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# Impact of Brain Training Activities on Working Memory and Age Related Differences: A Randomized Controlled Trial

## ABSTRACT

### Background & Aims

Working Memory is a set of information on which an individual plan actions. It forms a productive basis for accomplishing complex activities that require reasoning, learning, understanding and is classified into three domains; attention, executive function and short-term memory. Since, memory declines with increasing age it is predictive that training interventions can improve working memory of adults.

### Methodology

A Randomized controlled trial included undergraduate students between 18–24 years of age from different universities in Karachi. The participants were divided in two groups. Group-A performed basic manual brain training activities while group-B performed computer and mobile based training activities. Data was collected by using Working memory questionnaire (WMQ), reliability of scale has been assessed by Cronbach's alpha on 30 items of scale and was 0.89.

### Results

A total of 300 participants were included in the study divided into Group-A (n=150) and Group-B (n=150) with 21.5±1.62 and 21.9±1.66 mean age respectively. The pre-intervention total working memory score of group-A is 65.6±5.72 of group-B is 64.9±6.13. Post-intervention total working memory score of group A is 66.9±6.11 and of group B is 66.92±6.99.

### Conclusion

Working memory is malleable through advanced training in the post-intervention group and is strongly predictive of individual performance on different cognitive measures. Thus, training, strategy use and learning styles could be emphasized for a better adult generation.

### Keywords

Working memory, Attention, Short term storage, Executive functions, Cognition.

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# INTRODUCTION

Working Memory (WM) is viewed as an "interface" between knowledge and action[1]. It is a set of information on which an individual plans action. A well-functioning working memory forms a productive basis for accomplishing many complex activities that require reasoning, learning and understanding. It is also intricately linked to attention and other cognitive processes. It is classified into three domains namely; attention, executive function and short-term memory. Attention is defined as the ability to focus and maintain data about goals and to reduce distractions[2]; executive functioning is defined as observing and managing continuing thoughts and actions[3]; storage, is defined as conservation of task relevant information in conjunction with its processing and recovery. Storage capacity is also described as theoretical short-term memory (STM) of an individual[1]. Passive storage is the information available for a limited time period, irrespective of any optional, voluntary or mnemonic strategies, while active storage depends on mnemonic processes, and is a supplementation of passive storage[2]. Working memory capacity is an essential constituent of executive functioning and cognitive control, and a strong predictor of efficient multitasking. Neuroimaging studies reveals that the brain is less activated during complex multitasking, however as the task difficulty increases, a usual physiological pattern of additional neural recruiting is seen[4]. According to neuroscientific researches, both genders hinge on distinct brain pathways to accomplish same tasks[5]. Working memory processes include frontoparietal brain regions, principally the prefrontal, cingulate, and parietal cortices. Sub-cortical regions have known to have a definite role in adjustment and adaptation of information received, and is modulated by anterior cingulate cortex which functions as an attention manager. Discernment of these actions is appraised by parietal cortex, whereas encoding of data is initiated by caudate and thalamus. The parietal lobules monitor retrieval phase, and Medial thalamus is liable for maintenance stage[6]. It is evident that volume of white matter influences WM and processing speed predominately in frontoparietal, corpus callosum and posterior temporal lobe of brain. Researchers also investigated the relationship of gray matter and intelligence, governed by genetic factors[7], however, they have not discussed WM and the three domains; attention, STM, and executive function explicitly. Working memory applies to many contexts in daily life; whether it is influenced by sex differences or not, is an interesting topic to implement various working memory training protocols in different capacities may it be academic, professional or social life. WM performance is affected by several environmental factors as well such as; age, personality, environment, exercise, diet, and gender. It has been reported that men have an advantage in spatial working memory tasks in contrast to women having an advantage in verbal working memory because of their specificity of brain areas[8]; temporal lobe works for the retention and usage of verbal memory while occipital lobe works for visuo-spatial memory, which has been tested through Rey Auditory Verbal Learning Test (RAVLT) in different studies and showed higher percentage for verbal memory in women and visuo-spatial memory in men[9,10]. According to a study, women have a higher response rate, while men have higher accuracy rate in attention specific tasks. In memory tasks, including FNAME (Face Name Associative Memory Exam) and SRT (Situation Reaction Test), women outperformed men significantly[11]. Sex differences in CPT (continuous performance task), proved males to be risk takers, exhibiting higher rate of impulsivity, depicting stronger executive functioning than females[12]. Brain related anatomical differences among both genders were evaluated to determine cognitive abilities and were assessed by programmed cognitive test battery. The results did not show any significant difference in attention and memory between both genders[11]. In contrast, another study applied brain map database with the results showing strong evidence for gender differentiated working memory of females with more activated limbic brain structures including hippocampus and amygdala than males who have more developed parietal brain regions[5].Different aging studies have shown that working memory is one of the several cognitive functions that decline with increasing age. It is also evident that training through different interventions can have a positive impact on working memory which not only leads to improvements on the trained tasks but also causes improvements in other task based performances of participants which were not included in training even[34]. Owing to the modernization of education and technology with cultural changes and adaptations along with emerging demands and concepts regarding hormonal effects and brain differences, there is an essential need to reevaluate the impact of training on working memory of young adults. Therefore, the objective of this study is to determine the effectiveness of the brain training interventions towards working memory performance of undergraduate young adult students as well as to determine the working memory scores between different age groups of students that received a different intervention. Our results are compared with manual brain training intervention group which served as a control group. The study will lead to several implications and strategies benefiting populations and ages to improve their working memory.

## METHODOLOGY

### Study Setting
Data was collected from undergraduate students of different universities in Karachi.

### Target Population
Undergraduate students of age 18-24 years

### Study Design
Randomized controlled trial (RCT)

### Sample Size
Sample size of 300 was calculated using open EPI software. Participants were allocated into two groups; Group-A (n=150) and group B (n=150) through computer-based randomization.

### Sampling Technique
Simple random sampling

### Inclusion Criteria
Healthy undergraduate students of age 18-24 years[21]

### Exclusion Criteria
- Any psychiatric or neurological disorder[22].
- Use of psychiatric drugs, alcohol[23, 24].
- Excessive sport activities, i.e. > 3 times per week[25].
- Smokers[26].
- Any chronic, long-term disease[27].

### Data Collection Tool
Working memory questionnaire (WMQ) includes three different domains with 30 questions for each domain. The first domain is the short term storage which is the ability to store and maintain information for a short period of time. The second domain is attention including the questions on distractibility, mental activity, mental slowness, fatigue and dual task processing. The third domain is executive functioning which counts on decision making, planning ahead and strategic planning as well. The reliability of the scale has been assessed by measuring Cronbach’s alpha on 30 items of the WMQ scale. Cronbach’s alpha was 0.89 for healthy controls depicting good reliability of the questionnaire. Each question will be scored on a 5-

point Likert-type scale that ranges from 0 (no problem at all) to 4 (very severe problem in everyday life). Three sub scores will be computed and maximum score is 40 for each domain whereas total score is 120. Higher scores correspond to more difficulties and complain[28].

## Data Collection Procedure

Total 300 participants were enrolled in the study (150 male and 150 female) after obtaining written informed consent. An interview was conducted by researcher to inquire questions from the working memory questionnaire. The study comprises of two groups; Group A (n=150) which is the control group and group B (n=150) which is the experimental group.

## Intervention

### Group-A

The participants of group-A performed basic manual brain training activities which includes gaming activities such as word puzzles, cross words, scrabble, sudoku, and chess. The intervention was provided thrice a week, 1 hour each session for three consecutive months. Working memory of participants was evaluated after intervention through WMQ.

### Group-B

The participants of group-B performed computer and mobile based brain training activities which includes mobile gaming, play station, mind games, online puzzles. The intervention was provided thrice a week, 1 hour each session for three consecutive months. Working memory of participants of both groups was evaluated before and after intervention through WMQ.

## Statistical Analysis

Data will be analyzed using SPSS version 20. Qualitative variables are presented as mean ± Standard deviation. Pre and post mean differences were evaluated through paired T-test. The significant P value was <0.05.

## Ethical Consideration

Participants included in this research will not be subjected to harm in any ways. Consent will be obtained from each participant prior to data collection. Participants will have the right to withdraw from the study at any point. No compensation in any ways shall be made. Confidentiality of the data and anonymity of participants will be ensured. Deception and/or exaggeration of research objectives are avoided. Any other communication related to this will be done by sincere means.

## RESULTS

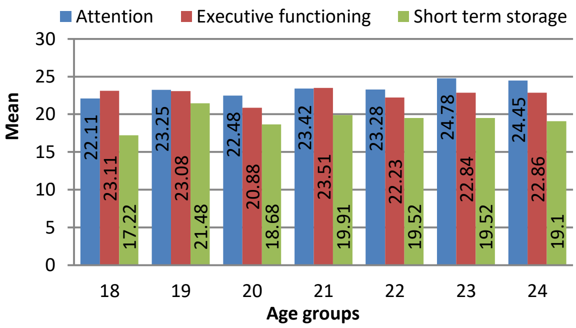
A total of 300 participants were included in the study divided into Group-A (n=150) and Group-B (n=150) with 21.5±1.62 and 21.9±1.66 mean age respectively with the highest age range reported that is 23 years (Figure 1). The demographics of the participants are presented in Table 1.

**Table 1: Demographics of the study participants**

| | Group-A (n=150) Mean±S.D | Group-B (n=150) Mean±S.D |
|---|---|---|
| **Age (years)** | 21.5±1.62 | 21.9±1.66 |
| **Gender** | 75 Males<br>75 Females | 75 Males<br>75 Females |

Mean scores of working memory domains were significantly variable in each age group. Highest level of attention score in pre-intervention group was found in age group of 23 years while the lowest score was of age group of 18 years. Executive functioning in pre-intervention group was found to be highest in age group of 21 years and lowest in the age group of 20 years. Short term memory storage in pre-intervention group was found to be lowest in age group of 18 years and highest in age group of 23 years (Figure 1).

Figure 1: Mean WM scores in different age groups among the Pre-intervention group




The pre-intervention total working memory score of group-A is 65.6±5.72 of group-B is 64.9±6.13. Post-intervention total working memory score of group A is 66.9±6.11 and of group B is 66.92±6.99.

**Table 2: Within the Group Analysis of Group-A and Group-B**

| Outcome Measures | | Group-A | Group-B |
|---|---|---|---|
| **Attention** | **Pre** | 24.6±7.12 | 24.71±6.41 |
| | **Post** | 25.56±8.11 | 26.99±7.11 |
| **Executive Functioning** | **Pre** | 22.99±5.11 | 23.11±5.89 |
| | **Post** | 23.99±6.21 | 24.981±6.19 |
| **Short term storage** | **Pre** | 24.66±5.12 | 24.12±6.77 |
| | **Post** | 25.77±6.18 | 26.34±7.81 |
| **Total Working Memory** | **Pre** | 64.8±5.14 | 65.21±5.66 |
| | **Post** | 66.9±6.11 | 66.92±6.99 |

***p<0.05***

The mean scores of working memory in group-A before the intervention is 64.8±5.14 which is low as compared to post-intervention score of 66.9±6.11. Whereas, the mean scores of working memory in group-B before the intervention is 65.21±5.66 which is low as compared to the post-intervention group with score of 66.92±6.99. The differences in mean scores of working memory between Group-A and Group-B as analyzed after 3 months of intervention is 66.9±6.11 and 66.92±6.99 respectively. In comparison between the groups, it is found that post-intervention working memory scores of Group-B are higher and improved as compared to group-A. Whereas, in comparison within the groups, it is found that post-intervention scores are higher than the pre-intervention scores for both the groups.

## DISCUSSION

In the present study, differences in working memory scores of students before and after brain training intervention were determined, with respect to three domains of working memory; Attention, Short term storage and Executive functioning. According to results obtained, there is insignificant difference in working memory in the pre-intervention group A and B both where as higher mean scores are observed after three consecutive months of brain training activities. However, when the individual domains of working memory were analyzed, it is observed that higher mean scores of attention and short-term storage are found as compared to mean score of executive functioning after the intervention. In a study conducted by Gabriel and Sridevi, 2016 showed that females have better short-term memory due to the active hippocampus which is boosted by hormone Estrogen[29]. Whereas a study by Solianik 2016, concluded that females have decreased attention scores and short-term memory scores as compared to males[11]. The results of the study show that the differences in executive functioning score before and after intervention is not vast enough to make a conclusion based on gender differences thus, indicating to the fact that executive functioning requires more brain training for longer time span irrespective of gender. According to a research conducted by Hill, et al., there is effect of gender on the impact of brain training activities which may be due to the females having more activated limbic system and prefrontal regions, which are responsible for emotions and memory, along with behavior, speech and logical reasoning[5]. The brain areas which includes parietal areas; the inferior and superior parietal lobe, precuneus are responsible for a variety of complex functions, such as, information processing, spatial orientation, recognition and association. Training of these brain areas can provide improvements in working memory[14].In this study, technology based brain training activities achieved higher scores in all three domains of working memory as compared to the manual brain training activities performed. According to another study, there are higher mean values in image segmentation, which is memorizing directions with the help of images of infrastructure and environment when brain training is done using technologies[16]. There is a significant difference of working memory across the different age groups[16]. Our results are inconsistent with the results of a study conducted by Vallat-Azouvi, et al which shows significant correlation of working memory with age and gender[28]. The highest mean score of Attention was found among age group of 23 years (24.78), while the lowest score was of age group of 18 years (22.11). Our results showed that age group of 21 years exhibited highest Executive functioning scores (23.51), while that of 20 years scored lowest with 20.88. Consequently, age group of 23 years displayed the greatest short-term memory score (21.86), while age group of 18 years only scored 17.22. These results reveal that the working memory scores increase variably with age among both genders. Cross-sectional data from a study by Eriksson et al, provided results on stability in working-memory performance between 20 - 50 years of age and an apparent decline from 55 - 60 and from 75 - 80 years of age. It is also stated that, age related differences in working memory exists less on simpler maintenance tasks as compared to more complex tasks that required both manipulation and maintenance of information particularly in older 75 – 80 years age group[30]. Some studies have suggested that it takes less time for individuals to develop full working-memory capacity. Gathercole et al. examined a large group of children of age group 4 - 15 years and observed a linear increase from 4 - 14 years that tapered off between 14 - 15 years. Similarly, in another longitudinal study including healthy adolescents, working memory markedly increase from 6 to about 15 years of age, flattening thereafter between 15 to 22 years of age[31]. A study by Cowan 2017, discusses the multiple factors that could affect the working memory performance with development[2]. Firstly, large quantities of knowledge cause an increase in visual array and spoken list of memory capacity. Secondly, as a person ages, they get better at filtering out irrelevant data, making more brain space for relevant information storage[32]. Another factor which could possibly affect working memory performance was the continuous practice of encoding items which develops a better concept recognition and memory. Thus, an increase in age is possibly related to a decline in working memory. Another study by Rhodes and Katz 2017, associates the phenomenon of neural plasticity to increase the working memory capacity in students[33]. Younger brains are more sensitive and responsive to experiences, which then declines with age. Thus, working memory capacity is limited and may only hold a small amount of information (approximately 3 or 4 simple items) but the individual memory capacity can be increased through practicing and learning bits of information and repeated training. Working memory functioning, changes across the entire lifespan of an individual and can be modified by training[30].

## CONCLUSION

An individual's working memory capacity is strongly predictive of their performance on an extensive variety of high level cognitive measures, such as abstract reasoning, fluid intelligence, language abilities, mathematics inclusive of their academic performance; cultural upbringing, training and schooling experience are relevant for executive task performance later in life as well indicating that working memory is malleable through training and strategy instruction. Our results show that training interventions can improve working memory among adults.

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