RELATIONSHIP BETWEEN AUDITORY WORKING MEMORY AND SPEECH PERCEPTION IN NOISE IN CHILDREN WITH AND WITHOUT ABACUS TRAINING

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Registration no: 18AUD032

This Dissertation is submitted as a part fulfillment for the Degree of

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Certificate

This is to certify that this dissertation entitled **"Relationship Between Auditory Working Memory And Speech Perception In Noise In Children With And Without Abacus Training"** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student with Registration Number: 18AUD032. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other Universities for the award of any other Diploma or Degree.

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Certificate

This is to certify that this dissertation entitled **"Relationship Between Auditory Working Memory And Speech Perception In Noise In Children With And Without Abacus Training"** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other Universities for the award of any other Diploma or Degree.

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Declaration

This is to certify that this dissertation entitled **“Relationship Between Auditory Working Memory And Speech Perception In Noise In Children With And Without Abacus Training”** is the result of my own study under the guidance of Dr. K. Rajalakshmi, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other Universities for the award of any other Diploma or Degree.

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Dedicated to
Appa, Amma,
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&

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Abstract

Working memory (WM) plays a major role in speech perception. Communication hampers, especially in the presence of noise, and this disturbance in speech signals will lead to a mismatch in the information. In such a situation WM plays a greater role. There is evidence for abacus training improving the WM in children (Lee et al., 2007). Hence, the current study aimed to investigate the correlation between WM and speech perception in noise (SPIN) in children with and without abacus training due to limited literature availability explaining the relationship of WM and SPIN. For this purpose, thirty normal hearing children who were native speakers of Kannada, of which 15 children with abacus training within the level 6 to 10 and 15 children without abacus training within the age range of 9- 11 years, were recruited for the study. The WM (auditory forward syllable span, auditory backward syllable span, and n-back test) and SPIN test was measured. Results showed that there was a significant difference in WM measures and SPIN test in children with abacus training when compared to children without abacus training. Also, a significant negative correlation between auditory forward syllable span test and SPIN right test was obtained following the Spearman rank correlation test. Abacus training improves children's mathematical calculations, where learning mathematical calculations are associated with WM. WM is said to be associated with improvement in SPIN. Thus, children with abacus training performed well in WM and SPIN tests. The study highlights the positive effects of abacus training and was helpful in understanding the relationship between WM capacity and SPIN in abacus training children.

Tables of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Abacus is an arithmetic learning program, in which individuals learn to perform arithmetic operations like addition, subtraction, multiplication, and division quickly. The word abacus derives from the Greek meaning of "abax" or "abacon", table or tablet. The use of the word "abacus" is documented in the literature even before 1387 A.D. In India, at around 1st-century sources '*Abhidharmakosa'* records the knowledge and the use of abacus by Indian clerks. In the 11th century, the Chinese Abacus *Suanpan* was devised with two beads above, a middle divider and five beads below it. The Chinese Abacus was modified by Japanese as *Sorobon* because of its necessity and importance. It is also known as a framework for counting, a tool made of a bamboo frame with beads sliding on a wire that used to have beans or stone moved in grooves in sand or wood stone tablets or metal tablets (Heffeifinger & Fiom, 2004). Nowadays, the abacus has been extensively practiced to teach mathematics for children in India. Initially, all the abacus trainees are taught to carry any mathematical calculation by manipulating the abacus instrument through their fingers, and at the final stage, they are trained to use the visual image of the abacus for carrying out the mathematical operations. Training in abacus involves carefully attending to the numbers for calculations by either through physical manipulation of abacus or by mental mode to calculate the arithmetic operation.

Memory is an act of an immense physiological process in every act of memorization of the information processing approach. There are various types of memory wherein data is coded stored and retrieved when required; one such memory is the working memory (WM). This is referred to as a brain network that temporarily manipulates and stores knowledge required for such complex cognitive tasks as reasoning, learning, and comprehension of language (Baddeley, 1996). Based on the stimulus used, working memory can be classified into visual and auditory WM. The ability to process, analyze, store temporarily, and recall the auditory information later is termed as auditory working memory, whereas the information provided through the visual mode becomes visual working memory. According to Baddeley and Hitch (2000) working memory (WM) includes the central executive (CE), and it has three systems the phonological loop (PL), the episodic buffer (EB), and the visuospatial sketchpad (VSSP). The four components mentioned above act as a dynamic mesh that allows the entry of desirable information and removes the undesirable information to the cognitive processing system (Baddeley et al., 2001).

Bhaskaran et al. (2006); Hatta and Ikeda (1988) reported that the use of abacus requires the coordination of finger movements, sound, and sight in order to increase synaptic links. Abacus-based mental calculation (AMC) is a mental arithmetic skill based on the manipulation of based on an imaginary abacus (Frank & Barner, 2012; Stigler, 1984). The physical task involved in solving the mathematical problems using abacus stimulates the cortex through the synaptic connections from visual, auditory, and sensory inputs. The recovery of relevant principles, temporary storage, and updating of intermediate outcomes and mental abacus manipulation are various cognitive processes incorporated into AMC operation (Hu et al., 2010; Hanakawa et al., 2003). These cognitive skills are also seen during the functioning of WM (Baddeley et al., 2001). Various functional magnetic resonance imaging (fMRI) studies revealed frontoparietal areas activation on both AMC and WM tasks (Du et al., 2013; Chen et al., 2011; Hanakawa et al., 2003; Ku et al., 2012; Tanaka et al., 2012; Owen et al., 2005; Wager & Smith, 2003). As the literature suggests similarities in terms of cognitive processing between AMC and WM tasks, AMC might serve as an effective involvement to influence the WM. However, there is a dearth in the literature regarding the same working memory tasks.

Bhaskaran et al. (2006) reported that kids use both hands to move beads in order to manage both small and large calculations while abacus calculations. Hence abacus related tasks created communication between the two brain hemispheres and promoted quick, balanced, and complete brain development. There are several studies reporting the enhancement of cognitive abilities post abacus training. Abacus training showed an improvement in numerical memory, photographic memory, logical reasoning, problem-solving, visualization skills, calculating skills, and also improving in auditory attention, memorization, and rate of reading and listening (Bhaskaran et al., 2006; Chen et al., 2011). Some of the fMRI studies have shown that the right hemisphere engaged for AMC agents, whereas for the untrained individuals left hemisphere contributes to mental calculation (Hatta & Ikeda, 1988; Wu et al., 2003).

Chermak and Musiek (2013) reported that intensive auditory training could lead to increased plasticity of brain which thereby improves the auditory performance. Children who receive training in abacus, listen to the dictated problems and solve mathematical operations. With constant training, the auditory stimuli are processed faster, problem-solving would become accurate and quick and this will improve one’s auditory attention. Yathiraj and Priyadarshini (2009) carried out a study where the children with abacus training performed better in dichotic test, which resulted in enhanced auditory performance. Abacus experts perform a mental calculation with exceptional speed and accuracy, which requires coordination of basic knowledge of abacus and complex cognitive processes. The algorithm acquired by long time practice by abacus experts enables to circumvent the short term memory (STM). If the STM improves, working memory also improves, and later on, this consolidation leads to long term memory (LTM).

Auditory working memory plays a part in speech and language development and its perception, comprehension of reading and academic achievement (Alloway et al., 2009; Gathercole et al., 2006; Gillam, 2018; Vuontela, 2003).

According to Rönnberg et al. (2013) Ease of language model (ELU) has a relationship with working memory. In regard to this model, any mismatch between speech input signal and its phonological representation stored in LTM disrupts the automatic vocabulary retrieval. It will lead to the use of busy processing model for developing speech understanding in noise in children, while predicting school-age children with higher WM skills have higher simple and complex quiet sentence identification compared to peers with poorer WM skills (Magimairaj & Montgomery, 2012). It is assumed that if any speech input sound matches with the phonological representation, language comprehension is achieved. But whenever the speech input signal is distorted, it creates a mismatch of information between phonological and the LTM representation. External disturbance of speech signals hampers the quality of the incoming signal, which is a major challenge for the listener (Sbompato et al., 2015). Baddeley (1996) defined impaired recall as the "irrelevant speech effect" in the presence of irrelevant auditory stimuli. When such mismatch happens, comprehension of speech is done through cognitive skills like attention, inhibition, and WM. ELU model suggests that speech processing will be better for people with greater WM than for people with poor WM abilities. This was justified by many authors (Besser et al., 2013; Holmer et al., 2016; Rönnberg et al., 2013; Sullivan et al., 2015). Osman and Sullivan (2014) conducted a study on children in two listening conditions, quiet and noisy listening situations. Various listening comprehension tasks were given in both the listening situation. The authors found that WM efficiency was reported to be considerably lower in terms of noise compared to quiet. This has been attributed to increased recruitment of cognitive resources in noise. Overall, the finding showed greater correlations between working memory and listening comprehension to quiet relative to noise. This was interpreted to represent the increased working memory demands for listening in noise.

Need for the study

Therefore through the previous studies, it is inferred that WM plays a major role in speech perception (Kraus et al., 2012). Communication hampers, especially in the presence of noise, and this disturbance in speech signals will lead to a mismatch in the information. In such a situation, WM plays a greater role, and children learn their basic education from school for their future. The unfavorable listening situation present in the classrooms will affect their communication as well as learning (Gillam, 2018; Osman & Sullivan, 2014). The existing literature has provided evidence for the positive impact of WM on auditory speech perception in noise. Additionally, there is also evidence that abacus training improves children's working memory (Lee et al., 2007). However, no studies have evaluated the combined effect of abacus training and WM skills on speech perception in noise. Therefore the present study aims to investigate the correlation between working memory and speech perception in noise in children with and without abacus training.

Aim

To investigate the relationship between auditory working memory and speech perception in noise in primary school children with and without abacus training.

Objectives

1. To measure and compare the auditory working memory and speech perception in noise in children with and without abacus training.
2. To find out the relationship between working memory and speech perception in noise in children with and without abacus training.

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Chapter 2

Review of literature

Working memory (WM) is a type of memory that is responsible for temporary storage and processing various everyday activities. In the aspect of an abacus, WM is one of the crucial factors to perform mathematical calculation, where the arithmetical calculation is a skill which is necessary and often challenge people in their lives. From the studies, it is inferred that mental calculations are dependent on WM, and they also involve well-learned procedures and problem-solving skills (Sokol et al., 1991). Currently, the research community has attracted a great deal of attention at the moment, as the WM differs across each individual (Miyake, 2001). Several studies (As observed in review given by Gathercole, 1999) have reported that WM plays a crucial role in defining the individual characteristics and performing cognitive tasks, which include intelligence quotient (IQ) and achievements of children in school. Studies conducted focusing mainly on individual difference approach found that language comprehension specifically contributed by working memory capacity (Daneman & Merikle, 1996), solving arithmetic problems, and following directions (Engle et al., 1991).

Abacus and working memory

Baddeley and Hitch (1974) proposed a WM model consisting of three systems: the central executive system (CES), the visuospatial sketch pad (VSSP), and the phonological loop (PL), in which the CES acts as a control system which co-ordinates its function with two other systems. The PL is responsible for storing speech like material, and the VSP plays a role in processing visual information.

Thompson and Paivio (1994) carried out a study to examine the mnemonic independence of nonverbal auditory stimuli and nonverbal visual stimuli (picture sound pairs, pictures, and corresponding environmental sounds). The study included three experiments, experiment 1 included 169 student participants, tested with three learning conditions (intentional with a rehearsal inhibiting distracter task, intentional standard, and incidental with the distracter task), and the results of the three experiments revealed that the best recall for the picture-sound item in all groups. Morris (1987) conducted three experiments to test the relationship between PL, VSSP, and CES. The study incorporated tracking tasks that were made to interfere in the primary tasks. The results revealed that the visuospatial sketch pad functioned independently of the phonological loop and also reported that the central executive source contributed majorly to tracking tasks. Thus each component serves an independent function. To serve such functions, there are anatomical correlates responsible for the changes to occur. There have been studies over neuro-anatomical correlates that underlie contributing to the improvement of WM in abacus trainees. It has been reported that training might result in the changes in brain functioning and behavioral performances in the abacus trainees as they have a greater capability in handling digits with unusual accuracy and speed and the effect of training has been extensively studied in the area of WM (Klingberg, 2010; Olesen et al., 2003) and mental calculation (Hanakawa et al., 2003; Delazer et al., 2005). Tanaka et al. (2002); Chen et al. (2006) reported that the frontoparietal region contributes majorly in mental calculation and digit working memory in abacus trained individuals. Similarly, longitudinal studies on the right hemispheric lesion (Tanaka et al., 2012) and a case study of EEG-fMRI (Ku et al., 2012) reported that the frontoparietal region to contribute majorly in abacus mental calculation. Li et al. (2013) sought to study the effect of abacus training on numerical WM in kids. The study comprised two groups, i.e., trained and untrained abacus. Each group was composed of 17 children aged between 9.6 and 11.2 years. The children were asked to perform two numerical WM tasks (digits and beads) where fMRI was simultaneously performed. The results of the fMRI revealed that children with abacus training showed higher activation in the right supplementary motor area and superior occipital gyrus or posterior superior parietal lobule compared to the untrained group in both tasks, as well as greater interaction between the right supplementary motor area, and right inferior frontal gyrus. Thus concluding that in the abacus trained group, there is a greater contribution of the frontoparietal network during numerical memory tasks.

There have been many studies conducted to study whether training in abacus contributes to the improvement in working memory using several tasks. Lu (2002) conducted a study comprising two experiments to investigate the impact of mental abacus training on memory span. In the study, participants were divided into two groups, non-mental abacus learners and mental abacus learners. In the first experiment, subjects were asked to perform the following tasks operation span, non-word span, complex spatial span, forward and backward digit span, which was measured on each participant. In the second experiment, participants had to perform two tasks; the primary task included mentally calculating addition, subtraction, multiplication, and division being manipulated to disrupt the performance of the subjects in secondary tasks concurrent spatial distraction. The results revealed that abacus trained individuals performed better with shorter response time and a higher percentage of accuracy in mental calculation tasks. The two groups did not differ in both the test of complex spatial span and backward digit span. The ability of the participant to store visual-spatial information was also improved with mental abacus training. Bhaskaran et al. (2006) conducted a study to evaluate the abacus learner's working memory. The study incorporated 50 children aged 5 to 12 years with an average regular school IQ and 50 abacus school children. The test included for objects were Mann-Buitar visual memory screen, Wechsler memory scale, and Mini-mental state exam. The results revealed that the abacus learners had better visual and auditory in comparison with non-abacus learners. Lee et al. (2007) conducted a study with two experiments to investigate the effect of skill training on mental abacus and music training on WM. The study included 32 participants; 16 of them received training in mental abacus and music; the remaining 16 had received no training. In experiment 1, the individuals were asked to perform the following tasks such as simple and complex spatial span test, operation span test, forward and backward digit span test, and non-word span test. The results of experiment 1 revealed that children who received the training showed a greater simple spatial span than other span tests. In experiment 2, the adults (age range 22 years) and children group who received musical training were asked to perform the same span tests. The results revealed that the adult experimental group performed better in digit and non-word span test compared to control groups. Similarly, in children, the experimental group performed better in all the span tests than the controlled group. Thus they conclude that mental abacus training has an effect on working memory. Chen et al. (2011) conducted a study to explore the effect of mental abacus training on WM for children. The study included 24 children of average age 10.8 years in which 12 children were trained in abacus, and 12 were the age-matched control group. The study included two tasks imagery memory task, distraction task, and digit span test. The results revealed that children who were trained in abacus performed better in digit span test compare to children who were not trained, and also, the study reported that for children who are not trained in abacus, the mental calculation depends on the phonological loop to store and maintain the numerical information. Thus authors concluded that children with abacus training have better performance in mental calculations compared to children who are not trained. Shanthala (2011) conducted a study to study the effect of abacus training on WM in children. The study incorporated 100 children of the age range 7-11 years, where they were not trained in abacus but later were enrolled for training. The subjects were asked to complete the following tests such as digit span test, picture recall test, story recall test, sentence repetition test, a battery of memory test, and paired association test. These tests were administered before and after abacus training. A significant increase in short term memory, auditory memory, and visual memory after abacus training. Roy et al. (2020) conducted a study aimed at assessing the difference in WM in children with and without abacus training. The study included 60 children, 30 abacus trained children, and 30 abacus-free children across the age range of 9 to 13 years. In individuals with and without abacus training, the reaction time and WM score for digit forward and backward test, ascending, and descending digit span test were compared. They also tried to correlate the level of abacus training with the reaction time and scores for all abacus training individuals. Results revealed that abacus trained children had a significantly better score and reaction time. Henceforth from these studies, it can be concluded that abacus training contributes majorly to the improvement of working memory.

Working memory and speech perception in noise

Hearing and comprehending the speech is one of the complex tasks which require a wide range of cognitive and sensory processing. Owing to the acoustic complexity, speech is sensitive to certain ambient sounds, people around particularly children's and elderly are therefore often faced with circumstances that make it difficult to understand speech in the presence of background noise (Kraus et al., 2012). Efficient factors often are not well known on SPIN. Research has shown that both the bottom-up audio processing and top-down cognitive and lingual processing are involved in the perception of speech in noise where WM mechanism, i.e., STM on phonological and LTM on linguistic and cognitive knowledge such as grammar and vocabulary and said to be involved in cognitive and lingual processing (Pichora-Fuller & Souza, 2003). Based on the cognitive point of view, the listener derives and stores the meaning from the acoustic pattern during speech perception and uses the stored information to summarize with an audio stream. When these acoustic patterns are in turn distorted with the noise recalling of theses acoustic patterns with stored vocabulary becomes difficult, thus exerting greater load on the working memory (Souza et al., 2015). To relate working memory and SPIN, two hypotheses have been studied in the past, states that working memory carries out a small amount of action compared to other cognitive tasks. Memory constraint occurs because mental activity takes a lot of work or time to process the information. The harder the processing, the system runs the slower the and second, ELU model, which states that any discrepancy between speech input and phonological representation retained in the LTM inhibits automated retrieval of vocabulary, contributing greater load on the working memory. Research has been conducted to study the relationship between WM and SPIN across a different population and have found varied results.

In general, it was noted that there is no correlation between WM and SPIN in people with normal-hearing (Füllgrabe & Rosen, 2016; Magimairaj et al., 2018; Pichora-Fuller & Souza, 2003). In the case of normal hearing, the individuals rather than depending on the cognitive abilities, they depend majorly on auditory abilities, thus WM cannot be a stronger predictor of SPIN. Füllgrabe et al. (2015) were unable to detect a link between reading span scores and speech identification in noise in older listeners of age ≥ 60 years with normal hearing sensitivity which was tested using signal to noise ratios, maskers, and speech (consonant and sentences). Füllgrabe and Rosen (2016) investigated the role of WM and SPIN identification among normal-hearing individuals. The study incorporated 132 participants of age range of 18-91 years with normal hearing sensitivity. The older individuals above 60 years screen using MMSE to rule out the absence of cognitive impairments. The study incorporated a reading span test to assess the WM capacity, and a matrix sentence (English version) was used to assess the SPIN identification. The results revealed that with an increase in age, the reading span and SPIN identification scores declined. In the younger age group, there was a weak correlation between WM and SPIN identification. Whereas in the middle age, younger and older age groups, there was a moderately stronger correlation. Thus the finding fails to provide proof that WM capacity is a reliable and good predictor of SIN intelligibility in young listeners with normal hearing in acoustically adverse listening circumstances. However, in contradiction with the above study, Millman and Mattys (2017) aimed to investigate the relationship between auditory WM and SPIN in modulated maskers among 30 listeners with normal hearing sensitivity over the 31 to 67 years age range. To the auditory-verbal WM, auditory stimuli from the subtest of automated WM assessment were used, which included forward and backward digit recall and non-word repetition. To assess speech in noise speech stimuli selected were IEEE sentences. The result revealed that, as the score of WM improved, the SPIN scores also improved in the normal hearing old age group. Sullivan et al. (2015) investigated WM and speech recognition performance in noise and comparing the performance on WM and speech recognition using two different noise sources, i.e., back and side noise among ten children across the age range of 8 to 10 years. The tests such as the automated version of Hearing in Noise Test was used to assess the SIN and to assess WM, backward digit recall was administered in quiet, noise-back, and noise-side condition. The results revealed that significantly poor performance was noted when noise was presented at 90 and 180-degree azimuth and also noted there was no effect on working memory. Thus there was no relationship noted between auditory WM in noise and speech recognition. Thus concluded that based on the task difficulty, children make use of cognitive and perceptual cues and chiefly uses cognitive resources during the performance of complex tasks and adverse listening conditions. Contradicting to the above study McCreery et al. (2016), the aim was to investigate the effect of cognitive and linguistic aspects on speech recognition in noise among 96 children aged 5 to 12 years with normal hearing sensitivity. The stimuli such as monosyllabic words, sentences that are syntactically correct with no meaning and sequence of 4 words which are syntactically and semantically incorrect were used to assess the speech recognition in noise and to assess the working memory, and four subtests were selected from the automated WM assessment. To assess the logistic skills Goldman-Fristoe test of Articulation, Pea body picture vocabulary test, and The Test of reception of Grammar was used. The results revealed that for all the three types of stimuli, higher WM was linked with better speech recognition in noise, and with respect to sentences, better speech recognition was associated with greater vocabulary. Thus they concluded that speech recognition in noise is influenced both by the WM and language abilities of the individuals.

Thus, there is no consistent evidence between the results of studies on the relationship between SPIN and WM. The consistency could depend on the tests used for investigating WM and differences in the variety and complexity of stimuli used in the SPIN test.

Chapter 3

Method

3.1. Participants

The study was conducted on 30 individuals age ranging from 9 to 11 years, which were further divided into two groups. The participants with abacus training as group 1 and participants without abacus training as group 2. All the participants were native Kannada speakers. Before recruiting, a written consent letter was obtained. These individuals were on a non-payment basis, which was described in the consent letter.

All the participants in group 1were within level 6 to level 10 of abacus training.

Inclusion criteria

All the subjects were selected based on the following criteria.

- Otoscopy observation revealed normal external ear canal and tympanic membrane verified with an unobstructed view of cone of light using an otoscope. Pure tone thresholds for octave frequencies of 250 Hz to 8000 Hz in both ears within normal limits -10dB HL to 15dB HL [ANSI S3.1 (1991)].
- Normal middle ear functioning confirmed with the type ‘A’ tympanogram and presence of both ipsilateral and contralateral acoustic reflexes in both ears.
- A fair agreement between speech recognition threshold (SRT) and pure tone threshold (PTA) (+/- 12dB).
- Speech identification scores at 40dB SL (ref SRT) greater than 90%.

Exclusion criteria

- Presence or history of the otological, neurological problem, and low IQ or any associated problems.
- Any illness on the day of testing.

3.2. Instrumentation

The following instruments were used in the present study:

- For pure tone threshold estimation, speech audiometry, and speech in noise scores, a calibrated two-channel diagnostic audiometer Inventis Piano with the transducers TDH-39 headphone (Telephonic 815 broad hollow road, Farmingdale, New York11735) and B-71 bone vibrator (Radioear, KIMMETRICS,smithbergs, MD 21783) were used.
- A calibrated middle ear analyzer, GSI-Tympstar (Grasen-Stadler Incorporation, USA), was used for tympanometry and to obtain acoustic reflex thresholds.
- A laptop Dell Vastro14 64 bit was used for performing working memory tests.
- Sennheiser HDA 200 circumaural headphones were used for the presentation of stimuli.

3.3. Test Environment

The study was carried out in an acoustically treated, adequate illumination air-conditioned room (ANSI S3.1-1999-R2013). In a two-room setup, pure tone audiometry, speech audiometry, and speech perception in noise (SPIN) were performed while tympanometry and working memory testing were administered in a single room suite.

3.4. Test Procedure: Routine audiological evaluation

Otoscopy was performed to rule out any external deformation of the ear, the presence of impacted wax, and an ear infection. The preliminary evaluation included case history, pure tone audiometry, immittance audiometry, and speech audiometry. All the participants took a detailed case history to rule out any otological, neurological, and medical conditions. Pure tone audiometry was performed using a modified Hughson-Westlake procedure (Carhart & Jerger, 1959) to evaluate pure tone thresholds for air conduction at octave frequencies from 250 Hz to 8000 Hz, and bone conduction from 250Hz to 4000Hz. The threshold of speech recognition was estimated in the native language of the participants using the standardized paired-word list. Speech identification scores were obtained at 40dB above SRT using standardized phonemically balanced (PB) word lists in the native language of the participants. Tympanometry was done using a 226 Hz probe tone to rule out any middle ear pathology, by varying the air pressure in the ear canal from +200 to -400 daPa. Ipsilateral and contralateral acoustic reflex thresholds were obtained from 500 Hz to 4000 Hz at octave frequency of the probe tone, as mentioned above.

Speech perception in noise test

Testing was carried out in a quiet room where the noise level was within permissible limits American National Standard Institute, 1999(ANSI S3.1-1999-R2013). The speech perception in noise ability was measured using the speech-in-noise test in

Kannada (SPIN-K) test (Vaidyanath & Yathiraj, 2012) was used. The test included bisyllabic words taken from the "phonetically balanced word identification test in Kannada," which has a vocabulary suitable for children aged five and above. An eight-speaker speech babble served as the noise. The compact disc version of SPIN-K was played using a computer, the output of which was routed through the same audiometer that was used for pure-tone audiometry, and the test was administered at 0dB SNR monaurally at 60dB HL delivered through a calibrated Sennheiser HDA 200 headphones. A total of 25 words from 4 lists were used. Participants were instructed to repeat the word while ignoring the noise, and it counted every correct response repeated. For the correct response, a score of 1 would be given, and 0 for the incorrect response. For each ear, the number of correct responses noted separately and scored.

Working memory

Working memory was assessed using the auditory forward syllable span test, auditory backward syllable span test, and n-back test. This was done through the 'Smriti Shravan' software (Kumar & Maruthy, 2013). Stimuli consisted of bisyllabic words, which were taken from standardized phonetically balanced word identification test in the Kannada language, which was presented binaurally at 60dB HL. The stimulus was presented in random order with a growing difficulty level with an inter-stimulus interval of 250ms and the minimum number of syllables presented being two. The stimulus was presented through the personal laptop with a calibrated headphone.

In the auditory span task, the forward syllable span and backward syllable span tests were assessed. In the forward syllable span test, the participants were presented with the cluster of syllables and were asked to repeat the syllables in the same order. In the backward syllable span test, the participants were instructed to repeat the syllable in the reverse order. For example, if the stimulus presented was /raiṱa/, /ʧa:ku/, /mola/, /ṱuti/ they had to repeat it in the same order as /raiṱa/, /ʧa:ku/, /mola/, /ṱuti/ and if the stimulus presented were /raiṱa/, /ʧa:ku/, /mola/, /ṱuti/ then they had to repeat it in reverse order as /ṱuti/, /mola/, /ʧa:ku/ , /raiṱa/. The scoring would be based on the one-up, one-down adaptive procedure. The final score would be the midpoint of the last three reversals.

In the n-back test, a string of numbers with varied lengths was presented in auditory mode. The length of digit strings was varied randomly across the trails from 4 to 7. The participants' task was to recall the second to last stimuli (two-span). Hence this test is also known as two n-back. For example, if the sequence of the stimuli is 4, 5, 6, 2, 3, the participant has to select the second to last stimuli (answer = 2). A score of 1 will be counted if the participant is able to recollect the second to last number correctly and a score of 0 if recollected wrong.

Chapter 4

Results

The present study aimed at investigating the relationship between the auditory working memory (WM) and speech perception in noise (SPIN) among primary school children with and without abacus training. The main objectives of the study were to

i. To measure and compare the auditory WM and speech perception in noise in children with and without abacus training.
ii. To study the relationship between WM and speech in noise in children with and without abacus training.

In order to meet the objectives mentioned, the study included 30 participants, who were grouped into participants with abacus training, i.e., Group 1 (n=15) and participants without abacus training, i.e., Group 2 (n=15). The parameters measured were working memory and speech perception in noise obtained using Smrithi Shravan software (Kumar & Maruthy, 2013) and speech-in-noise test in Kannada (SPIN-K) test (Vaidyanath & Yathiraj, 2012) respectively. The data obtained were analyzed using Statistical Package for the Social Sciences (SPSS version 21, IBM Corp., Armonk, NY, USA). A Shapiro-Wilk test of normality for all the test of working memory and speech perception in noise were not normally distributed ($p < 0.05$). Hence, nonparametric tests were carried out for analysis of data.

Working memory measures

Auditory forward syllable span test, auditory backward syllable span test, and n-back test were the measures used to study the working memory. The raw score of tests of the working memory of group 1 and group 2 are summarized into the median are represented in figure 4.1 and figure 4.2.

Figure 4.1

Representation of the median of auditory forward syllable span test and auditory backward syllable span test measures of working memory group 1 and group 2.

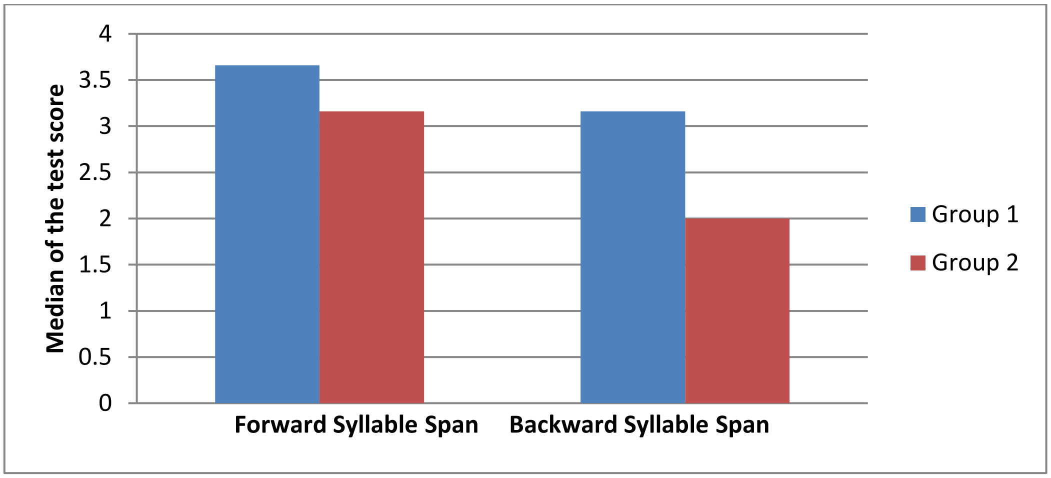
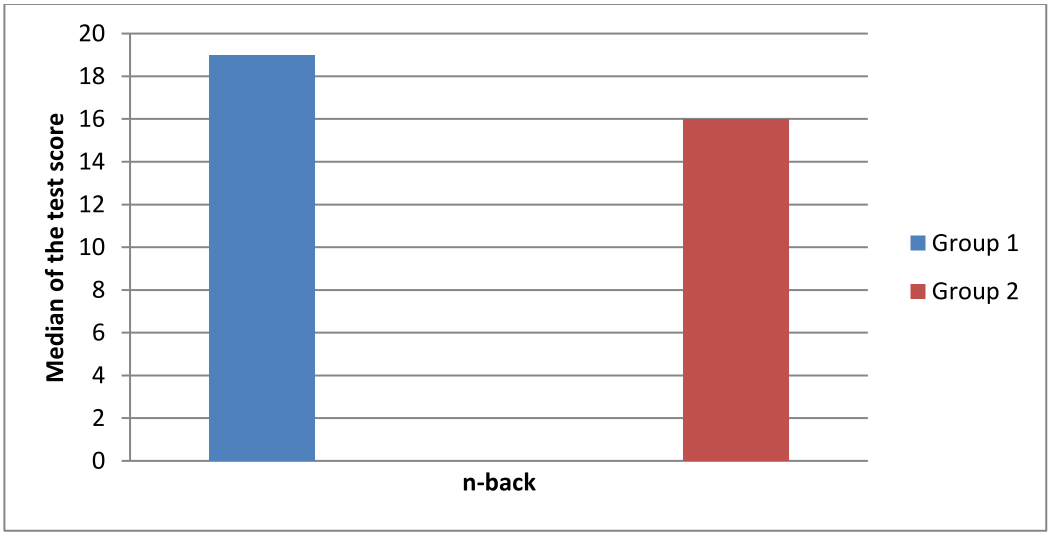


Figure 4.2

Representation of the median of n-back test measure of working memory group 1 and group 2.



The Mann-Whitney U test was done to compare differences between abacus training children (group-1) and without abacus training children (group-2). The auditory working memory results revealed that group 1 was performed significantly better than group 2, and that is represented in table 4.1. The n-back test results revealed that group 1 performed significantly better than (z = -3.172, p = .002) group 2, with an average rank of 307.50 while group 2 had an average rank of 157.50. The results of the auditory forward syllable span test revealed that group 1 performed significantly better than (z = -3.333, p= .002) group 2, with an average rank of 312.00, while group 2 had an average rank of 153.00. Similarly, for the auditory backward syllable span test revealed group 1 performed significantly better than (z = -4.452, p = .000) group 2, with an average rank of 338.50 while group 2 had an average rank of 126.50.

Table 4.1

Representation of the results of the Mann-Whitney U test comparing the scores for all the working memory tests.

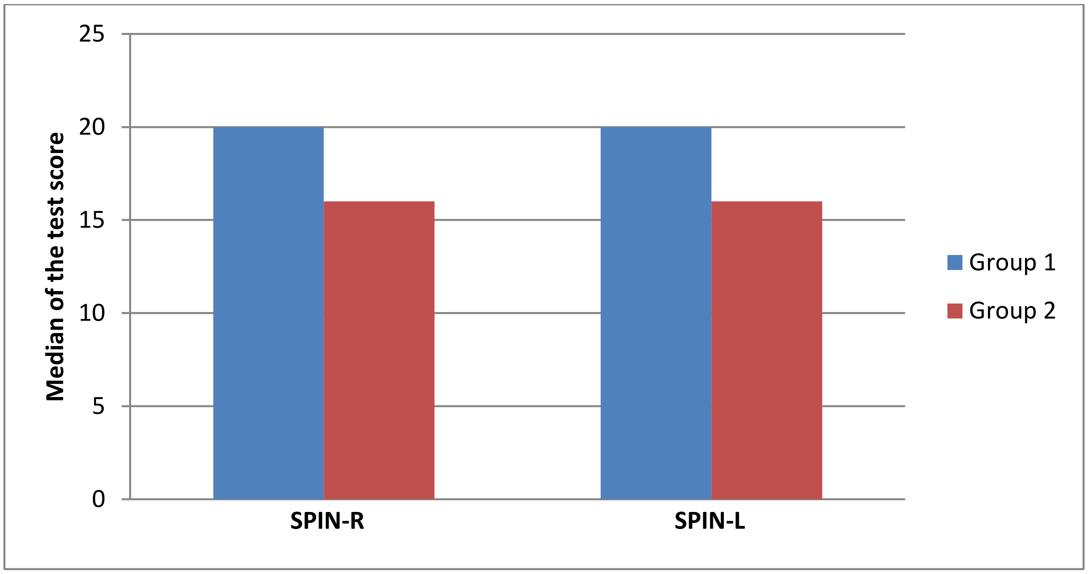
Tests	Z	*p*
n-Back test	-3.172	.002
Auditory forward syllable span test	-3.333	.001
Auditory backward syllable span test	-4.452	.000

Speech perception in Noise

Speech perception in noise (SPIN) test was done, and the raw scores of the SPIN right test and SPIN left test of group 1 and group 2 are summarized into the median which is represented in figure 4.3.

Figure 4.3

Representation of the median of Speech Perception in Noise-Right and Speech Perception in Noise-Left of group 1 and group 2.



To compare the difference between group 1 and group 2 Mann-Whitney U test was done, and it is represented in table 4.2. The results on speech perception in noise-right test revealed that group 1 performed significantly better than (z = -4.728, p = .000) group 2 with an average rank of 345.00, while group 2 had an average rank of 120.00. Similarly, for speech perception in noise- left test revealed that group 1 performed significantly better than (z = -4.713, p = .000) group 2 with an average rank of 345.00, while group 2 had an average rank of 120.00.

Table 4.2

Representation of the results of the Mann-Whitney U test comparing the scores for speech perception in noise tests between the groups.

Tests	Z	*p*
SPIN-Right test	-4.728	.000
SPIN- Left test	-4.713	.000

Further to see if there is any significant difference within the group Wilcoxon signed-rank test was done, and it is represented in tables 4.3 and 4.4. In group 1, auditory working memory tests result revealed that, there was a significant difference between auditory forward syllable span test and auditory backward syllable span test (z = -3.182, p = .001) and for speech perception in noise test results revealed that there was no significant difference between SPIN- right and SPIN- left test (z = -1.667, p= .096). For group 2, auditory working memory tests result revealed that there was a significant difference between auditory forward syllable span test and auditory backward syllable span test (z = -3.412, p = .001) and for speech perception in noise test results revealed that there was no significant difference between SPIN- right and SPIN- left test (z= -.531, p = .595).

Table 4.3

Representation of the results of the Wilcoxon signed-rank test within the comparison of group 1 scores of the working memory tests and speech perception in noise tests

Tests	Z	*p*
Auditory forward syllable span test- Auditory backward syllable span test	-3.182	.001
SPIN Left test- SPIN Right test	-1.667	.096

Table 4.4

*Representation of the results of the Wilcoxon signed-rank test within the comparison of group 2 scores of the working memory tests and speech perception in noise test*s

Tests	Z	*p*
Auditory forward syllable span test- Auditory backward syllable span test	-3.412	.001
SPIN Left test- SPIN Right test	-.531	.595

Relationship between working memory and Speech perception in noise

To study the relationship between working memory and speech perception in noise, Spearman's correlation was used. The scores of SPIN- right and SPIN- left were correlated with auditory forward syllable span test, auditory backward syllable span test, and n-back tests of the working memory in both with group 1 and group 2, and it is represented in table 4.5 and 4.6.

For children with abacus training, the results revealed that there was a strong negative correlation between auditory forward pan test and SPIN- right, which was statistically significant (r_s= -0.686, p=0.005). Similarly, there was a negative correlation between auditory forward span test and SPIN- left, which was not statistically significant (r_s= -0.105, p=0.710). On the other hand, there was a strong negative correlation noted between auditory backward pan test and SPIN- right, which was not statistically significant (r_s= -0.254, p=0.362). Whereas, there was a strong positive correlation noted between auditory backward span test and SPIN- left, which was not statistically significant (r_s= 0.242, p= 0.385). For the n-back test, the results revealed that there was a strong positive correlation noted between n- back test and SPIN- right, with no statistical significance (r_s= 0.180, p=0.521). Whereas, there was a negative correlation noted between n-back test and SPIN- left, with no statistical significance (r_s = -0.106, p= 0.708).

Table 4.5

Representation of the Spearman's correlation test scores on group 1 on working memory tests and speech perception in noise tests

Working memory measures	**Speech perception in noise**			
	Right ear		Left ear	
	r_s value	p value	r_s value	p value
Auditory forward syllable span test	-0.686**	0.005	-0.105	0.710
Auditory backward syllable span test	-0.254	0.362	0.242	0.385
n-Back test	0.180	0.521	-0.106	0.708

**. p< 0.01 level (2-tailed)

For children without abacus training, the results revealed that there was a strong negative correlation between auditory forward pan test and SPIN- right, which was not statistically significant (r_s= -0.092, p=0.744). However, there was a positive correlation between auditory forward span test and SPIN- left, which was not statistically significant (r_s=0.023, p=0.934). On the other hand, there was a strong negative correlation noted between auditory backward pan test and SPIN- right, which was not statistically significant (r_s= -0.404, p=0.136). Whereas, there was a strong positive correlation noted between auditory backward span test and SPIN- left, which was not statistically significant (r_s= 0.251, p= 0.367). For the n-back test, the results revealed that there was a strong negative correlation noted between n- back test and SPIN- right, with no statistical significance (r_s= -0.358, p=0.190). Similarly, there was a strong negative correlation noted between the n-back test and SPIN-left test, with no statistical significance (r_s = -0.104, p= 0.713).

Table 4.6

Representation of the Spearman's correlation test scores on group 2 on working memory tests and speech perception in noise tests

Working memory measures	**Speech perception in noise**			
	Right ear		Left ear	
	r_s value	p value	r_s value	p value
Auditory forward syllable span test	-0.092	0.744	0.023	0.934
Auditory backward syllable span test	-0.404	0.136	0.251	0.367
n-Back test	-0.358	0.190	-0.104	0.713

Chapter 5

Discussion

The present study aimed to investigate the relationship between auditory WM and speech perception in noise in primary school children with and without abacus training. Auditory forward syllable span test, auditory backward syllable span test, n-back test, and Speech perception in noise test were administered, and their measures were analyzed to see the relationship between WM and speech perception in noise skills with and without abacus training. Overall, the result of this study revealed that both auditory WM and speech perception in noise test were significantly better in children with abacus training compared to children without abacus training. The results are discussed under the following broad headings:

1. Working memory measures
2. Speech perception in Noise
3. Relationship between WM and Speech perception in noise

Working memory

The results of this study revealed that children with abacus training performed significantly better in the tasks of working memory, namely auditory forward syllable span test, auditory backward syllable span test, and n-back test than children without abacus training. The auditory syllable span test includes forward and backward tests. The span test of the auditory forward syllable works on immediate audible memory. It is a relatively structured, unchallenging attention test that uses STM to accomplish the task, while the auditory backward syllable span places greater attention demands. It not only uses STM but also includes information that is to be mentally manipulated. Hatano and Osawa (1983); Tanaka et al. (2002); Bhaskaran et al. (2006); Li et al. (2013) in their study reported that the individuals with abacus training are reported to have better STM, with greater activation noted to visuospatial WM, including superior parietal lobule and the bilateral superior frontal sulcus. Hatano and Osawa (1983); Tanaka et al. (2002) reported that individuals with abacus training in both forward and backward testing might recall 13-20 digits, and research also reported that abacus trained experts have a larger memory span for digits presented through auditory mode. Li et al. (2013) reported that abacus training might enhance the functional integration of the circuitry of visuospatial attention, thus enhancing the cognitive process at a high level. Roy et al. (2020) reported that increased auditory plasticity in the brain. Abacus training resulted in improved auditory working memory in abacus- trained children.

The present study results are in agreement with the above studies, which showed scores of working memory tasks are significantly better in children with abacus training than children without abacus training. The improvement in the memory scores in children with abacus training may also be due to learning experiences. Researchers have reported that abacus training improves children's mathematical calculations, where mathematical learning calculations are associated with WM. Thus children with abacus training have better WM than children without abacus training.

Speech perception in noise

Similarly, children with abacus training performed significantly better in SPIN- right and SPIN- left compared to children without abacus training in the present study.

Hearing and comprehending the speech is one of the complex tasks which requires a wide range of cognitive and sensory processing. During normal speech perception, the listeners derive and store the meaning from the acoustic pattern and use the stored information to summarize with the audio stream, but when these acoustic patterns are in turn distorted with the noise, recalling of these acoustic patterns with stored vocabulary becomes difficult thus exerting greater load on the working memory (Souza et al., 2015). Klingberg (2010); Morrison and Chein (2010) reported that children with better working memory are said to perform better in academics and language learning. In addition to this, WM is reported to play an important role in the ability to perceive SIN. Ingvalson et al. (2015) reported that WM capacity successfully predicts speech recognition in noise by older adults with normal hearing. In addition to this, training working memory is said to be associated with improvement in SPIN. There are several training methods or tasks implemented to improve the working memory, and studies have utilized digit span tests (Ingvalson et al., 2015), musical training, and abacus training (Lee et al., 2007). Abacus training improves children's mathematical calculations, where mathematical learning calculations are associated with working memory. In agreement with the above studies, which state the direct relationship between WM and SPIN, the results of this study show that children with abacus training performed better in functioning memory tasks and speech perception in noise compared to children without abacus training.

Relationship between working memory and speech perception in noise

Studies have been carried out in normal-hearing individuals to see the effect of WM on speech perception in noise. General findings are that individuals with poor speech perception abilities demonstrate low WM, and those with better speech perception abilities will demonstrate high WM (Pichora-Fuller et al., 1995; Conway et al., 2001; Desjardins & Doherty, 2013; Salant & Cole, 2016). As observed earlier in the results, the present study shows a strong negative correlation between auditory forward syllable span test and speech perception in noise right for children who are trained in abacus, which is statistically significant. It is in agreement with a few studies done earlier, where authors have concluded that there is a presence of correlation of WM and speech identification in noise, which is a weak correlation in younger age population, and correlation improved with increasing age (Füllgrabe & Rosen, 2016). The study failed to prove WM as a predictor of speech in noise identification; however, a relationship was established between them. Generally, it has been noted that there is no correlation between WM and SPIN in normal-hearing individuals (Füllgrabe & Rosen, 2016; Magimairaj et al., 2018; Pichora-Fuller & Souza, 2003). It is due to the fact that individuals usually depend more on auditory abilities than cognitive abilities for decoding sound. On the contrary, many authors concluded varying levels of correlation between WM and SPIN. In the task of forward and backward digit recall and non-word repetition given for normal hearing individuals to assess the relationship between auditory WM and SPIN in modulated maskers, results revealed that the score of WM improved, the SPIN scores also improved in the normal hearing old age group (Millman & Mattys, 2017). Similarly, with the aim of investing the effect of linguistic and cognitive aspects on SIN, McCreery et al. (2016) assessed WM and speech in noise. Results revealed that higher WM was linked to better recognition of speech in noise and concluded that recognition of speech in noise is influenced by the individual's WM and language abilities. However, there was no statistically significant correlation obtained in the present study between AWM and SPIN in children without abacus training, implying that WM and SPIN are not dependent. Supportive evidence has been observed in the literature, Füllgrabe et al. (2015) failed to detect a link between SIN identification and reading span scores in older listeners. Similarly, Sullivan et al. (2015) examined the performance of WM and speech recognition in noise, and the result revealed that no relationship was noted between auditory WM and speech recognition in noise. It can be concluded that based on the task difficulty, children make use of cognitive and perceptual cues, and chiefly use cognitive resources during the performance of complex tasks and in adverse listening conditions.

Chapter 6

Summary and Conclusion

Abacus training involves the recording of numbers and calculations and thus the training of auditory WM. Similarly, working memory plays a crucial role in performing cognitive tasks that include intelligence quotients, as well as improving academic performance in the right direction and helping to solve arithmetic problems (Gathercole, 1999; Engle et al., 1991). The aim of the current study was to find out the relationship between auditory WM and speech perception in noise in children with and without abacus training.

The objectives of the present study are as follows

1. To measure and compare the auditory WM and speech perception in noise in children with and without abacus training.
2. To find out the relationship between WM and speech in noise in children with and without abacus training.

To fulfill the study objective, thirty normal hearing children with abacus training and without abacus training are recruited or the study within the age range of 9-11 years. All participants were Kannada native speakers, and the abacus training children were in level 6 through level 10. The WM was measured, namely auditory forward syllable span, auditory backward syllable span, and n-back test. Speech in noise test in Kannada (Vaidyanath & Yathiraj, 2012) was used to measure the SPIN test. The results of this study showed that there is a significant difference in measures of WM and SPIN testing in children with abacus training compare to children without abacus training. Further, the Spearman rank correlation test showed that there is a significant negative correlation between auditory forward syllable span test and speech perception in noise test in right, whereas other than that, there are no significant differences between auditory working memory tests and speech perception in noise tests.

6.1. Implications of the study

1. This study adds on to the literature on abacus training and its effect on WM and speech perception in noise in children.
2. The current study is evidence of the positive effect of abacus training.
3. The study helps in understanding the relationship between WM capacity and speech perception in noise in abacus training children.

6.2. Future directions and limitations of the study

1. The study was conducted in a small sample size of 15 abacus trained children. For a better generalization of the results, a larger sample size is required.
2. The study results are limited to children in the age group of 9–11 years only. To verify the results obtained in the present study, children in other age groups should be studied.
3. Studies to assess the effect of abacus training on a clinical population like learning disability and other disorders that have impaired auditory processing can be considered.
4. Use of a varied number of tests to assess the auditory working memory and speech perception in noise.
5. Studies need to be taken up to check the factors influencing or affecting the effects of abacus training on children.

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