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 per-

forming 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 (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 tends 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 behav-

ioral 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). Fur-

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, Zanon, 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, & Böhner, 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 (Karch & 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 and or psychiatric or psychological disorder. All the participants were generally healthy, independent community dwelling adults, though some reported

Table 1. Demographic distribution of the participants

Demographics	Experimental group (N=31)	Control group (N=31)
Age (yr)		
M (SD)	51.74 (7.28)	51.61 (6.57)
Range	40-65	40-65
Gender (N)		
Male	9	10
Female	22	21
Years of education		
M (SD)	15.45 (.85)	15.65 (.95)
Employment (N)		
Active employment	12	13
Unemployed	19	18
Sleep hours (N)		
≥ 7 hours	25	24
< 7 hours	6	7
Eating habit		
≥ 3 meals/day	30	31
< 3 meals/day	1	0
Diabetes (N)		
Present	4	4
Absent	27	27
Hypertension (N)		
Present	1	3
Absent	30	28

N= number; M= mean; SD= standard deviation.

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-

signed by D'Souza, Bajaj, and Bhat (2016).

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

Figure 1. Timeline for assessments.

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.

sub tasks with varying stimuli and testing paradigms. These tasks have been described in Table 5.

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 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			
5.1 Face 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	Correct response - 1 Incorrect response - 0
5.2 Letter n-back		Training sequence - five sequences/complexity level	Correct response - 1 Incorrect response - 0
5.3 Object n-back			Correct response - 1 Incorrect response - 0
5.4 Word n-back			Correct response - 1 Incorrect response - 0
6. Verbal fluency		Two/task	Number of words/ word pairs generated
6.1 Simple letter 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.		
6.2 Complex letter fluency			
6.3 Simple letter alternating fluency			
6.4 Complex letter alternating fluency			
6.5 Simple category fluency	Participant had to generate as many words as possible in one minute which does not contain the letter 'E' by avoiding repetitions, use of proper nouns and word derivatives.	One	
6.6 Complex category fluency			
6.7 Simple category alternating fluency			
6.8 Complex category alternating fluency			
6.9 Excluded letter fluency			

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; Heinzl 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

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

any kind of discomfort or fatigue.

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 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 complexity-

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)	χ^2	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	.868
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 [$t_{(30)} = 12.20$, $p < .001$], multi-stage 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. The pre-training (Pre) and post-training (Post) mean spans for the double digit ordering task (DDO), semantic sorting task (SS), multistage problem solving task (MPS), and sentence ordering task (SO). The error bars represent the standard deviation.

* $p < .05$.

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

	Experimental group		Control group		<i>t</i> -value	<i>p</i> -value
	Mean	SD	Mean	SD		
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 ask	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.

Figure 5. The average number of words and word pairs generated (score), on the pre-training (Pre) and post-training (Post) assessment of the letter fluency tasks.

The error bars represent the standard deviation.

SLF=simple letter fluency task; CLF=complex letter fluency task; SLAF=simple letter alternating fluency task; CLAF=complex letter alternating fluency task; ELF=excluded letter fluency task.

* $p < .05$.

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 [$t_{(30)} = 9.09, p < .001$], simple letter fluency task [$t_{(30)} = 8.06, p < .001$], complex 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). The

Figure 6. The average of words and word pairs generated (score) on the pre-training (pre) and post-training (post) assessment of the category fluency tasks. The error bars represent the standard deviation.

SCF=simple category fluency task; CCF=complex category fluency task; SCAF=simple category alternating fluency task; CCAF=complex category alternating fluency task.

* $p < .05$.

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).

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-

Figure 7. The mean accuracy scores of pre-training (Pre), post-training (Post) and follow-up (FU) assessment of experimental and control group on the accuracy-based working memory (WM) tasks.

The error bars represent the standard deviation.

AWR=auditory word retrieval; AWLR=auditory word list recall; ADSR=auditory delayed sentence recall; VPR=visual picture recall; VWLR=visual word list recall; VDSR=visual delayed sentence recall.

* $p < .05$.

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 experi-

mental 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	<i>F</i>	<i>p</i>	η^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	.006	<.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	.402	.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	.076	<.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.

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	<i>F</i>	<i>p</i>	η^2	Pre-Post			Post-FU		
					E	C	E vs C	E	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	.005	.122						
	Time*Group (2,120)	3.41	.036	.054						
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						
	Time*Group (2,120)	16.91	<.001	.22						
Year ordering task	Time (2,120)	18.34	<.001	.23	<.001	.249	<.001	1.000	.068	.399
	Group (1,60)	4.53	.03	.07						
	Time*Group (2,120)	28.76	<.001	.32						
Digit and letter ordering task	Time (2,120)	5.35	.006	.08	.002	.605	<.001	.633	1.000	.162
	Group (1,60)	4.61	.03	.07						
	Time*Group (2,120)	11.95	<.001	.16						
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						
	Time*Group (2,120)	13.28	<.001	.18						

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.

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-train-

ing 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 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	<i>F</i>	<i>p</i>	η^2	Pre-Post			Post-FU		
					E	C	E vs C	E	C	E vs C
Face recall task	Time (2,120)	9.04	<.001	.13	<.001	1.000	<.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	.002	.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	.93						
	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.

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 (Karch & 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

(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, Nail, 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 & Buschkuhl, 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.

REFERENCES

- Au, J., Buschkuhl, M., Duncan, G. J., & Jaeggi, S. M. (2016). There is no convincing evidence that working memory training is NOT effective: A reply to Melby-Lervåg and Hulme (2015). *Psychonomic Bulletin & Review*, 23(1), 331-337.
- Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuhl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin & Review*, 22, 366-377. <https://doi.org/10.1016/j.cognition.2008.05.007>
- Baddeley, A. (1992). Working memory: the interface between memory and cognition. *Journal of Cognitive Neuroscience*, 4(3), 281-288.
- Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, 36(3), 189-208.
- Baddeley, A. D. (2001). Is working memory still working?. *American Psychologist*, 56(11), 851-864.
- Bairwa, M., Rajput, M., & Sachdeva, S. (2013). Modified Kuppuswamy's socioeconomic scale: social researcher should include updated income criteria, 2012. *Indian Journal of Community Medicine*, 38(3), 185-186.
- Bajaj, G., Deepa, N., Bhat, J. S., D'souza, D., & Sheth, P. (2014). Self-efficacy and verbal fluency--does age play a role?. *Healthy Aging & Clinical Care in the Elderly*, 6, 17-24.
- Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., ..., Willis, S. L. (2002). Effects of cognitive training interventions with older adults. *JAMA*, 288(18), 2271-2281.
- Banich, M. T. (2009). Executive function: the search for an integrated account. *Current Directions in Psychological Science*, 18(2), 89-94.
- Borella, E., Carbone, E., Pastore, M., De Beni, R., & Carretti, B. (2017). Working memory training for healthy older adults: the role of individual characteristics in explaining short and long-term gains. *Frontiers in Human Neuroscience*, 11, 99.
- Borella, E., Carretti, B., Cantarella, A., Riboldi, F., Zavagnin, M., & De Beni, R. (2014). Benefits of training visuospatial working memory in young-old and old-old. *Developmental Psychology*, 50(3), 714-727.
- Borella, E., Carretti, B., Riboldi, F., & De Beni, R. (2010). Working memory training in older adults: evidence of transfer and maintenance effects. *Psychology and Aging*, 25(4), 767-778.
- Borella, E., Carretti, B., Zanoni, G., Zavagnin, M., & De Beni, R. (2013). Working memory training in old age: an examination of transfer and maintenance effects. *Archives of Clinical Neuropsychology*, 28(4), 331-347.
- Bower, G. H., & Clark, M. C. (1969). Narrative stories as mediators for serial learning. *Psychonomic Science*, 14(4), 181-182.
- Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: training gains, transfer, and maintenance. *Frontiers in Human Neuroscience*, 6, 63.
- Brown, T. L., & Carr, T. H. (1989). Automaticity in skill acquisition: mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology: Human Perception and Performance*, 15(4), 686-700.
- Buschkuhl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., ... Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging*, 23(4), 743-753.
- Cantarella, A. N. (2015). *Working memory training in aging: from the nature of the training to the transfer effects in everyday life* (Doctoral dissertation). University of Padova, Padova, Italia.
- Cappell, K. A., Gmeindl, L., & Reuter-Lorenz, P. A. (2010). Age differences in prefrontal recruitment during verbal working memory maintenance depend on memory load. *Cortex*, 46(4), 462-473.
- Changeux, J. P., & Danchin, A. (1976). Selective stabilisation of developing synapses as a mechanism for the specification of neuronal networks. *Nature*, 264(5588), 705-712.
- Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review*, 17(2), 193-199.
- Corbin, L., & Camos, V. (2011). Improvement of working memory performance by training is not transferable. *Europe's Journal of Psychology*, 7(2), 279-294.
- Cowan, N. (2010). The magical mystery four: how is working memory capacity limited, and why?. *Current Directions in Psychological Science*, 19(1), 51-57.
- D'Souza, D., Bajaj, G., & Bhat, J. S. (2016). *Assessment of age related changes in self efficacy and everyday short term memory* (Master's thesis), Manipal Academy of Higher Education, Manipal.

- Dahlin, E., Neely, A. S., Larsson, A., Backman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science*, 320(5882), 1510-1512.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19(4), 450-466.
- Daroczy, G., Wolska, M., Meurers, W. D., & Nuerk, H. C. (2015). Word problems: a review of linguistic and numerical factors contributing to their difficulty. *Frontiers in Psychology*, 6, 348.
- Dunning, D. L., & Holmes, J. (2014). Does working memory training promote the use of strategies on untrained working memory tasks?. *Memory & Cognition*, 42(6), 854-862.
- Dunning, D. L., Holmes, J., & Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? a randomized controlled trial. *Developmental Science*, 16(6), 915-925.
- Endress, A. D., Korjoukov, I., & Bonatti, L. L. (2017). Category-based grouping in working memory and multiple object tracking. *Visual Cognition*, 25(9-10), 868-887.
- Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of Experimental Psychology: General*, 128(3), 309-331.
- Espy, K. A., Molfese, V. J., & DiLalla, L. F. (2001). Effects of environmental measures on intelligence in young children: growth curve modeling of longitudinal data. *Merrill Palmer Quarterly*, 47(1), 42-73.
- Eweida, R. S., Mekail, M. N., & Ramadan, F. H. (2017). Problem solving ability and working memory capacity of patients with schizophrenia: the effect of problem-solving training intervention. *JOJ Nurse Health Care*, 5(5), 555-671.
- Ferreira, D., Correia, R., Nieto, A., Machado, A., Molina, Y., & Barroso, J. (2015). Cognitive decline before the age of 50 can be detected with sensitive cognitive measures. *Psicothema*, 27(3), 216-222.
- Ferreira, D., Machado, A., Molina, Y., Nieto, A., Correia, R., Westman, E., & Barroso, J. (2017). Cognitive variability during middle-age: possible association with neurodegeneration and cognitive reserve. *Frontiers in Aging Neuroscience*, 9, 188.
- Fields, R. D. (2008). White matter matters. *Scientific American*, 298(3), 42-49.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental state: a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3), 189-198.
- Greenwood, P. M., & Parasuraman, R. (2016). The mechanisms of far transfer from cognitive training: review and hypothesis. *Neuropsychology*, 30(6), 742-755.
- Guye, S., Simoni, C. De, & von Bastian, C. C. (2017). Do individual differences predict change in cognitive training performance? a latent growth curve modeling approach. *Journal of Cognitive Enhancement*, 1(4), 374-393.
- Harbison, J. I., Atkins, S. M., & Dougherty, M. R. (2011). N-back training task performance: analysis and model experiment. *Proceedings of the Cognitive Science Society*, 120-125.
- Hassenstab, J. J., Sweat, V., Bruehl, H., & Convit, A. (2010). Metabolic syndrome is associated with learning and recall impairment in middle age. *Dementia and Geriatric Cognitive Disorders*, 29(4), 356-362.
- Heinzel, S., Schulte, S., Onken, J., Duong, Q. L., Riemer, T. G., Heinz, A., ... Rapp, M. A. (2014). Working memory training improvements and gains in non-trained cognitive tasks in young and older adults. *Neuropsychology, Development, and Cognition. Section B: Aging, Neuropsychology and Cognition*, 21(2), 146-173.
- Henry, J. D., & Crawford, J. R. (2004). Verbal fluency deficits in Parkinson's disease: a meta-analysis. *Journal of the International Neuropsychological Society*, 10(4), 608-622.
- Hertzog, C., Dixon, R. A., Hultsch, D. F., & Macdonald, S. W. S. (2003). Latent change models of adult cognition: are changes in processing speed and working memory associated with changes in episodic memory?. *Psychology and Aging*, 18(4), 755-769.
- Hester, R., & Garavan, H. (2005). Working memory and executive function: the influence of content and load on the control of attention. *Memory & Cognition*, 33(2), 221-233.
- Hofer, S. M., Berg, S., & Era, P. (2003). Evaluating the interdependence of aging-related changes in visual and auditory acuity, balance, and cognitive functioning. *Psychology and Aging*, 18(2), 285-305.
- Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, 12(4), 9-15.
- Jaeggi, S. M., & Buschkuhl, M. (2014). *Working memory training and transfer: theoretical and practical considerations*. In B. Toni (Ed.), *New frontiers of multidisciplinary research in STEAM-H (Science, Technology, Engineering, Agriculture, Mathematics, and Health)* (pp. 19-43). Switzerland: Springer.

- Jonides, J. (2004). How does practice makes perfect ?. *Nature Neuroscience*, 7(1), 10-11.
- Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: an individual-differences perspective. *Psychonomic Bulletin & Review*, 9(4), 637-671.
- Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, 133(2), 189-217.
- Karbach, J., & Verhaeghen, P. (2014). Making working memory work: a meta-analysis of executive-control and working memory training in older adults. *Psychological Science*, 25(11), 2027-2037.
- Klaassen, E. B., Evers, E. A. T., de Groot, R. H. M., Backes, W. H., Veltman, D. J., & Jolles, J. (2014). Working memory in middle-aged males: age-related brain activation changes and cognitive fatigue effects. *Biological Psychology*, 96(1), 134-143.
- Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, 14(7), 317-324.
- Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., ... Westerberg, H. (2005). Computerized training of working memory in children with ADHD: a randomized, controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry*, 44(2), 177-186.
- Kovacs, K., & Conway, A. R. A. (2016). Process overlap theory: a unified account of the general factor of intelligence. *Psychological Inquiry*, 27(3), 151-177.
- Kumar, N. P., Bajaj, G., & Bhat, J. S. (2015). Correlating conventional working memory tasks with variant everyday working memory tasks among young healthy adults. *Paripex-Indian Journal of Research*, 4(1), 120-122.
- LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology*, 6(2), 293-323.
- Lagishetti, S. K., & Venkatesh, L. (2011). Cognitive linguistic abilities in an elderly population. *Language in India*, 11(12), 477-494.
- Lange, G., & Pierce, S. H. (1992). Memory-strategy learning and maintenance in preschool children. *Developmental Psychology*, 28(3), 453-462.
- Lawton, M. P., Moss, M., Hoffman, C., Grant, R., Have, T. Ten, & Kleban, M. H. (1999). Health, valuation of life, and the wish to live. *The Gerontologist*, 39(4), 406-416.
- Li, S. C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: practice gain, transfer, and maintenance. *Psychology and Aging*, 23(4), 731-742.
- Logie, R. H., Gilhooly, K. J., & Wynn, V. (1994). Counting on working memory in arithmetic problem solving. *Memory & Cognition*, 22(4), 395-410.
- Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin*, 136(4), 659-676.
- Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: a review and future directions. *Neuropsychology Review*, 15(1), 109-119.
- Macpherson, H. N., White, D. J., Ellis, K. A., Stough, C., Camfield, D., Silberstein, R., & Pipingas, A. (2014). Age-related changes to the neural correlates of working memory which emerge after midlife. *Frontiers in Aging Neuroscience*, 6, 1-10.
- Martin, M., & Zimprich, D. (2005). *Cognitive development in midlife*. In S. L. Willis & M. Martin (Eds.), *Middle adulthood: A lifespan perspective* (pp. 179-206). California: Sage Publications, Inc.
- Mathew, M. M., Bhat, J. S., Sreya, N. M., & Arora, A. (2013). *Manipal manual for cognitive linguistic abilities*. Manipal: Manipal University Press.
- Matzen, L. E., Trumbo, M. C., Haass, M. J., Hunter, M. A., Silva, A., Stevens-Adams, S. M., ... O'Rourke, P. (2016). Practice makes imperfect: working memory training can harm recognition memory performance. *Memory and Cognition*, 44(8), 1168-1182.
- McAvinue, L. P., Golemm, M., Castorina, M., Tatti, E., Pigni, F. M., Salomone, S., ... Robertson, I. H. (2013). An evaluation of a working memory training scheme in older adults. *Frontiers in Aging Neuroscience*, 5, 20.
- McNamara, D. S., & Scott, J. L. (2001). Working memory capacity and strategy use. *Memory & Cognition*, 29(1), 10-17.
- Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? a meta-analytic review. *Developmental Psychology*, 49(2), 270-291.
- Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer": evidence from a meta-analytic review. *Perspectives on Psychological Science*, 11(4), 512-534.
- Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *The Psychological Review*, 63(2), 81-97.
- Miller, G. A., Galanter, E., & Pribram, K. H. (1960). *Plans and the structure of behavior*. USA: Holt, Rinehart and Winston, Inc.
- Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? the promise and challenges of enhancing cognition by training

- working memory. *Psychonomic Bulletin & Review*, 18(1), 46-60.
- Mridula, J., George, V. M., Bajaj, G., Namratha, H. G., & Bhat, J. S. (2017). Effect of working memory training on cognitive communicative abilities among young-and middle-aged adults. *Cogent Psychology*, 4(1), 1-14.
- Namratha, H. G., George, V. M., Bajaj, G., Mridula, J., & Bhat, J. S. (2017). Effect of yoga and working memory training on cognitive communicative abilities among middle aged adults. *Complementary Therapies in Clinical Practice*, 28, 92-100.
- Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: a meta-analysis of normative functional neuroimaging studies. *Human brain mapping*, 25(1), 46-59.
- Payne, B. R., & Stine-Morrow, E. A. L. (2017). The effects of home-based cognitive training on verbal working memory and language comprehension in older adulthood. *Frontiers in Aging Neuroscience*, 9, 256.
- Peng, P., & Fuchs, D. (2017). A randomized control trial of working memory training with and without strategy instruction: effects on young children's working memory and comprehension. *Journal of Learning Disabilities*, 50(1), 62-80.
- Penner, I. K., Vogt, A., Stöcklin, M., Gschwind, L., Opwis, K., & Calabrese, P. (2012). Computerised working memory training in healthy adults: a comparison of two different training schedules. *Neuropsychological Rehabilitation*, 22(5), 716-733.
- Persson, J., & Reuter-Lorenz, P. A. (2008). Gaining control: training executive function and far transfer of the ability to resolve interference. *Psychological Science*, 19(9), 881-888.
- Posner, M., & Rothbart, M. (2005). Influencing brain networks: implications for education. *Trends in Cognitive Sciences*, 9(3), 99-103.
- Prince, M., Wimo, A., Guerchet, M., Ali, M., Wu, Y., & Prina, M. (2015). *World Alzheimer report 2015: the global impact of dementia*. London. Retrieved from <https://www.alz.co.uk/research/WorldAlzheimerReport2015.pdf>.
- Rebok, G. W., Carlson, M. C., & Langbaum, J. B. S. (2007). Training and maintaining memory abilities in healthy older adults: traditional and novel approaches. *Journal of Gerontology - Series B: Psychological Sciences and Social Sciences*, 62B(1), 53-61.
- Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging*, 26(4), 813-822.
- Sacco, R. G. (2013). Re-envisioning the eight developmental stages of Erik Erikson: the Fibonacci life-chart method (FLCM). *Journal of Educational and Developmental Psychology*, 3(1), 140-146.
- Salthouse, T. A. (1994). The aging of working memory. *Neuropsychology*, 8(4), 535-543.
- Salthouse, T. A. (2009). When does age-related cognitive decline begin. *Neurobiology of Aging*, 30(4), 507-514.
- Salthouse, T. A. (2012). Consequences of age-related cognitive declines. *Annual Review of Psychology*, 63, 201-226.
- Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: common principles in three paradigms suggest new concepts for training. *Psychological Science*, 3(4), 207-217.
- Schaie, K. W., Willis, S. L., & Caskie, G. I. (2004). The Seattle longitudinal study: relationship between personality and cognition. *Aging Neuropsychology and Cognition*, 11(2-3), 304-324.
- Schooler, C. (1999). *The workplace environment: measurement, psychological effects, and basic issues*. In S. L. Friedman & T. D. Wachs (Eds.), *Measuring environment across the life span* (pp. 229-246). Washington, DC: American Psychological Association.
- Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? a meta-analysis including training conditions as moderators. *Educational Psychologist*, 50(2), 138-166.
- Schwarb, H., Nail, J., & Schumacher, E. H. (2016). Working memory training improves visual short-term memory capacity. *Psychological Research*, 80(1), 128-148.
- Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, 5, 772.
- Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Does working memory training generalize?. *Psychologica Belgica*, 50(3-4), 245-276.
- Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. (2016). Do "brain-training" programs work?. *Psychological Science in the Public Interest*, 17(3), 103-186.
- Singh-Manoux, A., Kivimaki, M., Glymour, M. M., Elbaz, A., Ferrie, J. E., & Dugravot, A. (2012). Timing of onset of cognitive decline: results from Whitehall II prospective cohort study. *BMJ*, 344, 1-8.
- Soederberg Miller, L. M., & Lachman, M. E. (2000). Cognitive performance and the role of control beliefs in midlife. *Aging, Neuropsychology, and Cognition*, 7(2), 69-85.
- Sperling, R. A., Aisen, P. S., Beckett, L. A., Bennett, D. A., Craft, S., Fagan, A. M., ... Phelps, C. H. (2011). Toward defining the preclinical stages of Alzheimer's disease: recommendations from the National Institute on Aging-

- Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & dementia*, 7(3), 280-292.
- Stern, Y. (2002). What is cognitive reserve? theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, 8(3), 448-460.
- Sternberg, R. J., Grigorenko, E. L., & Oh, S. (2001). *The development of intelligence at midlife*. In M. E. Lachman (Ed.), *Handbook of midlife development* (pp. 217-247). New York: Wiley.
- Stone, J. M. (2015). *How does practice affect working memory? The efficacy of adaptive-difficulty working memory training programs* (Doctoral dissertation). Lancaster University, Lancaster, England.
- Sutter, C., Zöllig, J., & Martin, M. (2013). Plasticity of verbal fluency in older adults: a 90-minute telephone-based intervention. *Gerontology*, 59(1), 53-63.
- Swanson, H. L. (2015). Cognitive strategy interventions improve word problem solving and working memory in children with math disabilities. *Frontiers in Psychology*, 6, 1099.
- Takeuchi, H., Taki, Y., & Kawashima, R. (2010). Effects of working memory training on cognitive functions and neural systems. *Reviews in the Neurosciences*, 21(6), 427-449.
- Thompson, T. W., Waskom, M. L., Garel, K. L. A., Cardenas-Iniguez, C., Reynolds, G. O., Winter, R., ... Gabrieli, J. D. E. (2013). Failure of working memory training to enhance cognition or intelligence. *PLoS One*, 8(5), 1-15.
- Turley-Ames, K., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language*, 49(4), 446-468.
- Verhaeghen, P., Cerella, J., & Basak, C. (2004). A working memory workout: How to expand the focus of serial attention from one to four items in 10 hours or less. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30(6), 1322-1337.
- von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: a review. *Psychological Research*, 78(6), 803-820.
- Waris, O., Soveri, A., & Laine, M. (2015). Transfer after working memory updating training. *PLoS One*, 10(9), 1-19.
- Wilkinson, A. J., & Yang, L. (2016). Inhibition plasticity in older adults: practice and transfer effects using a multiple task approach. *Neural Plasticity*, 2016.
- Willis, S. L., & Belleville, S. (2016). *Cognitive training in later adulthood*. In K. W. Schaie & S. Willis (Eds.), *Handbook of the psychology of aging* (pp. 219-243). London and San Diego: Academic Press.
- Willis, S. L., & Schaie, K. W. (2005). Cognitive trajectories in midlife and cognitive functioning in old age. *Middle Adulthood: A Lifespan Perspective*, 243-276.
- World Health Organization. (2015). *Dementia: a public health priority*. Retrieved from <https://doi.org/ISBN 9789241564458>
- Yaffe, K., Kanaya, A., Lindquist, K., Simonsick, E. M., Harris, T., Shorr, R. I., ... Newman, A. B. (2004). The metabolic syndrome, inflammation, and risk of cognitive decline. *JAMA*, 292(18), 2237-2242.
- Zimprich, D., & Mascherek, A. (2010). Five views of a secret: does cognition change during middle adulthood?. *European Journal of Ageing*, 7(3), 135-146.
- Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2013). Working memory training and transfer in older adults: effects of age, baseline performance, and training gains. *Developmental Psychology*, 50(1), 304-315.

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 적절한 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 작업기억 과제로 이루어진 10 회기의 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 치료 후 진전($p < .05$)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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