Research Paper

# Investigating the Effectiveness of Working Memory Training in Reducing Cognitive Failures in Individuals With Strok

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## ABSTRACT

**Objective:** Stroke is a brain injury caused by damage to the blood vessels in the central nervous system, often resulting in cognitive impairments, including memory issues. With the increasing number of stroke survivors, the demand for effective rehabilitation services is also increasing. This study evaluates the effectiveness of working memory training in mitigating cognitive failure and memory difficulties in stroke patients.

**Methods:** This quasi-experimental study involved 36 stroke patients from medical centers in Urmia City, Iran, and was conducted in October 2023. The participants were randomly assigned to two groups as follows: An experimental group and a control group. The experimental group received a total of ten 60-min training sessions twice a week, while the control group participated in the same number of sessions, focusing on physical exercise without any specific intervention. Data collection tools included the cognitive failures questionnaire, which evaluates the frequency of cognitive lapses in daily activities, such as attention, memory, and action failures, and the Wechsler memory scale, which assesses different aspects of memory performance. Both groups underwent pre-tests and post-tests, and the data were analyzed using the SPSS software, version 26, with a significance level of $P \leq 0.05$.

**Results:** Before the intervention, no significant differences in memory span or cognitive failure were observed. However, post-intervention results indicated a significant improvement in the experimental group ($P \leq 0.05$).

**Conclusion:** Working memory rehabilitation significantly enhanced cognitive functioning and memory in stroke patients.

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## Highlights

- Working memory training significantly improved memory performance and reduced cognitive failures in stroke patients.

- The intervention group showed notable post-treatment gains compared to the control group (P≤0.05).

- The cognitive failures questionnaire and the Wechsler memory scale effectively measured changes in cognitive functioning.

- Ten sessions of targeted cognitive training led to meaningful rehabilitation outcomes for stroke survivors.

## Plain Language Summary

Stroke is a neurological disorder caused by a disruption in the brain's blood flow, which can damage or destroy brain cells. It is the second leading cause of death worldwide and a major contributor to long-term disability. Cognitive problems such as forgetfulness, reduced attention, and memory difficulties are common after stroke and significantly affect daily life and independence. This study investigated whether working memory training could help improve mental performance in stroke survivors. A total of 36 stroke patients participated and were randomly divided into two groups. The experimental group received 10 sessions of working memory training, while the control group only took part in physical activities. Cognitive performance was measured before and after the intervention using the cognitive failures questionnaire and the Wechsler memory scale. The results showed that patients in the memory training group had significantly better memory and fewer everyday mental mistakes than the control group (P≤0.05). Accordingly, working memory rehabilitation can be an effective method to support cognitive recovery in stroke patients and may be recommended as part of post-stroke care.

## Introduction

Stroke is a major neurological disorder and the second leading cause of death worldwide, as well as the third leading cause of combined mortality and disability among adults (Feigin et al., 2021). Recent data suggest that one in four individuals over the age of 25 years will experience a stroke during their lifetime (Feigin et al., 2022). Stroke occurs when the brain's blood supply is interrupted, commonly due to a blocked blood vessel, which can result in clot formation. This blockage may lead to vessel rupture and bleeding, causing brain cell death due to oxygen deprivation (Kuriakose & Xiao, 2020). Previously, the World Health Organization (WHO) defined stroke as a set of clinical symptoms that rapidly lead to death or impairment of focal (or global) brain function lasting more than 24 h, with no apparent cause other than vascular origin (Aho et al., 1980). However, the American Heart Association and the American Stroke Association later expanded this definition to include silent infarctions and silent hemorrhages (Coupland et al., 2017). While a substantial body of research focuses on motor impairments caused by stroke, its impact extends far beyond physical symptoms.

Stroke often leads to emotional, social, cognitive, and financial consequences (Viktorisson et al., 2022). Among the most prevalent post-stroke complications are cognitive impairments, particularly memory problems and everyday cognitive failures, affecting nearly two-thirds of stroke survivors and significantly influencing their daily and professional functioning (Liao et al., 2020; Donnellan & Werring, 2020). These impairments contribute to reduced quality of life, increased dependence, and substantial healthcare costs, posing a heavy burden on patients, families, and healthcare systems (Draaisma et al., 2018; Rost et al., 2022).

Cognitive failure is a type of cognitive impairment that refers to making mistakes based on cognition while performing simple tasks that a person should normally be able to do without making mistakes (Martin, 1983; Voortman et al., 2019), such as forgetting an appointment or not paying attention to traffic signs (Könen & Karbach, 2018). Cognitive failure refers to all types of failure in the cognitive system, such as lack of attention, mind wandering, memory failure, and failure in action. (Unsworth et al., 2012). Research has indicated that even minor strokes and transient ischemic attacks can result in long-lasting cognitive impairments regardless of the location of the infarction (Marsh et al., 2022; Hbid et al., 2021; Morsund et al., 2019). These failures are found in more than 70% of stroke survivors (Rost et al., 2022) and hurt functional abilities, quality of life, motor improvement, and the ability to engage in rehabilitation after stroke (Loetscher et al., 2019).

Memory is the ability to encode, store, and retrieve information (Sternberg & Sternberg, 2012), and any disturbance in these processes can cause problems. Memory problems are common after conditions, such as severe head injury, progressive degenerative disease, or stroke (Wilson & Moffat, 2014). Meanwhile, 77% of people with stroke suffer from memory problems (Stroke Association, 2017), which have negative effects on these patients and their families (Tang et al., 2020).

Various interventions have been used to address the cognitive deficits, including computerized cognitive training, occupational therapy, and remote memory rehabilitation. However, most of these methods suffer from limited or inconclusive evidence regarding their effectiveness (Niemeijer et al., 2020; Gibson et al., 2022; Hara et al., 2021; Lawson et al., 2020). In particular, few studies have implemented structured, strategy-based cognitive rehabilitation programs specifically targeting working memory (WM), despite its central role in higher-order cognitive functioning (Hahn & Rose, 2020). This gap is particularly concerning given the growing number of stroke survivors and the increasing demand for targeted rehabilitation interventions (Stinear et al., 2020). This growing need for cognitive rehabilitation is particularly pressing in countries like Iran, where the annual cost of care per stroke patient is estimated to be around $12000, placing a significant burden on both families and the healthcare systems (Movahed et al., 2021). In the United States, post-stroke rehabilitation accounts for the largest share of related healthcare costs (Rajsic et al., 2019). Additionally, prolonged recovery, limited therapeutic progress, and feelings of helplessness can contribute to depression, decreased motivation, cognitive decline, and increased dependence on caregivers (Ezema et al., 2019). Therefore, identifying effective and evidence-based treatments is essential to reducing the emotional and economic toll of stroke on patients and caregivers. Among various approaches, cognitive rehabilitation, particularly interventions targeting WM, has shown promise. However, the effectiveness of WM training remains a topic of ongoing debate (Morrison & Chain, 2011; Shipstead et al., 2012; Melby-Lervåg & Hulme, 2013; Rode et al., 2014; Au et al., 2016). While some findings suggest potential cognitive benefits (Au et al., 2015; Karbach & Verhaeghen, 2014), others report limited transfer effects and question the generalizability of the improvements (Melby-Lervåg & Hulme, 2016). Despite numerous training studies and meta-analyses, a clear consensus is lacking (Matysiak et al., 2019). WM plays a key role in attention control, reasoning, learning, and memory integration. Systematic reviews have shown that stroke survivors often experience moderate-to-severe deficits across all WM components, and that natural recovery over time is typically minimal (Lugtmeijer et al., 2021). Cognitive rehabilitation that targets WM capacity, through structured exercises, mnemonics, and both internal and external strategies, has the potential to improve memory performance and reduce functional cognitive failures (Novick et al., 2019; Das Nair et al., 2016; Sohlberg et al., 2022).

Nevertheless, few quasi-experimental studies have investigated whether WM-based training can yield measurable benefits in real-life memory performance and daily cognitive functioning in stroke populations. Moreover, there is a lack of such studies within the context of Middle Eastern healthcare systems, including Iran, where rehabilitation services may be under-resourced or less specialized.

Accordingly, the present study evaluates the effectiveness of a structured WM training protocol in reducing cognitive failures and memory problems in individuals recovering from stroke. This was achieved through a quasi-experimental design using both the cognitive failures questionnaire and the Wechsler memory scale to assess pre- and post-intervention outcomes.

## Materials and Methods

### Participants and design

The present study employed a quasi-experimental clinical trial design, featuring both pre-test and post-test phases with a control group. The statistical population consisted of all stroke patients referred to medical centers in Urmia City, Iran, in October 2023. The sample size was determined based on various factors, such as population size, population heterogeneity, research design, and practical constraints. According to Cohen et al. (2002), a minimum of 15 participants per group is considered adequate for causal-comparative and experimental research designs. Accordingly, a total of 36 stroke patients (22 females, 14 males) were selected through convenience sampling, based on specific inclusion and exclusion criteria. The researcher obtained access to the list of stroke patients who had been admitted to the selected medical centers in 2023 through formal collaboration with the research and medical records units of those centers. Access was granted under the supervision of the ethics committee and was solely used for participant selection in this study. All patient data remained confidential, and only eligible individuals were contacted for consent and participation. Eligible participants were selected based on the inclusion and exclusion criteria, and informed consent was obtained from those who agreed to participate. In total, 36 stroke patients were enrolled and randomly assigned to either the experimental (n=18) or control group (n=18). All ethical guidelines and confidentiality standards were strictly observed throughout the sampling process. The participants in both groups completed pre-test and post-test assessments using two standardized tools as follows: 1) CFQ, which consists of 25 items measuring lapses in memory, attention, and action in daily life, and 2) the Wechsler memory scale-revised (WMS-R), specifically focusing on forward span, backward span, and total memory span subscales.

The pre-test was administered one week before the intervention, and the post-test one week after its completion. Both assessments were conducted in a quiet clinical setting by a trained psychologist under the supervision of the researcher (Figure 1).

## Inclusion and exclusion criteria

The inclusion criteria were as follows: a confirmed diagnosis of stroke based on neurological examination and brain imaging; willingness to participate in the study, with signed informed consent; having no history of cognitive, neurological, or memory impairments before the stroke, based on medical records and screening interview; and having the ability to read and write.

Meanwhile, the exclusion criteria were as follows: Withdrawal of consent during the intervention; incomplete assigned educational tasks; absence from more than two intervention sessions; concurrent enrollment in other treatment programs (to control for potential confounding variables, participants were instructed not to engage in any concurrent cognitive or psychological rehabilitation programs during the intervention period). Treatment history and current therapy status were assessed through interviews and medical record reviews before enrollment. Participation in general physical rehabilitation programs (such as physiotherapy) was permitted, provided they did not involve cognitive training components.

## Study procedures

### Demographic information

Demographic information was collected using a combination of open and closed questions and included age, sex, marital status, education level, dominant hand, type of stroke, duration after stroke, and hemisphere.

### Cognitive failure questionnaire

CFQ, developed by Broadbent et al. in 1982, is a self-report questionnaire used to measure a person's cognitive failures in their daily lives. The questionnaire

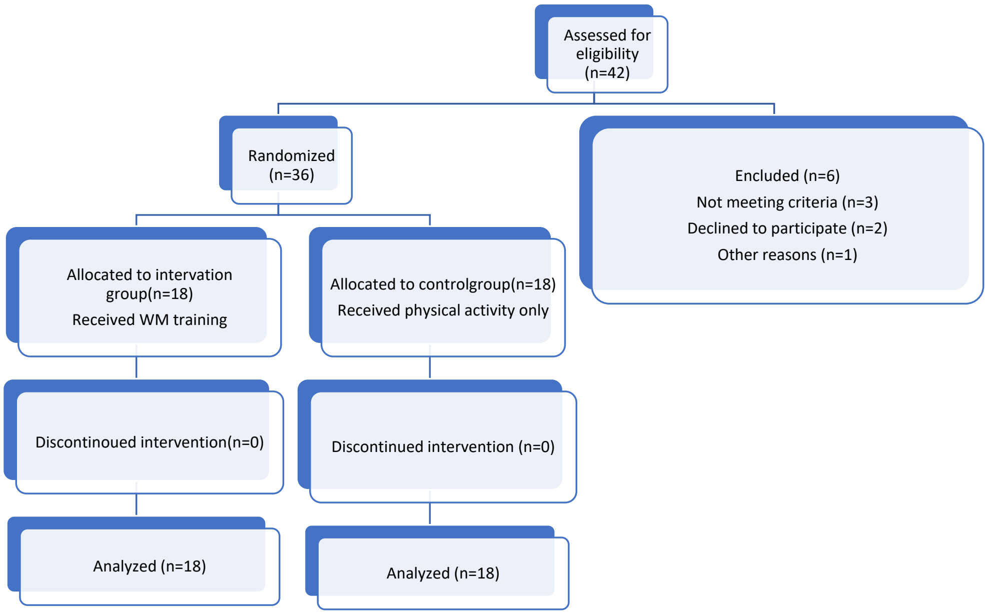


**Figure 1.** Consort flow diagram of participants recruitment, allocation, and analysis

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includes 25 items and four subscales, including distractibility (1, 3, 8, 10, 11, 12, 17, 18, 21), memory problems (13, 15, 19, 22, 23, 24, 25), blunders (2, 4, 5, 6, 9, 14, 16), and failure to remember names (7, 20). The distractibility factor refers to the perceptual aspects of tasks in which attention is diverted. The memory factor included questions that measured memory deficits and forgetfulness. Bunders refer to errors made during the execution of work and are related to physical accidents. The forgetting factor also included questions related to the memory of people's names. The subjects were scored based on a 5-point Likert scale (never=0, always=4). The scores ranged from zero to 100. A high score indicates an increased propensity for cognitive failure (Wallace et al., 2002). The Cronbach α coefficient and the internal consistency of this questionnaire were reported as 0.91 and 0.94, respectively (Wallace & et al., 2003). The test, re-test reliability of the questionnaire was 0.71 (Bridger et al., 2013). Linden et al. (2005) reported the internal consistency of the questionnaire as α=0.93. In Iran, Yazdi et al. (2015) also obtained an internal consistency coefficient of 0.83 using the Cronbach α coefficient for the entire questionnaire, and a test, re-test reliability coefficient of 0.77 with a one-month interval. In the current study, the Cronbach α coefficient was 0.77, indicating the validity of the tool.

### Wechsler memory scale

The Weschler digit span subscale is one of the main tools developed to measure the span of WM. The test is composed of two parts, namely forward and backward (reverse) memory span tests. The forward test involves repeating a set of digits (ranging from 3 to 9 digits) exactly as they are presented. The backward test requires repeating the same set of digits, but in reverse order. The number of digits in the set increased by one for each successful trial until the participant failed to repeat the digits correctly twice in a row (Conklin et al., 2000). The internal consistency reliability of the digit span subscale, which includes Digit span forward, backward, and sequencing, was reported to be 0.93. This is based on a coefficient called the stratified coefficient α (Gignac et al., 2019). Alloway (2006) obtained the direct and reverse numerical test, re-test reliability of 0.84 and 0.60, respectively. In Iran, Saed et al. (2008) obtained reliability coefficients using the Cronbach α for subscales ranging from 0.65 to 0.85 and for indices from 0.75 to 0.84. In the present study, the Cronbach α coefficient was 0.71, which demonstrates the validity of the measurement tool.

### Research method

After explaining the purpose and objectives of the study, participants provided written informed consent and completed a demographic questionnaire. Subsequently, a pre-test was conducted, and 36 subjects were randomly assigned to either the experimental or control group. The experimental group received a 10-session intervention, with each session lasting 60 min and held twice a week. In contrast, the control group attended sessions of equal number and duration, which consisted of supervised light physical activities, such as walking and stretching exercises, without any cognitive or psychological intervention. The intervention was inspired by principles from the Cogmed WM training, developed by Klingberg et al. (2002), and adapted based on prior protocols used in WM rehabilitation research. The program consisted of ten 60-min sessions over five weeks (two sessions per week). Each session included digit span tasks (forward and backward), visual-spatial memory exercises, such as recalling object locations or sequences of colored shapes, auditory memory tasks, and attention enhancement games with gradually increasing levels of difficulty (Table 1).

The training followed an adaptive difficulty principle; accordingly, task complexity was adjusted based on the participant's performance in real-time. All sessions were delivered by a licensed clinical psychologist in a distraction-free environment. The intervention also included verbal feedback, motivational reinforcement, and the use of memory strategies (e.g. chunking, rehearsal) to support metacognitive engagement.

Post-tests were conducted for both groups following the completion of the intervention. The pre-test was administered one week before the intervention, and the post-test one week after its completion. Both assessments were conducted in a quiet clinical setting by a trained psychologist under the supervision of the researcher.

### Data analysis

To analyze the data, descriptive statistics including Mean±SD, percentage, and frequency were used alongside inferential statistical methods appropriate to the study's hypotheses and research questions. Multivariate analysis of variance was applied after confirming the required assumptions using the Kolmogorov–Smirnov test for normality and the Levene test for equality of variances. All analyses were performed using the SPSS software, version 26, with the significance level set at P≤0.05.

**Table 1.** Summary of working memory training sessions in the experimental group

| Session | Duration | Main Content | Cognitive Focus |
|---|---|---|---|
| 1 | 60 min | Introduction to WM, explanation of goals, digit span (forward) | Sustained attention, basic WM |
| 2 | 60 min | Visual-spatial memory tasks (object-location recall) | Visual-spatial WM, mental organization |
| 3 | 60 min | Chunking strategies; digit span (backward) | Verbal WM strategies |
| 4 | 60 min | Dual task exercises with increasing load | Cognitive flexibility, selective focus |
| 5 | 60 min | Tasks with distraction and interference | Inhibitory control, selective attention |
| 6 | 60 min | Timed tasks using audio-visual sequences | Processing speed, cognitive coordination |
| 7 | 60 min | Logical reasoning task under WM load | Reasoning+working memory use |
| 8 | 60 min | Self-monitoring, reviewing strategies | Self-regulation, metacognitive control |
| 9 | 60 min | Integrative challenges in novel conditions | Transfer of training, problem solving |
| 10 | 60 min | Final review, consolidation, and real-life application | Functional generalization, performance boost |

WM: Working memory.

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## Results

### Descriptive findings

No participants were excluded or withdrew during the course of the study. Out of the 36 participants, 8 individuals (22.2%) were between 40 and 50 years old, 21 participants (58.3%) were aged 51–60 years, and 7 participants (19.4%) were aged 61 or older. Thus, the majority of participants were in the 51–60 years age range (Table 2).

Regarding gender, 22 participants (61.1%) were female, and 14 (38.9%) were male, indicating a predominance of female participants in the sample. In terms of marital status, 27 individuals (75.0%) were married, while 9 (25.0%) were single, suggesting that most participants were married.

As for educational background, 21 participants (58.3%) had not completed a high school diploma, 11 (30.6%) held a diploma, 2 (5.6%) had an associate degree, and 2 (5.6%) had a bachelor's degree or higher. These results demonstrate that the majority of participants had not obtained a formal academic degree.

In terms of handedness, 30 participants (83.3%) were right-handed, while 6 (16.7%) were left-handed. Most participants were therefore right-handed.

Regarding the type of stroke, 30 individuals (83.3%) had experienced an ischemic stroke, 3(8.3%) a hemorrhagic stroke, and 3(8.3%) a transient ischemic attack. The majority of participants had thus experienced an ischemic stroke.

As for the time since stroke onset, 25 participants (69.4%) had experienced a stroke within the last 1–3 months, 7 participants (19.4%) within 4–6 months, and 4 participants (11.1%) more than 6 months prior. Most strokes had occurred in the 1–3-month timeframe.

Finally, stroke location was predominantly in the right hemisphere, affecting 29 participants (80.6%), while 7 participants (19.4%) had experienced a stroke in the left hemisphere.

Due to the experimental nature of the study and limitations in sampling and intervention implementation, participants could not be matched based on demographic or clinical variables.

### First hypothesis: Rehabilitation based on WM is effective in reducing cognitive failures in individuals with stroke

The post-test Mean±SD scores for the experimental group were as follows: Distractibility=14.16±1.94; memory problems=10.83±1.75; blunders=12.66±2.40, failure to remember names=3.77±0.94; total cognitive failures=41.44±3.66 (Table 3).

**Table 2.** Frequency and percentages of demographic characteristics of participants

| Variables | | No. (%) | Density Frequency |
|---|---|---|---|
| Age (y) | 40-50 | 8(22.2) | 22.2 |
| | 51-60 | 21(58.3) | 80.6 |
| | ≥61 | 7(19.4) | 100 |
| | Total | 36(100) | |
| | 40-50 | 8(22.2) | 22.2 |
| Gender | Female | 22(61.1) | 61.1 |
| | Male | 14(38.9) | 100 |
| | Total | 36(100) | |
| Material Status | Married | 27(75.00) | 75.00 |
| | Single | 9(25.00) | 100 |
| | Total | 36(100) | |
| Education | No degree | 21(58.3) | 58.3 |
| | High School diploma | 11(30.6) | 88.9 |
| | Associate degree | 2(5.6) | 94.4 |
| | Graduate and Postgraduate | 2(5.6) | 100 |
| | Total | 36(100) | |
| Dominant hand | Right-handed | 30(83.3) | 83.3 |
| | Left hand | 6(16.7) | 100 |
| | Total | 36(100) | |
| Type of stroke | Ischemic | 30(83.3) | 83.3 |
| | Hemorrhagic | 3(8.3) | 91.7 |
| | Transient | 3(8.3) | 100 |
| | Total | 36(100) | |
| Duration after stroke (months) | 1-3 | 25(69.4) | 69.4 |
| | 4-6 | 7(19.4) | 88.9 |
| | >6 | 4(11.1) | 100 |
| | Total | 36(100) | |
| Hemisphere | Right | 29(80.6) | 80.6 |
| | Left | 7(19.4) | 100 |
| | Total | 36(100) | |

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**Table 3.** Descriptive indices Mean±SD of experimental and control groups in cognitive failures and their components

| Variables | Mean±SD | | | |
|---|---|---|---|---|
| | Control Group | | Experimental Group | |
| | Pre-test | Post-test | Pre-test | Post-test |
| Distractibility | 35.83±2.58 | 36.50±2.09 | 36.61±1.57 | 14.16±1.94 |
| Memory problems | 28.72±2.10 | 28.33±1.49 | 28.11±1.71 | 10.83±1.75 |
| Blunders | 28.61±3.10 | 28.27±2.51 | 28.55±1.91 | 12.66±2.40 |
| Failures to remember names | 8.38±0.916 | 7.33±0.970 | 8.05±0.937 | 3.77±0.942 |
| Total cognitive failures | 101.55±7.25 | 100.44±4.54 | 101.33±3.04 | 41.44±3.66 |

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There was a statistically significant difference between the experimental and control groups across all subscales of CFQ, including distractibility, memory problems, blunders, failure to remember names, and overall cognitive failures (P≥0.001; Table 4). Accordingly, WM training significantly reduced everyday cognitive failures in the experimental group. Therefore, the first hypothesis is supported.

### Second hypothesis: Rehabilitation based on WM is effective in improving memory in individuals with stroke

The post-test Mean±SD scores for the experimental group were as follows: Forward memory span=11.50±0.62; backward memory span=7.72±0.67; total memory span=19.22±0.81 (Table 5).

Table 6 demonstrates a significant difference between the experimental and control groups in forward, backward, and total memory span scores (P≤0.0001). The experimental group showed notable improvement across all memory span measures following WM training. These results confirm the second hypothesis, indicating that WM-based rehabilitation effectively enhances memory performance in individuals with stroke.

Overall, the findings support the effectiveness of WM-based rehabilitation in reducing cognitive failures and improving memory in stroke patients.

## Discussion

This quasi-experimental study investigates the effectiveness of WM training on cognitive failures in patients who had experienced a stroke. It was conducted using a pre-test, post-test design with a control group, including 36 stroke patients from medical centers in Urmia City, Iran, in October 2023. The results of statistical analysis indicated that WM training significantly reduced cognitive failures, such as distractibility, memory problems, blunders, and failure to remember names in the experimental group compared to the control group (P≤0.05). WM-based cognitive rehabilitation was effective in enhancing memory function and reducing cognitive lapses in stroke patients.

**Table 4.** Results of the multivariate analysis of covariance test on the indicators of cognitive failures and its components in the experimental and control groups

| Source | Dependent Variables | SS | Df | MS | F | P | Eta |
|---|---|---|---|---|---|---|---|
| Group | Distractibility | 3597.16 | 1 | 3597.16 | 831.48 | 0.000 | 0.965 |
| | Memory problems | 2198.48 | 1 | 2198.48 | 797.35 | 0.000 | 0.964 |
| | Blunders | 1837. 89 | 1 | 1837.89 | 382.00 | 0.000 | 0.927 |
| | Failures to remember names | 96.31 | 1 | 96.31 | 101.57 | 0.000 | 0.772 |
| | Total cognitive failures | 25455. 81 | 1 | 25455.81 | 1618.44 | 0.000 | 0.982 |

Abbreviations: SS: Sum of squares; Df: Degree of freedom; MS: Mean square.

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**Table 5.** Descriptive indices Mean±SD of the experimental and control groups in the wechsler memory test

| Variables | Mean±SD | | | |
|---|---|---|---|---|
| | Control Group | | Experimental Group | |
| | Pre-test | Post-test | Pre-test | Post-test |
| Forward memory span | 7.94±0.639 | 8.16±0.514 | 7.83±0.618 | 11.50±0.618 |
| Backward memory span | 5.11±0.582 | 5.11±0.676 | 4.83±0.618 | 7.72±0.669 |
| Total size | 13.03±0.639 | 13.27±0.958 | 12.66±0.766 | 19.22±0.808 |

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According to the findings, WM training can be considered a practical and effective cognitive intervention for stroke survivors. This approach may improve patients' attention and memory performance, which in turn can enhance their quality of life, support daily functioning, and reduce dependence on caregivers. These improvements may also help lower emotional distress and promote cognitive independence among patients in post-stroke recovery.

The present results align with previous research conducted by Johansson and Tornmalm (2012), Preiss et al. (2010), and Westerberg et al. (2007), all of whom reported a positive impact of WM training on everyday cognitive functioning. Johansson and Tornmalm (2012) found that WM training reduced patients' perceived cognitive difficulties in daily life. Preiss et al. (2010) demonstrated improved cognitive performance in large-scale interventions, and Westerberg et al. (2007) showed a significant decrease in symptoms of cognitive failure after WM training. However, the findings are not in line with those of Richter et al. (2015), who found no significant improvements following cognitive interventions.

Several possible explanations account for these findings. First, WM training may enhance cognitive performance through the acquisition of generalizable strategies that improve the organization and storage of information (Craik et al., 2007). Such cognitive strategies, once learned, can be transferred to novel tasks, particularly when the training involves complex cognitive skills (Gathercole et al., 2019).

Second, methodological considerations warrant attention. The reliance on self-report instruments may introduce confirmation bias, as participants might unintentionally provide responses that align with expected outcomes due to increased awareness or the Hawthorne effect. According to Preiss et al. (2010), self-report measures often show weak correlations with experimental methods, limiting the objectivity of reported cognitive changes. Peters (2022) emphasized that confirmation bias is a pervasive cognitive phenomenon, often independent of intelligence or motivation.

Third, differences in educational levels between the experimental and control groups may have influenced the results. Individuals with higher verbal and educational competence may be more attuned to recognizing and articulating changes in their cognitive functioning (Preiss, 2010).

Lastly, discrepancies between this study and Richter et al.'s (2015) may be attributed to differences in methodology. Richter et al. identified two key limitations in their study: 1) A brief interval between pre-test and post-test during which patients had limited exposure to everyday

**Table 6.** Results of the multivariate analysis of covariance test on the indicators of memory span and its components in the experimental and control groups

| Source | Dependent Variables | SS | Df | Ms | F | P | ETA |
|---|---|---|---|---|---|---|---|
| Group | Forward memory span | 92.38 | 1 | 92.38 | 269.75 | 0.000 | 0.903 |
| | Backward memory span | 58.96 | 1 | 58.96 | 125.77 | 0.000 | 0.797 |
| | Total size | 298.95 | 1 | 298.95 | 376.86 | 0.000 | 0.922 |

Abbreviations: SS: Sum of squares; Df: Degree of freedom; MS: Mean square.

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activities, and 2) The priming effect of pre-testing, which may have led to heightened awareness of certain cognitive lapses, thus inflating post-test scores.

Based on these findings, therapists and rehabilitation specialists are encouraged to incorporate WM training protocols into post-stroke treatment plans. Stroke patients often suffer from memory deficits and attention problems that affect their independence and social functioning. By targeting these areas, WM-based rehabilitation programs can promote neuroplasticity and enhance cognitive recovery. Moreover, providing patients with structured cognitive exercises may also foster their confidence, emotional regulation, and engagement in daily activities, ultimately contributing to a more comprehensive recovery process.

The results further revealed that WM training significantly improved direct (forward), reverse (backward), and total memory span scores in the experimental group compared to the control group. Therefore, the second hypothesis, that WM-based rehabilitation improves memory problems in stroke patients, was also supported.

These findings are congruent with previous studies by Richter et al. (2015), Raushanova et al. (2014), and Buschkuehl et al. (2008). For example, Richter et al. found that WM training enhanced word recall and improved prospective memory. Raushanova et al. (2014) demonstrated improvements in WM, auditory and spatial memory, and visual memory among young adults. Similarly, Buschkuehl et al. (2008) observed enhanced memory performance in trained participants immediately post-intervention.

The significant improvement observed in memory span following the intervention may be explained by the theoretical structure of WM. According to Baddeley's multicomponent model (2000), WM comprises a central executive and three subsidiary systems: The phonological loop, visuospatial sketchpad, and episodic buffer. These systems collectively support the temporary storage and manipulation of information, which is essential for various tasks, such as reasoning, attention, and recall. Previous literature has shown that stroke survivors often exhibit moderate-to-severe deficits in all WM subsystems (Lugtmeijer et al., 2021), which can hinder daily functioning and rehabilitation engagement.

By directly targeting and training WM through structured exercises, participants may have improved their ability to maintain and manipulate information, leading to better memory test performance. Furthermore, as WM capacity underlies various cognitive domains, enhancements in WM can result in near transfer effects to untrained tasks, supporting the ecological validity of such interventions (Buschkuehl et al., 2008; Novick et al., 2019). Moreover, the role of the therapist and the quality of the therapeutic alliance may also contribute to positive outcomes. Nejati (2023) emphasized the importance of therapist-related factors such as ethics, competence, adherence, and teamwork in determining the success of cognitive rehabilitation.

Individual differences among participants may have further influenced outcomes. Factors such as intrinsic motivation, cognitive engagement, baseline abilities, and personal beliefs about intelligence (Jaeggi et al., 2023) play a critical role in training effectiveness. Nejati (2023) also identified five learner-related factors, motivation, effort, expectations, individual variability, and family support, which collectively influence rehabilitation outcomes. Therapists must, therefore, tailor interventions to align with these personal and contextual variables to optimize cognitive rehabilitation.

## Conclusion

In summary, the findings of this study support the significant effectiveness of WM-based rehabilitation in reducing cognitive failures and improving memory function in stroke survivors. These outcomes highlight the potential value of incorporating WM training into cognitive rehabilitation programs for this population.

### Study limitations

Several limitations in this study must be acknowledged. First, the small sample size restricts the generalizability of the findings to broader populations with diverse cultural backgrounds. Second, baseline differences between the experimental and control groups may have confounded the results. Third, the non-randomized sampling design limits internal validity, and the absence of a long-term follow-up prevents conclusions about the durability of treatment effects. Finally, the study design does not allow for differentiation between treatment-induced improvements and natural recovery over time.

### Future research recommendations

Given the promising outcomes of WM training in reducing cognitive failures and improving memory performance among stroke survivors, further research is warranted to build upon these findings. Future studies should consider utilizing larger and more diverse samples across different age groups, severity levels, and clinical settings to enhance the generalizability of results. Additionally, incorporating long-term follow-up assessments would be valuable to determine the durability of the intervention's effects over time.

It is also recommended that future research explore the comparative efficacy of WM training concerning other cognitive rehabilitation approaches, such as attention training or metacognitive strategy instruction. Moreover, integrating neuroimaging or electrophysiological techniques could provide insights into the neural mechanisms underlying observed cognitive improvements. Researchers are encouraged to examine the role of individual differences, such as motivation, baseline cognitive status, or family support, in moderating training outcomes.

Finally, developing and validating standardized treatment protocols for WM rehabilitation, particularly tailored to stroke populations, is essential to ensure replicability and clinical utility. Healthcare professionals and rehabilitation specialists should consider incorporating structured WM training programs into routine post-stroke care to promote cognitive recovery and improve patients' functional independence and quality of life.

## Ethical Considerations

### Compliance with ethical guidelines

This study was approved by the Ethics Committee of Urmia University of Medical Sciences, Urmia, Iran (Code: IR.URMIA.REC.1402.024). The study was performed following relevant guidelines and regulations. Informed consent was obtained from all participants.

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### Authors' contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interpretation of the results, and drafting of the manuscript. Each author approved the final version of the manuscript for submission.

### Conflict of interest

The authors declared no conflict of interest.

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