Efficacy of Working Memory Training in Middle-aged Adults

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Objectives: Decline of working memory (WM) resources is an important concern for individuals right from middle age, as middle adulthood is comprised of cognitively demanding tasks which require higher cognitive performance. In view of the global efforts to promote greater cognitive reserves and the cognitive diversities observed among middle-aged adults, alongside a dearth of ethno-culturally relevant WM training programs for the Indian population, the present research aimed at examining the efficacy of a WM training for middle-aged adults. Methods: Sixty-two middle-aged adults between 40-65 years of age were divided into experimental and control groups, each group consisting of 31 participants. The experimental group underwent a 10-session WM training program comprising of 17 WM tasks, with each session lasting for 45 minutes to one hour, while no training was given to the matched control group. Results: The results showed significant improvement in post-training performance (p < .05) on the trained tasks and near transfer tasks among the experimental group in comparison to the control group. Conclusion: The present research highlights the benefit of WM training in enhancing the cognitive-communicative abilities with the help of a structured training program among middle-aged adults. These results seem encouraging for the promotion of healthy cognitive well-being among aging adults.

Keywords: Working memory, Middle aged adults, Training, Efficacy, Cognition

Working Memory and Middle Adulthood

Working memory

Working memory (WM), as described by Miller, Galanter, and Pribram (1960) refers to a work space in the memory system that allows for simultaneous storage and information processing during a cognitive task (Baddeley, 2001). According to Salthouse (1994), WM is an active system which involves temporary storage as well as manipulation of information. It allows for the interaction between attention, perception, and memory (Baddeley, 1992). WM can be reckoned as a vital cognitive-communicative process as it plays a pivotal role in basic language abilities; such as recognizing and comprehending words, understanding spoken discourse and reading comprehension. WM skills are vital for performing several day-to-day tasks; like conversations, remembering a phone number between the time of hearing it and dialing it, recalling the directions while driving until the destination is reached, and so on. WM has been considered as a paradigm essential for higher cognition. There is vast psychometric evidence which emphasizes WM capacity as an important factor influencing individual variances in fluid intelligence and executive functioning (Engle, Tuholski, Laughlin, & Conway, 1999), language acquisition (Baddeley, 2003), reading comprehension (Baddeley, 2003), reading comprehension (Daneman & Carpenter, 1980), a number of domain-specific reasoning skills (Kane et al., 2004) and non-verbal problem solving (Logie, Gilhooly, & Wynn, 1994).
Working memory in middle-aged adults

Decline in WM resources is strongly associated with age progression as structural changes are observed in the brain like shrinkage of brain tissues and reduction in white matter, which lead to functional changes mainly affecting frontal and temporal connections (Cappell, Gmeindl, & Reuter-Lorenz, 2010). The onset of age linked changes in WM performance is most evident during midlife or even before 50 years of age (Ferreira et al., 2015). Since the variations and declines in WM performance in middle adulthood tend to occur gradually and do not usually give rise to a significant disability or functional impairment (Willis & Schaie, 2005), middle-aged adults mostly tend to develop resources or methods to compensate for their performance deficits (Soederberg Miller & Lachman, 2000). However, individuals between the ages of 40-60 years have been shown to demonstrate performance declines on tasks related to attention, episodic memory, and executive functions (Schaie, Willis, & Caskie, 2004). Similarly, Salt house (2009) reported age-related changes in WM to be obvious even before the age of 50. Lagishetti and Venkatesh (2011) found WM task performance to decline at the earliest with age, as compared to the other cognitive domains, among participants in the age group of 40-55 years. Zimprich and Mascherek (2010) investigated the cognitive abilities over a period of 12 years on 346 middle-aged adults (mean age of 43.8 years). Their results revealed a significant mean-level change, with declines in memory, processing speed and fluid intelligence abilities. Moreover, differences in the strategies used for task performance could further add on to the variations in WM seen with the progression of age. Middle-aged adults rely more on rehearsal processes to perform a forward digit span task, whereas older adults use multiple strategies. WM changes seen with age have been associated with changes in fluid intelligence and inductive reasoning (Engle et al., 1999). However, according to the longitudinal models of Hertzog, Dixon, Hultsch, and Macdonald (2003), divergent patterns of age linked changes in WM and intelligence exist, especially after the age of 55. In the Whitehall II study; deterioration in reasoning, episodic memory, and verbal fluency abilities were reported over a period of 10 years among adults in the age range of 45-70 years (Singh-Manoux et al., 2012). Klaassen et al. (2014) reported middle-aged adults (50-61 years) to have slower reaction times and poorer scores on a behavioral WM task of letter digit substitution than younger adults (25-35 years). Macpherson et al. (2014) suggest low activation of frontal areas during WM retrieval to be the basis for WM declines occurring in middle age. Ferreira et al. (2017) reported that the variability of WM abilities among middle-aged adults, is associated with the neuronal degeneration in the white matter tracts connecting the parietal-temporal-occipital association cortex to the prefrontal dorsolateral cortex and the hippocampus. Evidence suggests that the neuronal degeneration would already be in an advanced stage by the time an individual reaches an older age (Sperling et al., 2011), implying middle adulthood to be an ideal age to target methods for improving or restoring age-related cognitive deficits.

Salient characteristics of middle adulthood, statistical predictions of age-linked cognitive impairments and importance of cognitive reserves

Deterioration in WM resources is an important issue for individuals during and after middle age (Lawton et al., 1999), as middle adulthood is comprised of cognitively demanding tasks requiring better cognitive performance than the younger and older age group (Martin & Zimprich, 2005). Schooler (1999) has argued that organizing, planning, problem solving and multitasking required for work and family related tasks during middle adulthood are much more challenging than the schooling or education related activities in younger age, or retirement linked concerns in old age. For example, family obligations (like taking care of an elderly parent, establishing family and managing children) peak in middle-aged adults. In the work domain, average job demands and workloads increase as one enters middle adulthood and then decrease towards age 65 to 70 (Martin & Zimprich, 2005). Moreover, during young age, cognitive development gets significantly shaped by formal training and is usually comprised of shared and homogeneous environments such as school classes or peer groups (Espy, Molfese, & DiLalla, 2001). While in old age, cognitive development is largely influenced by physiological factors such as sensory and sensorimotor functions (Hofer, Berg, & Era, 2003). Whereas in middle adulthood, cognitive demands and abilities are mostly influenced by environmental and social interactions like regulating success or failure in achieving goals and preparing to face consequences of the same (Sternberg, Grigorenko, & Oh, 2001). Furr-
thermore, several metabolic and hormonal changes which are reported to be highly prevalent in middle age (Hassenstab, Sweat, Bruehl, & Convit, 2010), have shown to produce negative effects on the cognitive functioning among adults in this age group (Yaffe et al., 2004). Cognitive communicative changes, as seen for working memory with advancing age, may be expensive, compelling retirement from challenging careers and endangering the ability to survive independently in a progressively complex society (Salt-house, 2012). Decline in WM abilities among middle aged adults also pose a concern with respect to changes in cognitive reserves. Functional imaging studies have suggested that if an individual can perform at higher difficulty levels, then there is an increased activation of areas in the brain in comparison to brain activation seen in less complex versions of the task. Additionally, attainment of higher skills also leads to recruitment of additional brain areas (Stern, 2002). This improved efficiency and greater dynamic range is recognized as the cognitive reserve. An individual with greater cognitive reserves might be able to cope more efficiently if he or she encounters cognitive communicative pathologies like Mild Cognitive Impairment and Dementia, later in life (Stern, 2002). Strengthening one’s cognitive reserves for abilities like WM becomes more significant in view of the statistical predictions about the incidence of age-linked cognitive impairments. According to the World Health Organization (2015), 47.5 million people are estimated to have a cognitive communicative disorder like dementia. It is anticipated that the prevalence and incidence would double every 20 years, with number of people with dementia estimated to be 75.6 million by 2030 and 135.5 million in 2050. In a highly populated country like India, where there is a rapid growth in the number of elderly persons, approximately 4.1 million people are projected to have dementia, and as the number is expected to double by 2030, the financial impact on families would be challenging (Prince et al., 2015). This grave scenario demands an imperative need for implementing effective measures towards preventing the occurrence or delaying the onset of the disorder, by maintaining or improving the cognitive-communicative reserves among individuals who are currently in middle adulthood. In view of the repercussions of the age related decline in WM and the need for greater cognitive reserves among middle aged adults, introduction of cognitive communicative training programs during middle adulthood may offer promising prospects for the future.

Working Memory Training

Cognitive communicative training programs have a long history. These programs operate on the premise of neuroplasticity and believe that brain has the potential to reorganize itself and effectively modify function to work at its maximum capacity. Training programs which target specific cognitive communicative domains, such as WM and executive functions, have better relative potential in improving cognitive-communicative abilities (Karbach & Verhaeghen, 2014). Researchers propose that WM has a pivotal role in the integration and coordination of several other cognitive processes, therefore training approaches which specifically target WM and executive functions may have promising outcomes in the enhancement of cognitive-communicative abilities (Borella et al., 2014; Greenwood & Parasuraman, 2016). For instance, the interaction of WM abilities with executive functions like inhibitory control, task monitoring and response selection have been well discussed with emphasis on the significant role played by the central executive component of WM (Hester & Garavan, 2005). This might be understood clearly with an example of a verbal fluency task where an individual is expected to generate as many words as possible in a given time span from a given category or letter while following certain constraints like avoiding repetitions, errors or word derivatives (Shao, Janse, Visser & Meyer, 2014). During this task, an individual uses executive functions to facilitate the target word retrieval and at the same time utilizes WM abilities to remember the generated words for preventing violations of any constraints. A deficit in WM ability may be seen as excessive repetitions or errors during a verbal fluency task. Therefore, enhancement of an individual’s WM abilities gets reflected in the form of better performance of executive function tasks like verbal fluency and vice versa. Although there are specific limits of WM capacity (Cowan, 2010; Miller, 1956), existing data suggests that training might have the potential to increase the capacity of WM and other cognitive functions (Chein & Morrison, 2010; Verhaeghen, Cerella, & Basak, 2004).

Task specific working memory training transfer effects

Transfer effects of training can be classified as near and far
transfer. Near transfer refers to the training effects on tasks which are untrained but closely linked to the trained tasks (e.g. performance gains on Short term memory (STM) after WM training) and far transfer signifies training gains on untrained tasks, that are dissimilar to the trained tasks (like improvements on reading comprehension/fluid cognitive skills after WM training) (Waris, Soveri, & Laine, 2015). Studies have explored the extent to which WM can be trained and its effects across lifespan (Borella, Carretti, Zanoni, Zavagnin, & De Beni, 2013; McAvinue et al., 2013). They have found that there may be improvements on specific trained tasks, with minimal to moderate effects transferred on untrained tasks which are closely linked to WM and other cognitive domains like STM, inhibitory control, and reasoning (Richmond, Morrison, Chein, & Olson, 2011; Zinke et al., 2013). Morrison and Chein (2011) reported enhancements on the trained task performance for WM training across different age ranges of participants and training approaches. Takeuchi, Taki, and Kawashima (2010) reported that the performance on non-trained tasks could improve even if the tasks’ stimuli and modalities were different from the trained tasks. Meta-analytic reviews propose near transfer effects of WM training among children, young adults, and old aged adults (Melby-Lervåg & Hulme, 2013; Schwaighofer, Fischer, & Bühner, 2015). Though transfer effects of WM training on trained and untrained tasks has been proven in many studies, there are several other studies suggesting no or limited evidence of transfer effects (Corbin & Camos, 2011). Klingberg (2010) stated that the improvements related to transfer effects were limited to only a few transfer tasks. Similarly, Borella, Carbone, Pastore, De Beni, and Carretti (2017) have reported that the gains of WM training on the near transfer measures could be short term. The effects of far transfer have either not been found (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008; Li et al., 2008) or have been reported to be present only for a few transfer tasks, and for a brief period (Brehmer et al., 2012; Buschkuehl et al., 2008). Meta-analytic reviews by Melby-Lervåg and Hulme (2013) and Melby-Lervåg, Redick, and Hulme (2016) reported no evidence of far transfer effects of WM training, whereas, meta-analytic studies by Schwaighofer et al. (2015) and Au, Buschkuehl, Duncan, and Jaeggi (2016) have reported some evidence of far transfer effects on fluid cognitive tasks after training, among healthy adults. While some studies reported similar maintenance effects for transfer benefits with WM training in the younger and older age groups (Brehmer et al., 2012; Dahlin et al., 2008), others have reported limited benefits (Borella et al., 2017; Zinke et al., 2013), and some others have found no benefits at all (Buschkuehl et al., 2008). The effect size of the benefits from training have been reported to range from medium to large for near transfer tasks, and very minimal for far transfer tasks (Karbach & Verhaeghen, 2014; Zinke et al., 2013). Simons et al. (2016) provided a comprehensive view of learning and transfer effects of some of the commercially available training programs like Nintendo, Lumosity, Brain HQ, and Cogmed. Their findings indicated that the training interventions may improve cognitive performance on those tasks which have been specifically trained. The efficacy of training programs was found to be minimal and short lived for the performance on closely and distantly related tasks. Overall, the existing literature on WM training suggests that the training benefits, if any, primarily involve the trained tasks and possibly near-transfer tasks. It is noteworthy that many studies which observed WM training gains for the range of trained and untrained tasks, found the gains to be short lived.

Present research

Amidst the mixed finding pertaining to the efficacy of cognitive communicative training, in general, and specifically the WM training, another concern which is relevant to the present research is that most of the training research has only targeted young and old aged adults. Middle adulthood has been overlooked in aging research and very limited studies have explored WM training effects among middle-aged adults (Mridula, George, Bajaj, Namratha, & Bhat, 2017; Penner et al., 2012). Moreover, the commercially available WM training programs such as CogniFit, Lumosity, and Cogmed have been developed in western countries. The cultural diversities found in a country like India are likely to induce differences in the task performance on the existing programs. Thus, it seems essential to explore the effects of WM training on cognitive communication abilities across diverse cultural groups, such as those in India. In view of the alarming global and national predictions regarding the multifold rise in incidence of age linked cognitive commu-
nicative impairments, several efforts to promote greater cognitive reserves and the cognitive diversities in middle adulthood along with the dearth of ethno-culturally relevant WM training programs for the Indian population, the present research aimed at examining the efficacy of WM training among middle aged adults by addressing two research questions. First, Is WM training effective in enhancing the performance on the trained tasks among middle-aged adults? Second, Is WM training effective in enhancing the performance on the near transfer cognitive tasks among middle-aged adults?

**METHODS**

The present research followed a non-randomized controlled pre-/post group treatment design. The research obtained the ethics approval from the Institutional Ethics Committee of Kasturba Medical College, Mangalore (IEC KMC MLR 04-15/60).

**Participants**

Sixty-two middle-aged adults between 40 to 65 years of age, as per Erickson’s classification (as cited in Sacco, 2013), participated in the research, with 31 participants each in the experimental and the control group respectively. The participants were included based on a cut off score of ≥ 26 as scored on Mini-mental state examination (MMSE) (Folstein, Folstein, & McHugh, 1975). The socioeconomic status of the participants was ascertained by the modified Kuppuswamy Socioeconomic Scale (Bairwa, Rajput, & Sachdeva, 2013) which yields a score of 3-29 based on education and employment of the head of the family in addition to the family income per month. According to the score, the scale categorizes the study population into high, middle, and low socioeconomic status. The participants belonged to the middle socio-economic status, and had normal or corrected vision and hearing. The participants were residents of Karnataka with Kannada as their native language and were proficient English speakers, having a minimum of 15 years of formal education with English as the medium of instruction. None of the participants reported a history or complaint of any neurogenic language disorder or psychiatric or psychological disorder. All the participants were generally healthy, independent community dwelling adults, though some reported having a history of diabetes (E = 4 & C = 4) and hypertension (E = 1 & C = 3) as shown in Table 1. The demographic characteristics of the study participants are shown in Table 1.

**Materials**

A battery of accuracy-based WM and span-based WM and STM tasks which were closely related to the trained WM tasks were used in the present research to examine the near transfer effects of WM training. The description of the assessment tasks is as follows:

**Near transfer assessment tasks**

The near transfer effects of WM training were assessed using accuracy-based working memory tasks from the Manipal Manual of Cognitive Linguistic Abilities (MMCLA; Mathew, Bhat, Shreya & Arora, 2013), span-based working memory tasks by Kumar, Bajaj, and Bhat (2015); and span-based short term memory tasks de-
The accuracy-based WM assessment tasks from the MMCLA were comprised of an auditory word retrieval task (AWR), auditory word list retrieval task (AWLR), auditory delayed sentence recall task (ADSR), visual picture recall (VPR), visual word list retrieval (VWLR) and visual delayed sentence recall (VDSR) tasks. The AWR, AWLR and VWLR tasks consisted of series of words while the ADSR and VDSR tasks consisted of sentences and the VPR task consisted of pictures.

The span-based STM assessment tasks, consisted of face recall (FR), name recall (NR), object recall (OR), first name-second name association (FSNA), face-name association (FNA) and face-object association (FOA) tasks. The stimuli of these tasks comprised of photographs of faces of young Indian males and females, photographs of common objects and names of people. The span-based WM assessment tasks consisted of the digit ordering (DO), letter ordering (LO), year ordering (YO), digit and letter ordering (DLO), and spell the word (STW) tasks. The stimuli of these tasks comprised of single digits, letters and years.

Procedure

An informed written consent was taken from all the participants. The participants of the experimental group underwent WM training while the participants in the control group underwent only the pre-training, post-training and follow-up assessment sessions and did not receive any training.

Pre-training, Post-training and follow-up assessment

A pre-training assessment for the trained tasks and the near transfer assessment tasks was carried out one day prior to the commencement of the WM training by the researcher. Blinding was not used in the present research; however, the post-training and follow-up assessments were conducted by other assessors who were blind to the non-random assignment of the participants, in order to minimize bias. The post-training assessment was held after a day or two following the completion of the WM training for the experimental group. For the participants of the control group, the post training assessment was conducted one month after the pre-training assessment, in order to match the assessment timeline with the experimental group who underwent 10 sessions of WM training over a period of almost one month. The follow-up assessment session was held 3 months after the post-training assessment session for both groups. The assessment timeline is shown in Figure 1 and the description of the accuracy-based WM, span-based WM and span-based STM tasks of the near transfer assessments is shown in Table 2, 3, and 4 respectively.

WM training module

The training module used in the present research was designed and administered in English. The WM training tasks were adopted from Namratha, George, Bajaj, Mridula, and Bhat (2017) comprising of double digit ordering, sentence ordering, multistage problem solving, semantic sorting, N-back and verbal fluency tasks. The N-back and verbal fluency tasks, further consisted of

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Figure 1. Timeline for assessments.
Prior research in WM training suggests that an effective WM training regime should focus on a variety of WM tasks, rather than solely on a single task (Brehmer et al., 2012; Li et al., 2008). A WM training following a multiple task paradigm has been reported to yield better results since training on a single task would lead to a more stimuli-specific training effect (Chein & Morrison, 2010). Incorporating multiple WM training tasks in a protocol also increases the likelihood of involving several components of WM, which further improves the training and transfer effects (Willis & Belleville, 2016). Therefore, the WM training protocol used in the present study was comprised of a varied range of tasks, which were salient with respect to the domain of WM construct they tapped, range of stimuli used in each of them, complexity hierarchy of the tasks, and the WM strategy each of these tasks elicited and aimed to enhance. Some of the training tasks like double digit ordering and sentence ordering had a closer relationship with the other ordering based WM span used as outcome measures, but significantly differed from outcome based measure tasks with

Table 2. Description of accuracy-based WM tasks

| Tasks                        | Description                                                                                                                                 |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Auditory word retrieval      | This task involves the retrieval of words from word lists presented through auditory modality. The number of words ranges from 3 to 6.         |
| Auditory word list recall    | This task involves the retrieval of words from a pair of word lists; beginning with the first word list, followed by the second word list and then again from the first word list, presented through auditory modality. The number of words in both the list ranges from 2 to 6. |
| Auditory delayed sentence recall | This task involves the presentation of two sets of sentences through auditory modality. Each sentence in the first set is followed by a question related to the sentence. During the presentation of the second set of sentences, the task requires the identification of sentences which were the same as in the first set of sentences. The number of sentences within each set ranges from 2 to 5. |
| Visual picture recall        | This task involves the recall of pictures in the same order as presented through visual modality. The number of pictures ranges from 3 to 5.       |
| Visual word list recall      | This task involves the retrieval of words from a pair of word lists, beginning with the first word list, followed by the second word list and then again from the first word list, presented through visual modality. The number of words in both the list ranges from 2 to 6. |
| Visual delayed sentence recall | This task involves the presentation of two sets of sentences through visual modality. Each sentence in the first set is followed by a question related to the sentence. During the presentation of the second set of sentences, the task requires the identification of sentences which were the same as in the first set of sentences. The number of sentences within each set ranges from 2 to 5. |

Table 3. Description of span-based WM tasks

| Tasks                        | Description                                                                                                                                 |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Digit ordering               | This task involves the recall of visually presented jumbled series of digits, in the ascending order. The number of digits ranges from 2 to 7.     |
| Letter ordering              | This task involves the recall of visually presented jumbled series of letters, in the alphabetic order. The number of letters ranges from 2 to 7.  |
| Digit and letter ordering    | This task involves the recall of visually presented jumbled series of digits and letters, in the ascending and alphabetic order, respectively. The number of items, which includes digits and letters, ranges from 3 to 7. |
| Year ordering                | This task involves the recall of visually presented jumbled series of years in the ascending order. The number of years ranges from 2 to 7.         |
| Spell the word               | This task involves the recall and re-arrangement of jumbled series of letters presented visually, in order to make a meaningful word. The number of letters ranges from 3 to 7. |

Table 4. Description of span-based STM tasks

| Tasks                        | Description                                                                                                                                 |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Face recall                  | This task involves the recall of faces presented through visual modality. The number of faces ranges from 2 to 7.                            |
| Name recall                  | This task involves the recall of names presented through visual modality. The number of names ranges from 2 to 7.                             |
| Object recall                | This task involves the recall of objects presented through visual modality. The number of names ranges from 2 to 7.                           |
| Face-name association        | This task involves the association or matching of faces and their corresponding names presented through visual modality. The number of face-name pairs ranges from 2 to 7. |
| Face-object association      | This task involves the association or matching of faces and their corresponding objects presented through visual modality. The number of face-object pairs ranges from 2 to 7. |
| First name-second name association | This task involves the association or matching of the first name and its corresponding second name presented through visual modality. The number of first and second name pairs ranges from 2 to 7. |
Table 5. Description of WM training module tasks

| Tasks                             | Description                                                                 | No. of stimuli in a task                                                                 | Scoring               |
|----------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-----------------------|
| 1. Double digit ordering         | Series of three to six double digits (ranging from 11-99) were presented on a computer screen for 2000ms with simultaneous auditory input (eg. ‘Thirty-two’, ‘twenty-four’). This was followed by a blank screen presented for 1,000 ms during which time the participant was asked to verbally recall the series of double digits in the ascending order. | Screening module - Five modules with two series of double digits/complexity level in each module Training module - One module with five sets of 10 series of double digits/complexity level | Correct response - 1 Incorrect response - 0 |
| 2. Semantic sorting              | Series of everyday words belonging to different categories were presented. Participant had to remember these words and recall them verbally within their respective categories when the response screen appeared. | Screening module - Five modules with two lists of words/complexity level Training module - One module with five sets of 10 words lists/complexity level | Correct response - 1 Incorrect response - 0 |
| 3. Multistage problem solving    | Problem statements were presented followed by a question. Participant had to remember what relationship each statement of the problem has with the other, and solve the problem by choosing the correct answer from the options provided. The option number key on the keyboard had to be pressed to indicate the answer. | Screening module - Five modules with two problem each/complexity level Training module - One module with three sets of 10 problems/complexity level | Correct response - 1 Incorrect response - 0 |
| 4. Sentence ordering             | Sentences were presented. Participant had to remember the sentence and re-arrange the words within the sentence in their increasing order of length and say the rearranged sentence aloud when the response screen appeared. | Screening module - Five modules with two sentences/complexity level Training module - One module with five sets of 10 sentences/complexity level | Correct response - 1 Incorrect response - 0 |
| 5. N-Back                        | Letters/Words/Images of Faces/Objects were presented. Participant had to press ‘1’ on the keyboard if they saw the same Letters/Words/Images of Faces/Objects as the one that immediately preceded it (1-back)/presented two positions before (2-back)/presented three positions before (3-back), if not press ‘0’. | Screening sequence - one sequence/complexity level Training sequence - five sequences/complexity level | Correct response - 1 Incorrect response - 0 |
| 6. Verbal fluency                | Participant had to generate as many words/word pairs as possible in 1 min beginning with the specified letters/categories by avoiding repetitions, use of proper nouns (e.g names of people), word derivatives (e.g pulling, after saying pull), and words belonging to unspecified categories. | Two/task Number of words/word pairs generated | Correct response - 1 Incorrect response - 0 |

respect to the nature of the stimuli, complexity range, and range of WM load and the linguistic load. The double digit ordering task involved double digits in place of single digits requiring more WM processing load (Daroczy, Wolska, Meurers, & Nuerk, 2015). Likewise, the sentence ordering task involved remembering and rearranging the words within a sentence using the knowledge of sequential redundancy in language.

Other tasks included in the present training module were semantic sorting tasks, multistage problem solving tasks, N-back tasks and the verbal fluency tasks. The semantic sorting task was inspired and modified on the basis of the category-based grouping task (Endress, Korjoukov, & Bonatti, 2017). Here, an individual, using WM abilities, categorizes items into the lexical superordinate while recalling them. The problem solving tasks in the pres-
ent study were inspired from the existing word problem solving tasks (Swanson, 2015) and reasoning tasks (Eweida, Mekail, & Ramadan, 2017). It is thought that the slave systems within the WM model help in retaining the information in an active state during the problem solving task (Banich, 2009). The problem statements which are presented visually, like the multistage problem solving task in the present study, are held within the WM system through the visuospatial sketchpad, and the phonological loop assists in the comprehension of the statements. The central executive further assists in integrating the information and solving the problem (Persson & Reuter-Lorenz, 2008). Therefore, when an individual strengthens the WM system through repeated practice, his or her ability to store and process greater information load improves, leading to better problem solving accuracy.

Although N-back and verbal fluency tasks are more commonly used as outcome measures, there have been WM training studies in the past which have recommended N-back tasks (Harbison, Atkins, & Dougherty, 2011; Heinzel et al, 2014) and verbal fluency tasks (Sutter, Zöllig, & Martin, 2013) in their training regime. The N-back task involves multiple processes such as WM updating, which involves the encoding of incoming stimuli, monitoring, maintenance, and updating of the sequence, and stimulus matching (Kane, & Engle, 2002). Training with N-back tasks has been observed to consistently activate significant neural regions responsible for WM like the dorsolateral prefrontal cortex as well as parietal regions (Owen, McMillan, Laird, & Bullmore, 2005). Present research included an N-back task for training with a wide range of linguistic and non-linguistic stimuli like letters, words, faces and objects across increasing complexity, to ensure that participants get an opportunity to enhance their WM strategies in a holistic and generalizable manner. With respect to verbal fluency tasks, participants are usually instructed to generate as many meaningful words as they can with a target letter or category within a given time period. Participants are also instructed to closely monitor their performance to avoid any errors, word derivatives or repetitions during the task. Therefore, for an optimum performance, participants must possess good WM abilities to keep the instructions and the earlier generated responses in their WM and ensure that irrelevant responses are being suppressed and repetitions are being avoided (Henry & Crawford, 2004; Shao et al., 2014). Optimum WM abilities during a verbal fluency task also allows the participants to generate sets of related words in succession and alter the search criteria while switching from one category to another (Shao et al., 2014). Verbal fluency tasks in the present training protocol, which were adopted from Bajaj, Deepa, Bhat, D’souza and Sheth (2014), comprised of a wide range of stimuli like letters and categories of varying difficulty index across conditions such as alternating verbal fluency and verbal fluency with exclusion to offer increasing cognitive-linguistic load during WM training to the participants.

All the tasks except verbal fluency tasks consisted of screening and training modules. The screening module of each task was administered on the participants in order to establish their baseline level from which the training could be initiated with them. Unlike the training phase, participants were not presented with any feedback and were not taught any WM strategy to enhance their performance while establishing their baseline on the training tasks. The training modules/sequences were used for the purpose of training the participants. All the tasks, except the verbal fluency task, were computerized and presented as experiments via the licensed version of PARADIGM software (v 2.5.0.68).

The WM training was provided in a well-lit quiet room, either at the residence of the participant or in the department situated within the hospital premises. Only the researcher and the participant were present in the room during the training sessions. For the computerized tasks, the participants were made to sit comfortably at a distance of one meter from the laptop screen. The participants were restricted from using paper, pens and calculators as they had to perform all the tasks through mental operation. The training protocol and schedule was the same for all the participants. The instructions for each task were provided to the participants at the beginning of the training and they were repeated whenever required. During the training, the participants were given feedback after every response. For correct responses, they were given verbal positive reinforcements while for incorrect responses they were encouraged to perform better on the next attempt. The training for each task was for a duration of approximately 8 minutes, with 3-4 trials per task, within a session, followed by a fixed break of two minutes. If the participant demanded, extra breaks were also provided during a session when they felt
Protocol for the working memory training

The WM training involved 10 sessions of training; provided twice a week for a total of five weeks, with every session fixed for a maximum duration of 45 minutes to one hour, in accordance with Penner et al. (2012). To facilitate an unconstrained administration of the training within the schedule, not all the tasks were trained on every session; instead, all the tasks apart from the verbal fluency tasks, were arranged into two equal sets, each of which were trained for five days on alternate sessions, as described in Table 6. The protocol of administering the training tasks in this method was in line with Dunning, Holmes, and Gathercole (2013). Each set had four tasks and it was ensured that the two sets had equal distribution of the visual and simultaneous auditory-visual modality tasks. With an exception of excluded letter fluency task, all other verbal fluency tasks consisted of two sets of stimuli as shown on Table 7.

All the tasks except verbal fluency tasks, followed an adaptive training paradigm, wherein, the training always proceeded from the lower levels of complexity to the higher, based on the participants performance and achievement at each complexity level.

The training procedures for the WM tasks are described in the sections below.

Table 6. An outline of the working memory tasks and the training sessions

| Training session | Working memory tasks                                                                 |
|------------------|--------------------------------------------------------------------------------------|
| 1                | Set I - Double digit ordering task, Semantic sorting task, Face n-back task, Letter n-back task |
|                  | Verbal fluency task-Stimulus set I and Excluded letter fluency task                  |
| 2                | Set II - Sentence ordering task, Multistage problem solving task, Object n-back task, Word n-back task |
|                  | Verbal fluency task-Stimulus set II                                                 |
| 3                | Set I - Double digit ordering task, Semantic sorting task, Face n-back task and Letter n-back task |
| 4                | Set II - Sentence ordering task, Multistage problem solving task, Object n-back task and Word n-back task |
| 5                | Set I - Double digit ordering task, Semantic sorting task, Face n-back task, Letter n-back task |
|                  | Verbal fluency task-Stimulus set I and Excluded letter fluency task                  |
| 6                | Set II - Sentence ordering task, Multistage problem solving task, Object n-back task, Word n-back task |
|                  | Verbal fluency task-Stimulus set II                                                 |
| 7                | Set I - Double digit ordering task, Semantic sorting task, Face n-back task and Letter n-back task |
| 8                | Set II - Sentence ordering task, Multistage problem solving task, Object n-back task and Word n-back task |
| 9                | Set I - Double digit ordering task, Semantic sorting task, Face n-back task, Letter n-back task |
|                  | Verbal fluency task-Stimulus set I and Excluded letter fluency task                  |
| 10               | Set II - Sentence ordering task, Multistage problem solving task, Object n-back task, Word n-back task |
|                  | Verbal fluency task-Stimulus set II                                                 |

Table 7. Stimuli for verbal fluency tasks

| Tasks                                 | Stimuli Set I | Stimuli Set II |
|---------------------------------------|---------------|----------------|
| Letter fluency tasks                  |               |                |
| Simple letter fluency                 | A             | R              |
| Complex letter fluency                | J             | U              |
| Excluded letter fluency               | E*            | E*             |
| Simple letter alternating fluency     | D-P           | H-M            |
| Complex letter alternating fluency    | I-K           | F-L            |
| Category fluency                      |               |                |
| Simple category fluency               | Vehicles      | Countries      |
| Complex category fluency              | Flowers       | Stationary     |
| Simple category alternating fluency   | Languages-Animals | Fruits-Soap brands |
| Complex category alternating fluency  | Sports-Body parts | Furniture-Clothing |

*E (Shores, Carstairs, & Crawford, 2006).

Double digit ordering task, semantic sorting task, multistage problem solving task, and sentence ordering task

The procedure for the training on the double digit ordering task, semantic sorting task, sentence ordering task and multistage problem solving task was similar, and a framework of the procedure is shown in Figure 2.

The baseline level of the participant’s performance on these four tasks was established with the screening modules of the tasks. As shown in Figure 2, if the participants failed to achieve correct response on both the stimuli of a particular complexity level in the screening module, the training began at that complexity level and...
Figure 2. An outline of the training procedure for double digit ordering task, semantic sorting task, multistage problem solving task, and sentence ordering task.

Figure 3. An outline of the training procedure for N-back tasks.

the participants had to achieve 80% accuracy on each complexity level to proceed with screening in order to determine the next complexity level to be trained. The baseline performance level of the participants and the level of complexity attained by the end of the training was noted for further analysis.

Scoring

For the double digit ordering task, sentence ordering task and multistage problem solving task, each level of complexity was given a score of 25% while for the semantic sorting task, the complexity levels were given a score of 20% each, allowing the participants to achieve 100% score on successful completion of all levels of complexity of a task.

N–back tasks

The n-back tasks comprised of three complexity levels, which included the 1-back, 2-back and 3-back levels. An outline of the training procedure for the n-back task is depicted in Figure 3.

As shown in Figure 3, the baseline level at which the training began for the n-back tasks was determined according to the performance of the participants on the screening sequence of each complexity level of the task. If the participants failed to achieve 80% accuracy on the correct identification of the target and non-target stimuli on the screening sequence of a particular complexi-
ty level, then training was given to the participants by making them practice on the first training sequence of that complexity level. If they failed to achieve 80% accuracy on either the targets or non-targets on the training sequence, then the training continued on the same complexity level with the next set of the training sequence.

Since the data for the pre and post-training n-back levels for all the N-back tasks did not follow normal distribution, a non-parametric test i.e. Wilcoxon’s sign rank test was applied to perform the statistical analysis.

Verbal fluency tasks
During the verbal fluency training, the participants were asked to do the tasks by avoiding repetitions, words beginning or belonging to an unspecified letter or category respectively; and by avoiding the use of derivatives and proper nouns. The researcher used a stopwatch to monitor the time duration required for each task, and at the end of one minute gave an indication to the participants. The participant’s responses were audio recorded and transcribed for analysis. The performance of the participants on all the verbal fluency tasks at the beginning and end of training was noted for further analysis.

Each training session was evaluated separately during the training and for all the verbal fluency tasks, except excluded letter fluency task, an average of the scores was obtained for the set of stimuli trained on the first and second sessions. The same procedure of averaging was followed for sessions five and six and also for the ninth and tenth sessions. The pre-training scores and the post-training scores were the average scores of the two sets of stimuli trained on the first and second sessions, and on the ninth and tenth sessions, respectively, for all the letter and category fluency tasks. While for the excluded letter fluency task, the scores obtained on the first and tenth sessions were considered as the pre and post-training scores respectively.

The scoring and analysis were different across the WM training tasks within the WM training module. The double digit ordering task, semantic sorting task, multistage problem solving task, and sentence ordering task followed the same scoring and analysis procedure; whereas the n-back tasks and the verbal fluency tasks had a different scoring and analysis procedure.

Data Analysis
The statistical analysis of the data obtained was done using the SPSS software version 16. A Shapiro-Wilk test was used as a test of normality. A Chi square test was conducted to examine the differences between the participants of both the groups for age, gender, years of education, and employment. Independent t-test was done to analyze and compare the baseline pre-training scores between the experimental and control group. A paired t-test (for parametric data) and Wilcoxon signed-rank test (for non-parametric data) was done to analyze the effect of WM training on the trained tasks among the participants of experimental group. A mixed model ANOVA with a post hoc Bonferroni pairwise analysis was carried out for examining the WM training effects on the near transfer tasks between the experimental and the control group.

RESULTS

Participant characteristics
No statistically significant difference was found between the participants of both the groups, with respect to the demographic variables i.e. age, distribution of males and females, years of education and employment. These results are depicted in Table 8.

As depicted in Table 9, the differences between the two groups

Table 8. Demographic characteristics of participants of experimental and control group

| Demographics       | Experimental group (N=31) | Control group (N=31) | χ²  | p-value |
|--------------------|---------------------------|----------------------|-----|---------|
| Age (yr)           |                           |                      | 1.042 |        307 |
| M (SD)             | 51.74 (7.28)              | 51.61 (6.57)         |     |         |
| 40-50(N)           | 16                        | 12                   |     |         |
| > 50(N)            | 15                        | 19                   |     |         |
| Gender             |                           |                      | .076 | .783    |
| Male               | 9                         | 10                   |     |         |
| Female             | 22                        | 21                   |     |         |
| Years of education |                           |                      | .729 | .393    |
| M (SD)             | 15.45 (.85)               | 15.65 (.95)          |     |         |
| Graduates (N)      | 24                        | 21                   |     |         |
| Post graduates & above (N) | 7                  | 10                   |     |         |
| Employment         |                           |                      | .284 | .668    |
| Employed           | 12                        | 13                   |     |         |
| Unemployed         | 19                        | 18                   |     |         |

N = number; M = mean; SD = standard deviation.
for baseline scores were not statistically significant \( (p > .05) \) for all the accuracy-based STM and WM tasks and span-based WM tasks, except digit ordering task \( (t = 2.86, p = .006) \), year ordering task \( (t = 3.14, p = .003) \) and face-name association task \( (t = 3.75, p < .001) \), wherein the control group showed a significantly higher pre-training score than the experimental group.

The pre-training and post-training scores obtained by the participants for all the trained and untrained tasks were tested for normality using Shapiro-Wilk test. The test showed a significant departure from normality only for the pre-training and post-training scores of the N-back tasks \( (p < .001) \). Therefore, non-parametric tests were applied to study the training effects with the N-back tasks.

**WM training effects on the trained tasks**

Training effects on double digit ordering task, semantic sorting task, multistage problem solving task, and sentence ordering task

As shown in Figure 4, the post-training WM span scores were greater than the pre-training WM span for all four tasks. A paired t-test revealed significant improvements on the post-training WM span for the sentence ordering task \( [t_{(30)} = 12.20, p < .001] \), multistage problem solving task \( [t_{(30)} = 11.33, p < .001] \), semantic sorting task \( [t_{(30)} = 7.73, p < .001] \) and double digit ordering task \( [t_{(30)} = 6.52, p < .001] \).

![Figure 4](https://example.com/figure4.png)

**Table 9.** The baseline performance on the accuracy-based WM tasks, span-based WM tasks and span-based STM tasks of the participants of experimental and control group

| Task                          | Experimental group | Control group | t-value | p-value |
|-------------------------------|--------------------|---------------|---------|---------|
| **Accuracy-based WM tasks**   |                    |               |         |         |
| Auditory word retrieval task | 14.29 ± 2.25       | 13.68 ± 3.34  | 847     | .400    |
| Auditory word list recall task| 6.26 ± 1.63        | 6.42 ± 1.34   | 43      | .672    |
| Auditory delayed sentence recall task| 11.00 ± 1.61 | 11.55 ± 1.95 | 1.21    | .232    |
| Visual picture recall task    | 3.65 ± 0.95        | 3.84 ± 1.04   | .77     | .446    |
| Visual word list recall task  | 6.58 ± 1.95        | 6.58 ± 1.31   | .00     | 1.000   |
| Visual delayed sentence recall task| 11.68 ± 1.85 | 11.94 ± 1.41 | 62      | .54     |
| **Span-based WM tasks**       |                    |               |         |         |
| Digit ordering task           | 5.87 ± 1.12        | 6.52 ± 0.57   | 2.86    | .006    |
| Letter ordering task          | 4.06 ± 1.55        | 4.26 ± 1.15   | 56      | .579    |
| Digit and letter ordering task| 4.97 ± 1.38        | 5.35 ± .88    | 1.32    | .192    |
| Year ordering task            | 2.71 ± 0.74        | 3.45 ± 1.09   | 3.14    | .003    |
| Spell the word task           | 4.26 ± 1.29        | 4.61 ± 1.33   | 1.06    | .291    |
| **Span-based STM tasks**      |                    |               |         |         |
| Face recall task              | 3.32 ± 1.05        | 3.71 ± 1.16   | 1.38    | .173    |
| Name recall task              | 3.58 ± 1.09        | 3.55 ± .77    | .13     | .893    |
| Object recall task            | 6.10 ± .79         | 6.10 ± 1.11   | .00     | 1.000   |
| First name-second name association task| 2.90 ± .75 | 3.23 ± .80    | 1.64    | .107    |
| Face-name association task    | 2.65 ± .61         | 3.19 ± .54    | 3.75    | .000    |
| Face-object association task  | 3.32 ± 1.22        | 3.58 ± .81    | 98      | .330    |

\( p \)-value < .05 has been highlighted in bold.
Training effects on verbal fluency task

As shown in Figure 5, the overall scores on all the letter fluency tasks showed a statistically significant improvement post WM training for the participants of experimental group (N = 31).

The mean number of words/word pairs generated post-training was observed to be significantly more than pre-training on the excluded letter fluency task \( t(30) = 8.06, p < .001 \), simple letter fluency task \( t(30) = 5.87, p < .001 \), simple letter alternating fluency task \( t(30) = 5.99, p < .001 \), and complex letter alternating fluency task \( t(30) = 8.05, p < .001 \).

The performance on the category fluency task as shown in Figure 6 was observed to have similar trends with training as that of the letter fluency tasks.

A statistically significant improvement was observed on the paired t-test for the number of words/word pairs generated, post-training for the simple category fluency task \( t(30) = 6.21, p < .001 \), complex category fluency task \( t(30) = 6.53, p < .001 \), complex category alternating fluency task \( t(30) = 7.34, p < .001 \), and simple category alternating fluency task \( t(30) = 6.08, p < .001 \).

Training effects on N-back tasks

The pre and post-training differences for the n-back task was examined using the descriptive statistics (shown in Table 10).

Table 10. The pre and post-training median and interquartile range (IQR) of the n-back levels for the N-back tasks

| N-back tasks       | Pre     | Post    |
|--------------------|---------|---------|
| Face n-back        | 1 (0-1) | 2 (1-3) |
| Letter n-back      | 1 (1-2) | 3 (2-3) |
| Object n-back      | 1 (0-2) | 3 (3-3) |
| Word n-back        | 1 (1-2) | 3 (2-3) |

Values are presented as median (IQR).

The results on Wilcoxon’s sign rank test indicated a significantly higher post-training n-back level than pre-training for all the tasks, which include face n-back task \( Z = 4.57, p < .001 \), letter n-back task \( Z = 4.70, p < .001 \), object n-back task \( Z = 4.61, p < .001 \), and word n-back task \( Z = 4.64, p < .001 \).

WM training effects on near transfer tasks

Though all participants took part in the pre-training and post-training assessment; there was, however, an attrition of 10 participants in the experimental group and eight participants in the control group at the follow-up assessment. Taking into account the attrition at the follow-up assessment, an intention-to-treat analysis was applied using the last observation carried forward method, wherein, the post-training assessment scores of the participants who did not follow-up were considered as the scores for their fol-
low-up assessment.

Training effects on accuracy–based working memory tasks

The overall mean accuracy scores for all the accuracy-based WM tasks, as observed in Figure 7, revealed the control group to have higher pre-training scores than the experimental group on all the tasks except auditory word retrieval tasks and visual word list recall tasks. The post-training and follow-up assessment scores, however, were observed to be significantly higher among the experimental group in comparison to the control group on all the tasks, except AWLR and ADSR, wherein, the control group also showed significant improvement.

The mixed model ANOVA and post-hoc Bonferroni pairwise analysis was performed and the results are depicted in Table 11.

Training effects on span–based working memory tasks

The control group had greater mean spans on the pre-training assessment than the experimental group on all the span-based WM tasks, as seen in Figure 8. However, with training, the experimental group showed better performance during post-training with an improvement in the mean spans on all tasks.

Table 12 shows the mixed model ANOVA results and the post-hoc Bonferroni pairwise analysis.

Training effects on span–based short term memory tasks

From Figure 9, it can be noted that the improvements in the mean spans from pre-training to post-training were seen in the experimental group on all the span-based STM tasks, except object recall task, wherein, both the groups were observed to have a similar performance change.

The results also reveal that the average pre-training score on the object recall was higher in comparison to the pre-training score of all the other STM tasks in both the groups, and that the improvement on the mean spans observed on the post-training assessment was retained at the follow-up assessment for all the STM tasks in both the groups.

The group specific differences in the STM mean spans using a mixed model ANOVA and a post-hoc Bonferroni pairwise analy-
### Table 11. Mixed model ANOVA and p values of the pairwise analysis of pre-training, post-training and follow-up assessment on the accuracy-based WM tasks in the experimental (E) and control (C) group

| Tasks                          | Effects                | F       | \( \rho \)   | \( \eta^2 \) | Pre-Post | Post-FU |
|-------------------------------|------------------------|---------|---------------|-------------|---------|---------|---------|
|                               |                        |         |               |             | E | C | E vs C | E | C | E vs C |
| Auditory word retrieval task  | Time (2,120)           | 29.51   | < .001        | .33         | < .001  | 1.000  | < .001  | .442 | .595 | 1.000  |
|                               | Group (1,60)           | 11.89   | .001          | .165        |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 32.79   | < .001        | .35         |         |        |         |     |     |        |
| Auditory word list recall task | Time (2,120)           | 63.58   | < .001        | .51         | < .001  | < .001 | < .001  | 1.000 | 1.000 | .362  |
|                               | Group (1,60)           | 10.72   | .002          | .15         |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 16.09   | < .001        | .21         |         |        |         |     |     |        |
| Auditory delayed sentence recall task | Time (2,120)  | 41.53   | < .001        | .41         | < .001  | < .001 | < .001  | .976 | 1.000 | .243  |
|                               | Group (1,60)           | 5.15    | .02           | .08         |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 15.33   | < .001        | .20         |         |        |         |     |     |        |
| Visual picture recall task    | Time (2,120)           | 27.82   | < .001        | .31         | < .001  | 1.000  | < .001  | .791 | 1.000 | .597  |
|                               | Group (1,60)           | 10.71   | .002          | .15         |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 23.35   | < .001        | .28         |         |        |         |     |     |        |
| Visual word list recall task  | Time (2,120)           | 58.86   | < .001        | .49         | < .001  | 1.000  | < .001  | 1.000 | 1.000 | .349  |
|                               | Group (1,60)           | 20.57   | < .001        | .25         |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 51.88   | < .001        | .46         |         |        |         |     |     |        |
| Visual delayed sentence recall task | Time (2,120) | 37.10   | < .001        | .38         | < .001  | < .001 | < .001  | .249 | .976 | .053  |
|                               | Group (1,60)           | 11.40   | .001          | .16         |         |        |         |     |     |        |
|                               | Time*Group (2,120)     | 19.43   | < .001        | .24         |         |        |         |     |     |        |

\( p \)-value < .05 has been highlighted in bold.

### Figure 8. The mean spans of pre-training (Pre), post-training (Post) and follow-up (FU) assessment of experimental and control group on the span-based working memory (WM) tasks.

The error bars represent the standard deviation.

Do = digit ordering; LO = letter ordering; YO = year ordering; DLO = digit and letter ordering; STW = spell the word.

\(* p < .05\).
sis was conducted and the results are shown in Table 13.

An analysis excluding the missing participants’ data from the follow up assessment was performed to examine the difference in the performance across all the near transfer tasks from post-training assessment to follow-up assessments in both the groups. There were no significant differences in the performance from post-training assessment to follow-up assessment among both groups, except for year ordering task; wherein, the participants of the con-

Table 12. Mixed model ANOVA and p values of pairwise analysis of pre-training, post-training and follow-up assessment on the span-based WM tasks in the experimental (E) and control (C) group

| Tasks                              | Effects                  | F     | p     | \( \eta^2 \) | Pre-Post | Post-FU |
|-----------------------------------|--------------------------|-------|-------|--------------|----------|---------|
|                                   |                          |       |       |              | E        | C       |
|                                   |                          |       |       |              | E vs C   | E vs C  |
| Digit ordering task               | Time (2,120)             | 22.25 | < .001| .27          | .006     | .002    | .106    | 249 | 1.000 | .179 |
|                                   | Group (1,60)             | 8.31  | .055  | .122         | .005     | .097    | .363    | 288 | 1.000 | .490 |
|                                   | Time*Group (2,120)       | 3.41  | .036  | .054         | .036     | .152    | .249    |     |       |     |
| Letter ordering task              | Time (2,120)             | 26.69 | < .001| .31          | < .001   | 1.000   | < .001  | 288 | 1.000 | .490 |
|                                   | Group (1,60)             | 5.75  | .02   | .08          | .02      | .22     | .001    |     |       |     |
|                                   | Time*Group (2,120)       | 16.91 | < .001| .22          | < .001   | 1.000   | < .001  | 288 | 1.000 | .490 |
| Year ordering task                | Time (2,120)             | 18.34 | < .001| .23          | < .001   | .249    | < .001  | 1.000 | .068 | .399 |
|                                   | Group (1,60)             | 4.53  | .03   | .07          | .03      | .07     | .07     |     |       |     |
|                                   | Time*Group (2,120)       | 28.76 | < .001| .32          |         |         |         |     |       |     |
| Digit and letter ordering task    | Time (2,120)             | 5.35  | .066  | .08          | .002     | .605    | < .001  | 633 | 1.000 | .162 |
|                                   | Group (1,60)             | 4.61  | .03   | .07          | .03      | .07     | .07     |     |       |     |
|                                   | Time*Group (2,120)       | 11.95 | < .001| .16          | < .001   | 1.000   | < .001  | 633 | 1.000 | .162 |
| Spell the word task               | Time (2,120)             | 20.51 | < .001| .25          | < .001   | 1.000   | < .001  | 1.000 | 1.000 | .293 |
|                                   | Group (1,60)             | 5.35  | .02   | .08          | .02      | .08     | .08     |     |       |     |
|                                   | Time*Group (2,120)       | 13.28 | < .001| .18          | < .001   | 1.000   | < .001  | 1.000 | 1.000 | .293 |

p-value < .05 has been highlighted in bold.

Figure 9. The mean spans of pre-training (Pre), post-training (Post) and follow-up (FU) assessment of experimental and control group on the span-based short-term memory (STM) tasks. The error bars represent the standard deviation. FR = face recall; NR = name recall; OR = object recall; FSNA = first-name-second-name association; FNA = face-name association; FOA = face-object association. *p < .05.
control group had a significant change in performance from the post to follow-up assessment. These findings are similar to the findings of the intention to treat analysis, therefore it can be assumed that the results obtained on the follow-up assessment on an intention to treat analysis may not be depicting inflated means.

**DISCUSSION**

**WM training effects on the trained tasks**

In the present research, the specific WM training effects on the 17 trained tasks among the participants of the experimental group were analyzed and the results showed significant gains on all the trained WM tasks from the pre to post-training assessments. This finding is similar to earlier studies which have reported evidence for substantial enhancements in the performance on the trained tasks with WM training (Guye, Simoni, & von Bastian, 2017; Matzen et al., 2016; von Bastian & Oberauer, 2014). Similar evidence on the improvements on the trained tasks have been reported among young-aged and old-aged adults (Karbach & Verhaeghen, 2014; Melby-Lervåg et al., 2016) and in our earlier research among middle-aged adults (Mridula et al., 2017; Namratha et al., 2017).

Although the tasks in the training protocol were closely related to the outcome measurement tasks, they differed with respect to the type and range of stimuli, the complexity levels, and the WM strategy used. The outcome measurement tasks were taken from standardized tests such as the Manipal Manual of Cognitive Linguistic Abilities (MMCLA; Mathew et al., 2013), span-based working memory tasks by Kumar et al. (2015); and the span-based short term memory tasks designed by D’Souza et al. (2016) and served as the assessment battery for the near transfer effects. With respect to the WM training, the baseline performance of the participants on each training task was established through the screening modules of the task and the administration of the screening module was devoid of any form of feedback or training. The training for a task was then initiated at the baseline level obtained on the screening module and it was compared with the level achieved at the end of training sessions to determine the training gains on each of the trained tasks.

With each training task being different from the other, the training gains would be selective among the trained tasks.

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**Table 13.** Mixed model ANOVA and p values of the pairwise analysis of pre-training, post-training and follow-up assessment on the accuracy-based WM tasks in the experimental (E) and control (C) group

| Tasks                              | Effects                  | F    | p     | η²  | Pre-Post E | C | E vs C | Post-FU E | C | E vs C |
|------------------------------------|--------------------------|------|-------|-----|------------|--------|--------|------------|--------|--------|
| Face recall task                   | Time (2,120)             | 9.04 | < .001| .13 | <.001      | 1.00   | <.001  | 1.000      | 1.000  | .766   |
|                                   | Group (1,60)             | 4.66 | .03   | .07 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 16.42 | < .001| .215|            |        |        |            |        |        |
| Name recall task                   | Time (2,120)             | 31.91 | < .001| .34 | <.001      | 1.000  | <.001  | .249       | 1.000  | .317   |
|                                   | Group (1,60)             | 10.93 | .02   | .15 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 26.59 | < .001| .307|            |        |        |            |        |        |
| Object recall task                 | Time (2,120)             | 33.39 | < .001| .35 | <.001      | <.001  | .560   | 1.000      | 1.000  | .661   |
|                                   | Group (1,60)             | 4.56  | .03   | .07 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 0.43  | .64   | .007|            |        |        |            |        |        |
| First name-second name association task | Time (2,120)         | 16.78 | < .001| .22 | <.001      | 1.000  | <.001  | .791       | .552   | .086   |
|                                   | Group (1,60)             | 6.13  | .01   | .03 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 20.97 | < .001| .259|            |        |        |            |        |        |
| Face-name association task         | Time (2,120)             | 15.08 | < .001| .20 | <.001      | 1.000  | <.001  | .482       | 1.000  | .656   |
|                                   | Group (1,60)             | 4.66  | .03   | .07 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 19.37 | < .001| .244|            |        |        |            |        |        |
| Face-object association task       | Time (2,120)             | 26.72 | < .001| .31 | <.001      | .605   | <.001  | .633       | 1.000  | .827   |
|                                   | Group (1,60)             | 6.23  | .01   | .09 |            |        |        |            |        |        |
|                                   | Time*Group (2,120)       | 16.75 | < .001| .218|            |        |        |            |        |        |

p-value < .05 has been highlighted in bold.
(Thompson et al., 2013). In the present research also, although all the trained tasks showed significant improvements over the sessions; the magnitude of the training gains differed across the tasks. Among the double digit ordering, semantic sorting, sentence ordering, and multistage problem solving tasks; the sentence ordering task was shown to have the highest training gain, followed by the multistage problem solving task, semantic sorting task, and the double digit ordering task, which had the lowest gain. Similarly, among the n-back tasks, the face n-back task exhibited the lowest training gain when compared to the letter, object, and word n-back tasks. The magnitude of improvement in the n-back levels from pre to post-training on the letter, object, and word n-back tasks were, however, similar. Among the verbal fluency tasks, the excluded letter fluency task had the highest training gain as compared to the other letter fluency tasks and the simple category fluency task was shown to have the highest training gain than all the other category fluency tasks. The differences in the training gains across the trained tasks could be attributed to the differences in the inherent properties of each task.

The specific improvements observed on the trained tasks could be attributed to the practice effect. It has been suggested that repeated practice on tasks facilitates an automatization process, which leads to the use of very minimal resources for processing (Brown & Carr, 1989), thereby decreasing the capacity demands (LaBerge & Samuels, 1974) as the task performance progresses across the training sessions. Stone (2015) emphasized that, in WM training, practice effects improve an individual’s WM capacity, and this is generally measured by comparing the performance on a trained task on the first and last session of the training. Studies have demonstrated that neural changes like myelination and an increase or decrease in synaptic connections can be induced by environmental experiences (Changeux & Danchin, 1976; Fields, 2008), and moreover practice effects could be an indication of these plastic changes in the underlying neural structures (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010; Posner & Rothbart, 2005). Some studies in the past have shown improvements on practiced tasks targeting cognitive processes such as WM and executive functions among individuals in their early and late adulthood, indicating practice-induced plasticity (Wilkinson & Yang, 2016).

It is suggested that the effect of practice on trained tasks depends on the approach or strategies deployed by the participants for task performance during the training (Peng & Fuchs, 2017). According to Jonides (2004), when individuals practice a task, the performance on the task is reported to gradually improve over time, due to either an increase in the efficiency with which they use their own strategy or due to them learning to apply a new strategy to perform the task, which further makes the task less effortful with limited demands on the executive control processes. This relationship between the WM abilities and the executive control processes can be better understood with respect to tasks like verbal fluency used in the present research. There was a significant improvement observed with respect to the number of items generated for a range of verbal fluency tasks along with minimal instances of repetitions and errors during the task in the post training condition. This signifies that when individuals are able to better retain the generated items in their memory space, their response selection and inhibitory control also shows considerable improvement and vice versa.

**WM training effects on near transfer tasks**

The results revealed the experimental group to have significantly higher scores after the WM training than the control group on most of the near transfer tasks, except for the object recall and digit ordering tasks. The present findings seem to be in line with some of those studies in literature which have reported some near transfer effects from pre to post-training assessments (Klingberg, 2010; Mridula et al., 2017; Namratha et al., 2017; Shipstead, Redick, & Engle, 2012). Research evidence suggest that improvements in trained tasks may strengthen the performance on the tasks which rely on cognitive processes similar to that of the trained tasks or which share similar neural connections as that of the tasks used during training (Dahlin et al., 2008). Dunning and Holmes (2014) have suggested two possible explanations with respect to the WM training transfer effects on the untrained tasks. Firstly, with training the WM capacity is reported to increase in an individual, allowing more storage of information. Repeated cognitive demands on the capacity limits during training further induces changes in the neural networks within the brain regions which are responsible for WM. These neural changes increase WM capacity for other
cognitive skills which rely on the same neural networks of the WM resources which are reflected as neuronal overlaps, suggesting the neural link between the trained and transfer tasks to be an essential requirement for transfer effects (Dahlin et al., 2008). Secondly, it is hypothesized that transfer effects can be facilitated through the acquisition of strategies or skills during WM training which encourages more efficient use of WM resources existing in an individual (Holmes, Gathercole, & Dunning, 2009). Evidence suggest that individuals learn to apply some common strategies such as rote rehearsals, which involves the constant repetition of the information that is required to be remembered within the mental capacity (Turley-Ames & Whitfield, 2003); chunking, which involves the recall of sets of items to be remembered by grouping them into fewer chunks or items (Lange & Pierce, 1992); visualization, which involves the creation of a visual imagery of the item to be remembered (McNamara & Scott, 2001); and semantic associations, which involve linking meaning with the items to be remembered (Bower & Clark, 1969).

The near transfer tasks in the present research were comprised of WM and STM tasks, and the transfer effects were observed on the tasks of both of the cognitive domains. According to Schwaighofer et al. (2015), the differences between the STM and WM tasks exist only in the subcomponent processes like rehearsal and updating. WM training produces near transfer effects on the tasks measuring WM and STM immediately and in a sustained manner. A study by Brehmer et al. (2012) showed significant near transfer effects on verbal and visual STM tasks among young aged (20-30 years) and old aged (60-70 years) adults after five weeks of adaptive spatial and verbal WM training. The near transfer WM training effects in the present research may also get some support from the findings of McAvinue et al. (2013), who reported significant improvements among older adults (64-79 years) on an auditory STM span task, after a five-week online training on auditory and visuospatial STM and WM tasks. Similarly, Schwarb, Nair, and Schumacher (2016) reported a transfer of WM training-related gains on visual STM capacity. Waris et al. (2015) suggested that WM training produces transfer effects, and the cognitive overlap between the trained and transfer tasks may determine the magnitude of the transfer effects. The theoretical basis of the WM training effects according to the process overlap theory (Kovacs & Conway, 2016) is that, with WM task practice it is possible to enhance the WM capacity, as well as achieve transfer effects on some of those untrained tasks which may share similar cognitive processes with WM.

Besides the underlying neural mechanisms, the transfer effects in the present research may also be attributed to certain factors related to the training regimen. One such factor can be the use of a single or multiple tasks training paradigm. WM training following a multiple task paradigm is reported to be better than one with a single task, since training on a single task would lead to a more stimuli-specific training effect (Chein & Morrison, 2010). It has been suggested that the use of multiple and variant training tasks, including verbal or visuospatial stimuli, allows the WM process to be practiced in different task contexts, thereby promoting transfer effects (Schmidt & Bjork, 1992). The presence of some near transfer effects in the present research could possibly be due to the WM training paradigm used, which was comprised of multiple WM tasks along with variants of certain tasks such as n-back, which included faces, objects, letters and words as stimuli. Although the tasks differed, the processes targeted during training were limited to WM and executive functions, which could be considered as another reason for the near transfer effects. It has also been reported that narrow WM training paradigms, which target only one specific cognitive process, have greater chances of mediating near transfer effects (Schwaighofer et al., 2015).

Another factor which could facilitate transfer effects of WM training is the utilization of an adaptive training procedure; wherein task difficulty is attuned in accordance to the person’s performance during the training. Literature evidence supports the benefit of adaptive training in the use of specific strategies during task performance (Jaeggi & Buschkuehl, 2014), and in near transfers (Brehmer et al., 2012; Klingberg et al., 2005), which is reported to increase the efficiency of WM training. It has been postulated that adjusting task difficulty according to an individual’s performance allows the training to remain in close proximity to the individual’s capacity and retains the motivation levels of the individuals during the training (Cantarella, 2015). The mechanism through which this performance enhancement occurs is referred to as the naïve physical-energetic model (Melby-Lervåg & Hulme, 2013), which proposes that as the participants perform the diffi-
cult trials; their neural system strengthens, thereby leading to improvements in performance.

The present research findings also reveal no significant change in the performance from the post-training assessment to the follow-up assessment in both groups, with scores remaining higher for the participants of experimental group than the control group. This finding supports a positive trend in maintenance of the near transfer gains as compared to some of the existing studies which have reported limited maintenance (Buschkuehl et al., 2008). However, there is some evidence in support of the present findings, indicating the presence of maintenance of near transfer gains (Ball et al., 2002; Lustig et al., 2009). Maintenance of transfer effects of n-back training after three months has been reported among young and older adults (Li et al., 2008). Similarly, Payne and Stine-Morrow (2017) reported short term maintenance of transfer effects of verbal WM training among adults in the age range of 60 years and above, signifying the evidence for plasticity of WM in later adulthood. Maintenance of training gains is considered to be an indication that individuals have developed successful self-initiated processing abilities, which leads to enhanced capacity and flexibility, in addition to a more proficient representation of knowledge (Borella, Carretti, Riboldi, & De Beni, 2010). It has been reported that continuing to engage in a cognitive-stimulating environment and practicing the skills and strategies learnt during the training may also explain the presence of maintenance effects (Rebok, Carlson, & Langbaum, 2007).

Although the performance change observed from pre to post-training assessment was maintained at the follow-up assessment, there was a slight decrease in the mean performance on some of the near transfer tasks at follow-up assessment, as compared to the post-training assessment. We assume that this slight decrease in the pre-post change observed at follow-up could be due to the WM training being limited to only 10 sessions. It is likely that if the number of training sessions were extended beyond 10, then the maintenance might be better and longer. These findings suggest the importance of constantly engaging the brain in everyday cognitively demanding tasks, in order to maintain healthy cognitive wellbeing.

Limitations and future direction

The present research was limited to a non-randomized research design with a passive control group, and could not employ a controlled random assignment of participants. Research on WM training effects among middle-aged adults with a randomized control design, along with the inclusion of an active control group would be interesting to explore in the future. Also, the research was limited to examining the short-term benefit of the WM training and did not explore the long-term maintenance of the training gains. The WM training far transfer effects were not in the scope of the present research, and research in this direction could be carried out in the future. The control group did not have the same level of activity or attention as the treatment group. Therefore, the present results could be partially attributed to the participants’ engagement in extra activities rather than the specific working memory tasks. Moreover, certain aspects such as the motivation levels of the participants and WM training impact on more functional daily tasks and on the quality of life can also be examined in future research, which could offer additional insights about the effectiveness of WM training on the overall mental well-being of individuals belonging to middle adulthood. Furthermore, it would also be interesting to conduct longitudinal/cross-sectional research that examines the impact of WM training initiated at various points throughout the lifespan.

CONCLUSION

The effects of WM training observed in the present research offers considerable evidence and helps to broaden the understanding that WM abilities may be enhanced with the help of a structured training program among healthy middle-aged adults. The WM training module utilized in the current research has offered some effectiveness that can be applied in this direction. The research findings also widen the implication that the WM training module can be applied to healthy aging individuals, and may even be researched and considered for treatment among individuals having WM deficits or cognitive impairment. Although the present research was limited to a non-randomized research design, the results obtained seem encouraging in light of several efforts being made globally to encourage a sense of healthy cognitive wellbeing.
in aging adults. Such WM training protocols, when advocated and practiced routinely, may prove to be a promising primary preventive measure in cognitive aging, by improving the cognitive reserves which may offer a protective mechanism against cognitive communicative disorders.

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국문초록

중년 성인의 작업 기억 훈련 효과

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배경 및 목적: 중년 시기에는 높은 수준의 인지 수행능력이 필요한 인지적 과제를 해야하기에 작업 기억 능력의 쇠퇴는 중년 성인에게 중요한 문제가 된다. 인도인을 대상으로 하는 인종적, 문화적으로 적합한 작업 기억 훈련의 부족 문제를 해결하는 것과 더불어 중년 성인의 인지 능력과 다양성을 향상시키기 위하여 본 연구는 중년 성인을 대상으로 하는 작업 기억 훈련의 효과를 살펴보고자 하였다. 방법: 총 62명의 40-65세 성인이 실험집단(31명)과 통제집단(31명)으로 나뉘어졌다. 실험집단은 17개의 작업 기억 과제로 이루어진 10회기 훈련 프로그램을 받았다. 각 회기는 45분-1시간 정도의 길이였다. 통제집단은 훈련을 받지 않았다. 결과: 실험집단은 통제집단과 비교, 훈련 과제, 그리고 이와 유사한 전이 과제에서는 통계적으로 유의한 차로 향상(\(p < .05\))을 보였다. 논의 및 결론: 본 연구는 중년 성인을 대상으로 하는 작업 기억 훈련이 구조적인 훈련 프로그램과 더불어 인지-의사소통 능력을 향상시키는데 도움이 된다는 점을 강조한다. 이러한 결과는 이후 노년기 성인의 인지적 안녕을 도모하는데 도움을 줄 수 있을 것이다.

핵심어: 작업 기억, 중년 성인, 훈련, 효과, 인지

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