have poor visual short-term memory. Similar findings were also reported by Ouyun et al. (2010), as discussed in the previous section, wherein CWS were observed to have lower scores on a paired-association task in visual modality. Together, these studies indicate general WM deficits among CWS and not modality-specific.

The absence of a significant difference in the BSS task in the current study may be explained from two perspectives. First, the lack of verbal or phonological content in this task may explain why CWS did not differ from CWNS, as it minimizes the contribution of the phonological loop, a system that appears particularly vulnerable in CWS. This interpretation aligns with the view that phonological WM is a primary area of difficulty in CWS (Anderson & Wagovich, 2010; Ofoe et al., 2018; Bowers et al., 2018), while purely spatial WM may be more relatively intact. Second, in view of the literature on general WM deficits discussed previously, it is possible that the spatial memory task in the current study was not cognitively loading enough to unveil group differences or the subtle deficits in CWS. Therefore, the null hypothesis that *there is no significant difference in backward span – spatial task performance between CWS and CWNS* is *accepted*.

Comparison of WM Performance across Modalities for CWS and CWNS

WM Performance of CWS

Findings of the present study indicated that CWS tended to perform best on the backward span visual task, followed by the spatial and auditory tasks. While this pattern was not statistically significant, the numerical trend of a slight visual advantage within the CWS group is an interesting observation. One possible explanation for this trend is that the backward span visual task, which presents digit stimuli on a screen, may afford CWS a degree of additional processing time through visual persistence, allowing them to visually encode and mentally reverse the sequence with slightly less reliance on rapid phonological processing compared to the auditory modality. Since rapid phonological encoding under time pressure has been identified as a specific area of difficulty in CWS (Perkins et al., 1991; Pelczarski & Yaruss, 2016), the slight advantage of the visual modality may reflect a compensatory reliance on visual encoding strategies in CWS.

The absence of a statistically significant within-group difference in CWS indicates that CWS do not demonstrate a clear modality-specific pattern in WM performance across the three domains tested. This finding is consistent with Ofoe et al. (2018), whose meta-analysis reported that WM deficits in CWS did not consistently favour one modality over another. The present findings thus suggest that the WM profile of CWS is characterized by generalized, cross-modal weaknesses rather than selective, modality-specific impairment.

WM Performance of CWNS

Similar to CWS, a similar performance was noted for all three tasks in CWNS. Absence of statistically significant difference was expected as the participants in this group were typically developing children screened for any cognitive deficits. The descriptive data showed that CWNS also performed best on the backward span visual task, followed by the auditory and spatial tasks. Support is drawn from Alhamdan et al. (2023), who report that visual WM and non-verbal intelligence significantly improved with age in children aged 5–10 years and were strongly associated with faster multisensory motor reaction times. They suggested that visual WM emerged as the strongest predictor of multisensory processing and visuomotor performance, whereas auditory WM showed limited contributions.

Based on the above findings it is clear that CWS have significant WM deficits in comparison to the typically developing peers. Further, there is evidence to suggest that the observed deficits reflect a global reduction in WM capacity in CWS relative to CWNS, rather than a selective impairment in one particular modality. Some studies do report no difference in the performance between CWS and CWNS for the visuospatial modality; however, these differences could be attributed to methodological differences, particularly the nature of the tasks. It is possible that the tasks that place minimal or low cognitive load on the WM system, may yield performance similar to CWNS. This aspect needs further investigation.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The aim of the study was to compare and evaluate the working memory performance of CWS in comparison with their age- and gender-matched typically developing peers using backward span tasks in three different modalities – auditory, visual and spatial. 19 school-age children who stutter (CWS) and 19 age-and gender matched typically developing children were recruited as participants. The working memory skills were evaluated using the *backward span tasks (auditory, visual, & spatial)* in the Smriti Shravan version 1.0 software. The mid-point values for each of the tasks were considered for further statistical analyses.

The majority of the variables violated the assumption of normality; hence, non-parametric inferential statistics were employed. Descriptive statistics revealed that CWNS obtained a higher median score than CWS on the backward span auditory (BSA) task, while comparable median scores were obtained on both the backward span visual (BSV) and backward span spatial (BSS) tasks for both groups. The results of the Mann-Whitney U test revealed statistically significant (with medium effect sizes) between-group differences on both the auditory and backward span visual tasks, with CWNS outperforming CWS in both modalities. In contrast, no significant difference was observed for the BSS task between the groups. Analyses using the Friedman test revealed no statistically significant difference in performance across the three modalities for either CWS or CWNS. However, in both groups, visual modality yielded the highest mean rank, indicating a consistent but non-significant trend favouring the visual modality within both CWS and CWNS.

Overall, the findings of the current study are in accordance with the literature and is suggestive of working memory deficits that may extend beyond the phonological loop component. However, further investigations are warranted.

Implications of the Study

- The findings of the study contribute to existing literature on the working memory deficits in CWS, particularly adding significant information regarding modality-specific deficits.
- This knowledge of domain-specific working memory abilities may be used to make informed decisions regarding targeted cognitive assessments, training and interventions for CWS.
- The findings on modality-specific working memory skills among CWS in comparison to CWNS will provide deeper insight into cognitive and executive function mechanisms underlying stuttering.

Limitations of the Study

- The findings of the study need to be generalized with caution owing to small sample size.
- The study employed only backward span tasks as measures of working memory. Other working memory paradigms, such as forward span tasks, N-back tasks, and complex span tasks (e.g., reading span, operation span) were not included, limiting a comprehensive characterization of all working memory components.

Future Directions

- Future research may include a more comprehensive battery of working memory tasks across all modalities including forward span tasks, N-back tasks, complex span tasks (e.g., reading span, operation span, symmetry span), and dual-task paradigms to provide a more complete characterization of all components of Baddeley's multicomponent model in CWS.

- Future studies may also investigate domain-specific working memory skills using tasks of varying complexity within each modality.

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INSTITUTE REVIEW BOARD (IRB) APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROPOSAL INVOLVING HUMAN SUBJECTS AT AIISH

AIISH Institute Review Board (IRB)

Date: 11.03.2026

Ref: SH/IRB/M.5/SLP.17/2025-26

Title of the Dissertation	: Comparison of Working Memory Abilities across Modalities in School-age Children who Stutter and Children who do not Stutter
Name of the Student	: Fathima Neba
Guide	: Dr. Divya Seth
Co-Guide (if any)	: Dr. Chandni Jain
Proposed Duration of the Project	: 06 months
Source of funding	: Non-funded Master's dissertation
Estimated budget	: Nil
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A clear statement of the decision reached IRB meeting (In the vent of the proposal is not approved, a statement of reasons for the same must be indicated)	**: APPROVED**
Advice & suggestions (if any)	: NIL

Signature & Name of the Member Secretary-IRB

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