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Working memory training in post-stroke aphasia: Near and far transfer effects

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A R T I C L E I N F O

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A B S T R A C T

Purpose: Individuals with aphasia (IWA) show various impairments in speech, language, and cognitive functions. Working memory (WM), a cognitive system that functions to hold and manipulate information in support of complex, goal-directed behaviors, is one of the impaired cognitive domains in aphasia. The present study intended to examine the effects of a WM training program on both memory and language performance in IWA.
Method: This quasi-experimental study with an active control group was performed on 25 people with mild or moderate Broca's aphasia aged 29–61 years resulting from left hemisphere damage following ischemic stroke. Participants were assigned into two groups, including a training group (n = 13) and a control group (n = 12). The treatment and control groups received WM training and routine speech therapy, respectively. Two separate lists of WM tests, including one list for both pre-training assessment and training program and a second list for the post-training assessment, were used in this study.
Results: The treatment group showed significant improvements in both trained and non-trained WM tasks (near transfer effect) and language performance (far transfer effect) compared to the control group.
Conclusion: Given the good generalizability of the WM training program on both WM and language performance, WM training is suggested as part of the rehabilitation program in aphasia.

1. Introduction

Aphasia is a neurological disorder that affects communication skills. Current evidence points to a wide range of communication deficits in individuals with aphasia (IWA) (Helm-Estabrooks, 2002; McNeil, Odell, & Tseng, 1991; Murray & Clark, 2006). Impairments in attention (Murray, 2004), processing speed, executive function (Purdy, 2002), memory (Murray, Ramage, & Hooper, 2001; Murray, 2004; Wright & Shisler, 2005), and working memory (WM) (Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion,

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2003; Majerus, 2018; Murray et al., 2001; Tompkins, Bloise, Timko, & Baumgaertner, 1994; Wright & Shisler, 2005) are a few of the cognitive deficits in IWA. WM impairment is a frequent and persistent deficit in aphasia, which also may be seen in people who recovered from their language impairments (Majerus, 2018). Extensive evidence, also, refers to the role of WM research in understanding the nature of aphasia (Ivanova & Hallowell, 2014; Majerus, 2018) and the effectiveness of WM training in IWA (Mayer & Murray, 2002; McCarthy, Kalinyak-Fliszar, Kohen, & Martin, 2017; Salis, Hwang, Howard, & Lallini, 2017; Vallat-Azouvi, Pradat-Diehl, & Azouvi, 2014; Vallat-Azouvi et al., 2005; Winans et al., 2012; Zakariás, Keresztes, Marton, & Wartenburger, 2018). WM is also of interest to aphasiologists due to its contribution to language processing (Salis, Kelly, & Code, 2015).

WM is involved in learning (Gathercole, Dunning, Holmes, & Norris, 2016), reasoning (Brehmer, Westerberg, & Bäckman, 2012; Gathercole, 1999), decision-making, problem-solving (Brehmer et al., 2012), and spoken and reading comprehension (Chein & Morrison, 2010; Gathercole, 1999; Just & Carpenter, 1992; Salis, 2012). Various conceptual and theoretical models have been suggested for WM (Baddeley, 2012). According to the original model of Baddeley and Hitch (1974), the WM system consists of three major parts: the central executive system (CES), the phonological loop, and the visuospatial sketchpad. The CES as a supervisory system utilizes the information held in both phonological loop and visuospatial sketchpad, as verbal and visual stores, respectively (Baddeley & Hitch, 1974). The fourth component of WM is characterized as an episodic buffer, which has been added to the original model (Baddeley, 2000). This component functions as a system with limited capacity that provides temporary storage of information. The episodic buffer is a basis for binding information from subsidiary systems and long-term memory (Baddeley, 2000). This model defines WM as a system that provides temporary storage and manipulation of information simultaneously, which are required for complex cognitive activities (Baddeley A, 2003).

Extensive evidence, including studies on language development during childhood (Gathercole & Baddeley, 2014), second language learning (Juffs & Michael, 2011), and language disorders (Gathercole & Baddeley, 2014), demonstrates a complex interaction between WM and language (Majerus, Norris, & Patterson, 2007; Martin, Shelton, & Yaffee, 1994). For instance, the phonological loop contributes to language learning and the visuospatial sketchpad performs an active role in language comprehension (Baddeley AD, 2003). The episodic buffer binds multimodal experiences to shape the perception of events as a coherent whole (Gathercole, 2008). The CES also is responsible for extensive cognitive processes from reading comprehension to learning complex concepts (Baddeley AD, 2003). Moreover, neuroimaging studies also imply the involvement of Broca's area in WM tasks (Bard & Thompson-Schil, 2002; Burton, Diamond, & McDermott, 2003), as well as the activity of sensory association cortices and the prefrontal cortex (Curtis & D'Esposito, 2003; Linden, 2007).

Past studies have examined the impact of WM training on various aspects of cognition ranging from rote learning to expertise in some highly specialized domains such as chess and academic learning (Gathercole et al., 2016). Thus, different WM training activities have been applied depending on the studies' goals and populations. Other studies with IWA cumulatively imply the positive effects of WM training in aphasia, although methodological limitations in this literature domain seriously undermine the quality of the evidence (Majerus, 2018; Salis et al., 2017; Zakariás, Kelly, Salis, & Code, 2018). For instance, WM training studies demonstrate the expansion of word (Berthier et al., 2014; Eom & Sung, 2016), digit (Eom & Sung, 2016; Francis, Clark, & Humphreys, 2003; Koenig-Bruhin & Studer-Elchenberger, 2007; Majerus, Vanderkaa, Renard, Van Der Linden, & Poncelet, 2005; Salis, 2012), sentence (Harris, Olson, & Humphreys, 2014; Kalinyak-Fliszar, Kohen, & Martin, 2011), and rhyme span (Harris et al., 2014) as near transfer effects. The generalization of the WM training outcomes to various aspects of language processing is characterized as an index of far transfer effects (Berthier et al., 2014; Eom & Sung, 2016; Francis et al., 2003; Koenig-Bruhin & Studer-Elchenberger, 2007). Thus, improvement in rhyme judgment (Kalinyak-Fliszar et al., 2011; Majerus et al., 2005), processing efficiency, reading comprehension (Mayer & Murray, 2002), and everyday activities (Salis et al., 2017; Zakariás, Salis, & Wartenburger, 2018) has been reported as far transfer effects. Taken together, whereas past studies point to the positive effects of WM training on both WM performance and language domains in aphasia, most studies only focus on the "repetition" or "storage and processing" segment in one of the three WM's components (including CES, the phonological loop, and the visuospatial sketchpad) (Majerus, 2018; Zakariás, Kelly et al., 2018).

Given the prevalence of cognitive deficits in aphasia, evaluation and treatment should not only be limited to language components of the disorder (Ivanova & Hallowell, 2014). In this study, we developed a WM training program, including two repetition-based tasks (e.g., using digits and words) to treat verbal item and serial order retention capacities, and one recognition-based task (e.g., using digits) to treat attentional and executive aspects of WM. We examined the outcomes of our training program on both trained and non-trained WM tasks (i.e., near transfer effect) and language performance (i.e., far transfer effect). We aimed to address some of the past studies' limitations using WM training in aphasia in terms of 1) research design (using a quasi-experimental with an active control group versus a single-case design), 2) sample size (including 25 participants compared to single-subject studies, only 1–5 cases (Majerus, 2018)), 3) heterogeneity in IWA (including cases with Broca's aphasia versus different types of aphasia), and 4) type of therapy. As noted above, previous studies used treatment approaches that targeted "repetition" or "storage and processing" components of WM. In the present study, our treatment incorporated both components of WM (e.g., CES and the phonological loop). We also used several WM tasks to investigate both near (i.e., the effect of training on non-trained WM tasks), and far transfer effects (i.e., the effect of training on language performance). We had three major hypotheses: 1) WM training is beneficial for IWA and results in improvements in both 2) trained and non-trained tasks (i.e., near transfer effect) and 3) language performance (i.e., far transfer effect).

2. Methods

2.1. Participants

This quasi-experimental study with an active control group was performed on 25 IWA aged 29–61 years (mean = 49.55 ± 9.82

years) between 6 (Cherney, Halper, Holland, & Cole, 2008) to 60 months (Friedmann & Gvion, 2003) after stroke (Table 1). IWA with mild to moderate Broca's aphasia subsequent to left hemisphere damage due to an ischemic stroke, were included in the study. The lesion locations were diagnosed using magnetic resonance imaging (MRI) or computerized tomography (CT) by a neurologist. The IWA were selected from caseloads in outpatient clinics of Iran University of Medical Sciences (IUMS). The Persian Aphasia Battery (PAB) test was used to determine the type of aphasia (Jafari, Esmaili, Delbari, Mehrpour, & Mohajerani, 2017; Nilipour, Pour Shahbaz, Goreishi, & Yousefi, 2016). The PAB test is a valid and reliable diagnostic tool for Persian speakers, which was developed based on the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Caplan, 1972). The Battery could be used to determine the aphasia type as well as the disease severity (Nilipour et al., 2016). In the present study, participants were diagnosed with Broca's aphasia based on the PAB. All participants were also confirmed to have lesions that included Broca's area using MRI or CT. MRI or CT was performed within one week of language and WM assessments. Participants with Broca's aphasia were selected because of their preserved comprehension skills, as well as to minimize the effect of heterogeneity of lesion sites on the findings. Participants were monolingual, native Persian speaker, right-handed, with sufficient literacy level (at least a high school degree), and an intelligence quotient (IQ) score ranging from 90 to 110 based on Raven's colored progressive matrices (RCPM) (Raven, 1984). Individuals with symptoms of severe apraxia (Yadegari, 2014) and/or severe dysarthria (Nilipour et al., 2016), untreated vision problem and/or hearing impairment (based on basic audiometric assessments) (Jafari, Esmaili, Delbari, Mehrpour, & Mohajerani, 2016), acalculia (given our informal assessment and participants' opinions), and/or severe comprehension disorders identified by the Persian version of revised Western Aphasia Battery (P-WAB-1) (Nilipour, Pourshahbaz, & Ghoreyshi, 2014) were excluded from the study. Participants with aphasia were assigned into two groups, i.e., a training group (n = 13, 2 females and 11 males) and a control group (n = 12, 2 females and 10 males) by the first author. Male participants were allocated a number from 1 to 21 based on the order that they entered the study. We reduced the bias driven by the order of entry into the study using the even/odd assignment. Odd numbers were categorized as IWA-T and even numbers were categorized as IWA-C. The same process was applied to female participants. Individuals in the control group were blind to the study groups. The two groups were identical in terms of the treatment dosage, and were matched in age, gender, and the severity of language disorder.

The ethics committee of the IUMS approved the present study (ethical code: #93/D/105/5226). Written informed consent was obtained from all individuals before participation in the study. In the written informed consent for the IWA-T group, participants were told that the training program has no harm or side effects, and its impact on memory performance may range between no to significant improvement. At the end of the study, the IWA-C group was informed considering the possibility of taking advantage of a WM training program, and those who were interested, received a similar program.

2.2. Study procedure

The study incorporated three steps: 1) pre-training assessments for treatment and control groups, 2) a WM training program for the treatment group, and a routine speech therapy program for the control group, and 3) post-training assessments for the two groups. Language assessments also were performed for both groups in pre- and post-training periods. All treatment sessions were conducted by the first (for IWA-T) and the second (for IWA-C) authors, although treatment fidelity was not formally evaluated.

2.2.1. The pre-training assessments

Four WM tests including the n-Back test (Kane & Conway, 2007), the paced auditory serial addition test (PASAT) (Nikravesh et al., 2017), the categorization working memory span (CWMS) (Borella, Carretti, Riboldi, & De Beni, 2010), and forward and backward digit memory span tests (DMST) (Wechsler, 1981), as well as P-WAB-1 were performed as the pre-training assessments during two separate 60 min sessions.

In all WM tests, two individual lists of stimuli were used. The first list was used for both pre-training assessment and training sessions (except for the n-Back test that was not applied for the training program), and the second list only was carried out for the post-training assessment.

2.2.2. Tests of working memory

2.2.2.1. The n-Back test. Two types of auditory n-Back stimuli, including words and digits, were used at two difficulty levels (2 and 3-Back). N-Back tests consisted of form A and form B of both 2-back and 3-back digit tests, which contained digits 1–9. We also used form

Table 1
Demographic characteristics of the control and treatment groups.

	Control (n = 12)	Treatment (n = 13)	*p*
Age (y), mean (SD)	50.33 (9.62)	48.77 (10.02)	0.695†
Sex, n (%)			0.930‡
Male	10 (83.3)	11 (84.6)	
Female	2 (16.7)	2 (15.4)	
Education (y), mean (SD)	14.17 (2.33)	14.31 (2.29)	0.880†
Post onset stroke (m), mean (SD)	26.25 (17.27)	25.23 (17.96)	0.886†

SD, standard deviation; ‡chi-squared test; †independent *t*-test.

A and form B of both 2-back and 3-back word tests, including two- or three-syllable words with high to medium occurrence frequency. Word frequency was determined using a Persian reference book (Bijankhan & Mohseni, 2012). Each form included 100 audio-recorded stimuli with 1-sec inter-word intervals. Participants were asked to raise their hands after hearing the stimulus if it was matched the one that appeared n items before. The test was scored based on the percent of total correct responses (maximum score of 20 for each form) (Kane & Conway, 2007). Form A and form B were used in the pre-training and post-training assessments, respectively.

2.2.2.2. The paced auditory serial addition test (PASAT). The Persian version of PASAT consisted of 61 audio-recorded single-digit numbers, which were presented with a 3-second interval between digits (Nikravesh et al., 2017). During the presentation, participants were asked to sum the last two digits. For instance, after listening to digits 2 and 4, the correct response is 6 as the sum of the two last digits. When number 3 is presented as the next digit, the correct sum of the two most recent digits would be 7. The PASAT score was based on the percent of total correct responses during the test (maximum score 60).

2.2.2.3. The categorization working memory span (CWMS) test. The CWMS involved two lists of 100 two- or three-syllable words with high to medium frequency (word occurrence frequency was determined based on a Persian reference book (Bijankhan & Mohseni, 2012)). The words were classified into five levels. The first level involved 10 words in two groups of five words (Fig. 1). The second level included 15 words in three groups of five words. The third level included 20 words in four groups of five words. The fourth level included 25 words in five groups of five words. The fifth level consisted of 30 words in six groups of five words. In each list, 28 % of the words were the name of a few animals. The CWMS was an audio-recorded task with one word per sec presentation rate. Participants were asked to raise their hands whenever they heard an animal name (i.e., the processing phase). The interval between the series of word lists was 2-sec. At the end of each word list, participants were asked to recall the last word of each group in the list (i.e., the maintenance phase). Passing the processing phase was required to proceed to the maintenance phase. The sum of the number of correct recalled words was characterized as the measure of the WM performance (maximum score 20) (Borella et al., 2010).

2.2.2.4. The digit memory span test (DMST). DMST is the most frequent test used in IWA research (Murray, Salis, Martin, & Dralle, 2018). The test consists of a forward digit span and a backward digit span. In the forward DMST, single-digit, audio-recorded numbers were presented with 1-sec inter-digit interval. Participants had to repeat the numbers in the order presented. The complexity of the test was increased by raising the numbers from three to eight digits (6 levels of difficulty). In each complexity level, two sets of digits were presented. For instance, two sets of three digits were presented in the first complexity level, and the participant was given two opportunities to pass the level. One credit was given per each correct answer. The test was terminated if the correct answer was not obtained in any of the two opportunities, and the last successful set of numbers was considered as the participant's score. DMST scores were based on the total correct responses (maximum score 12) (Dehn, 2008). The backward DMST was performed with the same procedure and scoring method as the forward DMST. The participants, however, were asked to repeat each series of numbers in reverse, from the last number to the first one. The test was made more complex by increasing the number of words in each set of digits from 2 to 7 (Dehn, 2008).

To avoid any difficulties of fluency, naming, or speech intelligibility problems on DMST and PASAT, participants also were given the choice of pointing to the printed numbers instead of verbal responses (Friedmann & Gvion, 2003). None of our participants, however, required to use this possibility.

2.2.3. Test of language performance

We used P-WAB-1 to test various components of language performance. The P-WAB-1 is a test battery to determine the severity and type of aphasia, which has been adapted from WAB-R for a quick clinical screening. This comprehensive language test includes six subscales: spontaneous speech content, fluency of spontaneous speech, auditory comprehension, sequential commands, repetition, and naming. The maximum score for each subscale is ten, and the total score of subscales or "aphasia quotient" (AQ) (i.e., ranging from 0 to 100) is an operational index of the overall severity of language deficits in aphasia (Nilipour et al., 2014).

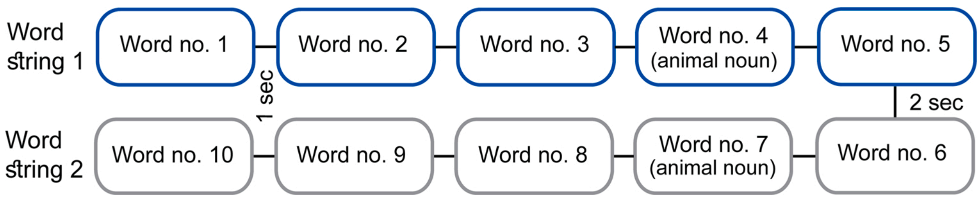

Fig. 1. A schematic illustration of the CWMS test at the first level. An audio-record of two-word strings with an inter-word interval of 1-sec and an inter-string interval of 2-sec is presented (e.g., a 1-sec interval between words no. 1 and 2, and a 2-sec interval between words no. 5 and 6). Participants are required to raise their hand on words no. 4 and 7, and also memorize words no. 5 and 10. CWMS, categorization working memory span task.

2.2.4. WM training program

We adapted our WM-training program from past studies with some modifications in terms of the diversity of WM and language assessments and WM training materials (Lundqvist, Grundstrom, Samuelsson, & Ronnberg, 2010; Westerberg et al., 2007). The WM training program was carried out for the treatment group (n = 13) within 15 sessions, 60 min per session, twice a week. Participants took a 10-minute break after the first 30 min of the training program. In the first training session, each task was started with a low difficulty level (Borella et al., 2010; Brehmer et al., 2012). The first difficulty level in the forward DMST was sequences of three digits, which were presented verbally, and the participant was expected to recall the sequences. In each session, 30-digit sequences were presented at two difficulty levels (e.g., 15-digit sequences with the first difficulty level, and 15-digit sequences with the second difficulty level). The participants came into the next level if they correctly passed 60 % or more of the first difficulty level; otherwise, they remained at the same level with different digit sequences. The first level of difficulty in the backward DMST consisted of two digits in each sequence, and the same procedure as the forward DMST was followed.

In the CWMS test, the first session was started with a low difficulty level. The difficulty level was individually set during each training session and moving to the next level required a 100 % correct score. For training with PASAT, various digit sequences, including digits 1–9, with 3-sec inter-digit interval were presented verbally, 20 min per session. The order of WM tests was different throughout 15 training sessions. The SLP nodded to confirm the correct answers during training tasks. At the end of each session, the SLP explained the improvement if there was any. In each training session, the level of task difficulty was set based on the last level achieved in each WM test in the previous session.

2.2.5. Routine speech therapy for IWA-C

The IWA-C group (n = 12) took part in a speech therapy program for 15 sessions, 60 min per session, twice a week. The program was provided by a certified SLP (the second author) with expertise in the field of aphasia who was not blind to the study groups. The speech therapy program was performed in non-structured sessions. The training included three 20 min segments per treatment session. Before each segment, the SLP provided verbal instructions. In the first segment, word retrieval was treated using a cueing hierarchy that consisted of providing the first syllable of target words (Love & Webb, 1977). In each session, two sets including five pictures of objects and five pictures of actions taken from the PAB test or the Persian Aphasia Naming test (Nilipour, 2011) were practiced. In the

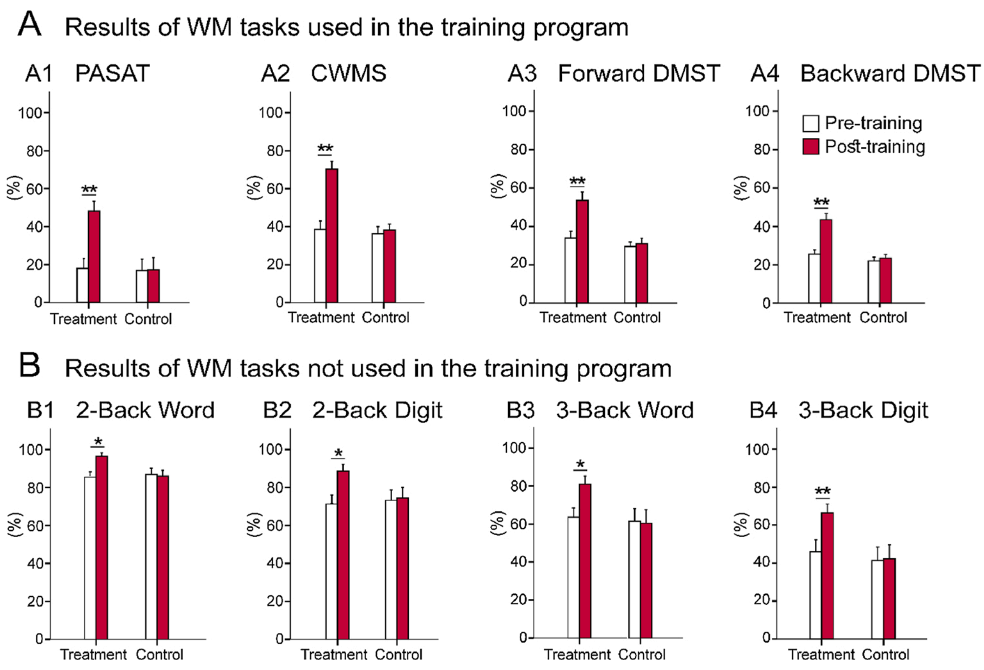

Fig. 2. Comparison between pre- and post-training working memory (WM) assessments in the two groups. Section A demonstrates the results of WM assessments for the tests used in the training program including: A1) PASAT: paced auditory serial addition test, A2) CWMS: categorization working memory span, A3) Forward DMST: forward digit memory span test, and A4) Backward DMST: backward digit memory span test. Section B exhibits the results of WM assessments for the tests not used in the training program including: B1) 2-Back Word, B2) 2-Back Digit, B3) 3-Back Word, and B4) 3-Back Digit. Results reported as mean ± 2SE. Asterisks indicate $^{*}p < 0.05$ or $^{**}p < 0.01$.

second segment, the PAB's pictures were used for the verbal picture description task. Participants were asked to name the objects and actions in the picture, and then used those words in a picture description task. In the third segment, the category-specific tasks (Berndt, 1988) were carried out for practicing word retrieval. In each session, two to three categories (e.g. the initiation of animals, vegetables, or words with a specific consonant) were practiced. The participants received feedback on their performance at the end of each session.

2.2.6. The post-training assessments

Four weeks after training (Lundqvist et al., 2010), the post-training WM assessments using n-Back, PASAT, CWMS, and DMSTs, as well as the P-WAB-1 test were administered for both groups. All assessments were completed during two sessions (60 min per session) to avoid the potential effect of fatigue on participants' performance. The four-week time interval between the last training session and post-training tests was considered to evaluate the maintenance of treatment programs in IWA groups (Zakariás, Salis et al., 2018). During this period, the participants received no other training programs.

2.3. Statistical analysis

In this study, continuous variables were presented as mean ± standard deviation (SD) and categorical variables as number (percentage). The Kolmogorov-Smirnov test was used to examine the normality of dependent variables (e.g., post-test scores). The assumption of normality was met for all study variables (all $p > 0.05$). Demographic characteristics were compared between groups using t-tests for continuous variables and chi-square tests for categorical variables. Analysis of covariance (ANCOVA) was applied to compare the two groups after controlling for pre-test scores. In this method, the post-treatment score, pre-treatment score, and treatment group were considered as the dependent variable, the covariate, and the independent variable, respectively. Furthermore, partial eta squared (η^2_p), which estimated the magnitude of the mean differences, was calculated. η^2_p values of 0.01−0.06, 0.06−0.14, and > 0.14 were considered as a small, moderate, and large effect size, respectively (Cohen, 1988). Statistical analyses were performed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA), and the level of significance was set at 0.05.

Table 2
Results of ANCOVA test in examining group effect on post-training scores for WM tasks.

Tasks/Groups	Pre-Test Mean (SD)	Post-Test Mean (SD)	Adj Post-Test Mean (SE)	Adjusted Mean Difference between Groups (95 % CI)	$F_{(1,22)}$	*p*	ES (η^2_p)	ES Magnitude
2-Back Word								
Control	17.33 (2.06)	17.08 (1.98)	17.17 (0.32)	2.29 (1.36, 3.22)	26.33	<0.001	0.545	Large
Treatment	17.62 (1.66)	19.54 (0.97)	19.46 (0.31)					
2-Back Digit								
Control	14.33 (3.63)	14.67 (3.58)	14.90 (0.42)	3.04 (1.84, 4.25)	27.43	<0.001	0.550	Large
Treatment	14.92 (3.28)	18.15 (2.23)	17.94 (0.40)					
3-Back Word								
Control	12.25 (4.29)	12.00 (4.49)	12.23 (0.46)	3.78 (2.47, 5.09)	35.64	<0.001	0.618	Large
Treatment	12.77 (3.77)	16.23 (3.06)	16.01 (0.44)					
3-Back Digit								
Control	8.42 (4.46)	8.50 (4.64)	9.10 (0.43)	3.96 (2.72, 5.21)	43.68	<0.001	0.665	Large
Treatment	9.85 (4.86)	13.62 (3.38)	13.06 (0.41)					
Forward DMST								
Control	3.67 (0.98)	3.83 (1.11)	4.01 (0.27)	2.37 (1.59, 3.14)	40.06	<0.001	0.645	Large
Treatment	4.00 (1.63)	6.54 (2.03)	6.38 (0.26)					
Backward DMST								
Control	2.75 (0.87)	2.92 (0.79)	3.04 (0.20)	2.15 (1.57, 2.72)	59.69	<0.001	0.731	Large
Treatment	3.00 (1.15)	5.31 (1.49)	5.19 (0.19)					
PASAT								
Control	11.58 (12.75)	11.83 (13.16)	10.90 (1.81)	18.89 (13.67, 24.11)	56.27	<0.001	0.719	Large
Treatment	9.46 (13.51)	28.92 (12.34)	29.79 (1.74)					
CWMS								
Control	7.33 (2.27)	7.58 (2.02)	7.68 (0.47)	6.84 (5.48, 8.20)	109.29	<0.001	0.832	Large
Treatment	7.69 (3.45)	14.62 (2.40)	14.52 (0.45)					

CI, confidence interval; CWMS, categorization working memory span; DMST, digit memory span test; SD, standard deviation; SE, standard error.

3. Results

The demographic characteristics of the control and treatment groups are summarized in Table 1. There was no significant difference between the two groups in age (p = 0.695), gender (p = 0.930), education (p = 0.880), and time post-onset of stroke (p = 0.886).

Fig. 2 compares the mean ± 2 S.E.M of the pre-training and post-training assessments in four WM tasks (e.g., PASAT, forward DMST, backward DMST, and CWMS) used for the training program (Fig. 2A), as well as in four non-trained WM tasks (e.g., 2-Back word, 2-Back digit, 3-Back word, 3-Back digit) (Fig. 2B).

Table 2 represents the results of the ANCOVA test for WM tasks to examine group differences. A significantly higher score (including a large ES) was observed in the treatment group relative to the control group in all WM tests, in the post-training assessments. In language assessments, a significantly higher score was also found in AQ (i.e., an index of reduced language deficits) ($F_{(1, 22)} = 52.76$, $p < .001$, $\eta^2_P = 0.706$), speech fluency ($F_{(1, 22)} = 4.40$, $p = 0.048$, $\eta^2_P = 0.167$), auditory comprehension ($F_{(1, 22)} = 9.59$, $p = 0.005$, $\eta^2_P = 0.303$), naming ($F_{(1, 22)} = 5.14$, $p = 0.034$, $\eta^2_P = 0.189$), and repetition ($F_{(1, 22)} = 29.22$, $p < .001$, $\eta^2_P = 0.570$) in the treatment group compared with the control group, in the post-training assessments (Table 3). Although the scores of the speech content and sequential commands for the post-training assessments showed improvement compared to the pre-training assessments (including a small to medium ES) in the treatment group, the differences were not statistically significant. In the post-training assessment, the control group demonstrated no significant improvement neither in WM nor in language tests.

4. Discussion

In this study, we examined the effectiveness of an intensive WM training program on WM function (using both trained and non-trained WM tasks) and language performance in aphasia. Given Baddeley's model, our training model focused on specific processing and storage components (a) to increase the ability to hold the information for a limited time (i.e., using forward DMST, CWMS

Table 3

Results of ANCOVA test in examining group effect on post-test scores for P-WAB-1 subtests.

Tasks/Groups	Pre-Test Mean (SD)	Post-Test Mean (SD)	Adj Post-Test Mean (SE)	Adjusted Mean Difference between Groups (95 % CI)	$F_{(1,22)}$	*p*	ES (η^2_p)	ES Magnitude
AQ								
Control	83.16 (6.96)	83.16 (6.64)	81.63 (0.66)	6.69 (4.78, 8.60)	52.76	<0.001	0.706	Large
Treatment	79.47 (9.74)	86.90 (7.62)	88.31 (0.63)					
Speech Content								
Control	7.92 (1.08)	8.00 (1.04)	7.87 (0.18)	0.24 (-0.28, 0.77)	0.92	0.347	0.040	Small
Treatment	7.62 (1.39)	8.00 (1.29)	8.12 (0.17)					
Speech Fluency								
Control	7.08 (1.31)	7.08 (1.08)	6.97 (0.18)	0.53 (0.01, 1.05)	4.40	0.048	0.167	Large
Treatment	6.77 (1.09)	7.38 (1.04)	7.49 (0.17)					
Auditory Comprehension								
Control	9.17 (0.83)	9.17 (1.03)	8.78 (0.18)	0.81 (0.27, 1.35)	9.59	0.005	0.303	Large
Treatment	8.08 (1.98)	9.23 (1.36)	9.59 (0.18)					
Sequential Commands								
Control	9.17 (1.03)	9.25 (1.14)	9.41 (0.18)	0.36 (-0.15, 0.88)	2.16	0.156	0.090	Medium
Treatment	9.65 (0.75)	9.92 (0.28)	9.77 (0.17)					
Naming								
Control	7.92 (1.00)	8.00 (0.95)	7.58 (0.20)	0.66 (0.06, 1.26)	5.14	0.034	0.189	Large
Treatment	6.85 (1.21)	7.85 (1.14)	8.24 (0.19)					
Repetition								
Control	8.67 (1.23)	8.42 (1.44)	8.43 (0.18)	1.33 (0.82, 1.85)	29.22	<0.001	0.570	Large
Treatment	8.69 (1.18)	9.77 (0.44)	9.76 (0.17)					

CI, confidence interval; SD, standard deviation; SE, standard error.

(storage phase)), and (b) to improve the ability to process and manipulate the information to extract the correct response (i.e., using CWMS (processing phase), PASAT, and backward DMST). The treatment group showed significant improvements in both WM and language performance compared to the control group. The findings were in line with multiple past studies that demonstrate the positive impacts of repetition- and recognition-based WM training on WM function and capacity, as well as on language domains in aphasia (Francis et al., 2003; Kalinyak-Fliszar et al., 2011; Majerus et al., 2005; Majerus, 2018; Mayer & Murray, 2002; Salis, 2012; Vallat-Azouvi et al., 2014; Vallat-Azouvi et al., 2005; Zakariás, Kelly et al., 2018).

4.1. WM tasks used for the training program

Several WM tasks were applied as part of our WM training program. PASAT, which is one of the most sensitive tests for measuring potential improvement after WM-related training (Flavia, Stampatori, Zanotti, Parrinello, & Capra, 2010; Gray, Robertson, Pentland, & Anderson, 1992; Niemann, Ruff, & Baser, 1990), is characterized as a complex WM test that includes processing, manipulation, and recalling procedures (Tombaugh, 2006). PASAT also requires sustained attention, storage, and manipulation of information to respond correctly (Lundqvist et al., 2010; Tombaugh, 2006), and imposes an extensive load on WM capacity (Forn et al., 2006; Sherman, Strauss, & Spellacy, 1997). The post-training PASAT score demonstrated the positive impact of the WM training program on attention, storage capacity, and processing efficiency, which are cognitive requirements to execute PASAT.

The CWMS is a complex WM span task that monitors both storage and processing information at the same time. Previous studies, which have used the CWMS content as a training and follow-up tool, demonstrate the long-lasting effects of CWMS on the WM span (Borella et al., 2010). The training process in CWMS, which contains various difficulty levels, has been shown to enhance cognitive resources, encoding, and maintaining information in WM (Borella et al., 2010). Our findings also support the effectiveness of CWMS in increasing WM span and cognitive abilities in information processing in aphasia.

Digit span is one of the most commonly used WM tests in aphasia (Francis et al., 2003; Majerus et al., 2005; Salis, 2012; Vallat-Azouvi et al., 2014; Vallat-Azouvi et al., 2005), and as a predictor of language performance (Leff et al., 2009). In our study, there was a significant increase of WM span in both forward and backward DMST before the training program, which was consistent with previous work in aphasia (Eom & Sung, 2016; Francis et al., 2003; Koenig-Bruhin & Studer-Elchenberger, 2007; Majerus et al., 2005; Salis, 2012).

4.2. Near transfer effect

The near transfer effect is an important aspect of a training program and represents the generalizability of training outcomes to non-trained tasks that are similar to those used in the training program (Mahncke et al., 2006; Mozolic, Hayasaka, & Laurienti, 2010; Mozolic, Long, Morgan, Rawley-Payne, & Laurienti, 2011; Richmond, Morrison, Chein, & Olson, 2011). The WM training program resulted in improvements not only in the trained tasks but also in non-trained tasks, such as n-Back tasks. Based on previous studies, n-Back is a valid WM test that requires storage, manipulation, and updating of information for recall (Kane & Conway, 2007). The n-Back enables investigators to manipulate linguistic load, as well as to eliminate the requirement for verbal output (Christensen & Wright, 2010; Mayer & Murray, 2012; Zakariás, Keresztes et al., 2018). The near transfer effect observed in our study implies that the impacts of WM training programs could be generalized to other aspects of WM function. This effect is the major goal of all WM training programs (Morrison & Chein, 2011), and is associated with neuroplastic alterations in neural networks underlying WM functions (Klingberg, 2010).

4.3. Far transfer effect

The generalization of treatment benefits to other aspects of cognitive functions is called the “far transfer effect” (Salis et al., 2017). In the present study, the overall severity of language impairments was considered as a measure of the far transfer effect (Murray, 2012). We found a significant improvement in speech fluency, auditory comprehension, naming, and repetition subscales of P-WAB-1 following the training program. Linguistic sequences are essential for fluency in spoken language. These sequences originate from serial order maintenance that is part of the WM function (Acheson & MacDonald, 2009; Ellis, 1996). Thus, it might be interpreted that the extension of serial order maintenance can lead to an improvement in speech fluency. The significant improvement also was found in the auditory comprehension subscale of the language assessment, which was consistent with past publications in aphasia (Eom & Sung, 2016; Francis et al., 2003; Harris et al., 2014; Murray & Clark, 2006; Salis, 2012). Naming was another subscale of the language assessment that showed improvement following the training program. The results of a few past studies related to the impact of WM training on naming ability, however, are inconsistent with this finding (Eom & Sung, 2016), and further studies using similar language tools are required to draw a conclusion in this area. Repetition was the language domain with the most improvement within all language subscales in our study. This finding was expected given the evidence that shows repetition ability is influenced by WM capacity, as the result of the training program (Francis et al., 2003; Koenig-Bruhin & Studer-Elchenberger, 2007).

Sequential commands and speech content were the two language subscales that did not show a significant improvement. The results of our pre-training assessment demonstrated that the subscale of sequential commands was almost not impaired in both treatment (e.g., mean = 9.65 ± 0.74 out of 10) and control (mean = 9.17 ± 1.03 out of 10) groups. In past studies, improvement in picture description has been used as a measure of speech content (Berthier et al., 2014; Koenig-Bruhin & Studer-Elchenberger, 2007). The discrepancy of the studies in sequential commands and speech content might result from differences in research methods such as using different test materials, which require further studies in the future.

Significant improvement in AQ subsequent to the WM training program supports the findings of past studies considering a strong association between scores of WM and language performance (Caspari et al., 1998; Wright, Newhoff, Downey, & Austermann, 2003). A five-point or more change in the WAB score has been shown to reflect the clinical significance of the intervention (Katz & Wertz, 1997). In our study, a 6.69-point increase was observed in the P-WAB-1 score, which shows the clinical significance of our WM training program in language domains. But in the control group, no significant difference was observed between the pre- and post-training assessments in all WM and language assessments. This finding implies that significant improvements found in the treatment group were not resulting from random alternations or environmental effects over time. This finding suggests that an intensive speech therapy program may not be effective as an intensive WM program for IWA. In conclusion, our findings are in line with past publications in aphasia that show a WM training program consists of storage, process, and manipulation of information can activate cognitive resources to efficiently manage information processing (Borella et al., 2010).

4.4. Effect size

The effect size is characterized as an index of the degree to which the findings have practical significance or the extent to which the research hypothesis is true regardless of the study sample size (Hojat & Xu, 2004). In clinical research, the word "clinical" is commonly used instead of "practical" importance (Schober, Bossers, & Schwarte, 2018). In comparisons between the two aphasia groups, the ES corresponded with large clinical significance in all WM tests (e.g., 2-Back word 0.545, 3-Back digit 0.550, 3-Back word 0.618, 3-Back digit 0.665, forward DMST 0.645, backward DMST 0.731, PASAT 0.719, and CWMS 0.832); as well as between small to large in language assessments (e.g., speech content 0.04, sequential commands 0.90, speech fluency 0.167, naming 0.189, auditory comprehension 0.303, repetition 0.570, and AQ 0.706).

4.5. Limitations

Based on the CONSORT 2010 checklist (Schulz, Altman, & Moher, 2010), our study had several limitations, which may be considered as useful directions for future research in this area. Among four WM tests carried out for WM assessments, except for n-Back tests, the other three tests (e.g., PASAT, CWMS, and DMST) were also used in the training program. Although separate lists of WM tests for the training program and the post-training assessments were used in this study, the familiarity with the tests' structure may contribute to a percentage of improvements found in the WM tests. Multiple follow-up assessments also could provide information related to the persistence and reproducibility of the training outcomes that were not examined in this study. The lack of an immediate post-training assessment was another study drawback that limits the interpretation of the persistence of treatment effects. To prevent the potential effects of the heterogeneity of the lesion site on findings, only cases with mild or moderate Broca's aphasia (with a lesion in Broca's area) were included in this study. Therefore, our findings could not be generalized to other subtypes of aphasia. The extent (size) of brain lesions also was not included in this study, which could provide further information on the association between lesion size and training outcomes. In this study, we only applied auditory stimuli in the WM training program. The application of other sensory stimuli compared to the auditory stimuli is proposed to be used in the future. We also failed to use treatment fidelity checklists or other methods of assessing treatment fidelity, and the examiners who completed pre- and post-training tests were not blind to the study groups. Finally, our aphasia cases only were chosen from caseloads in outpatient clinics of IUMS, and no specific statistical formula was applied to quantify the sample size.

5. Conclusions

Our WM training program was associated with significant improvements in both trained and non-trained WM tasks (i.e., near transfer effect), as well as a significant decrease in language deficit severity (i.e., far transfer effect). The results of this study emphasize the feasibility and effectiveness of WM training in clinical practice for aphasia. Our findings are applicable for both researchers and clinicians in the fields of speech-language rehabilitation, clinical psychology, and cognitive rehabilitation. The effects of factors such as age, gender, and the aphasia severity, subtypes, and time post-onset of stroke on results, as well as the durability and reproducibility of findings post-treatment, are required to be examined in future research.

Authors' contributions

M.N. and Z.J. contributed to the study idea, methodology, funding acquisition, writing the first draft, review, and critique of the manuscript; M.A. and A.S. helped during project administration; S.M. assisted for statistical analysis; and Z.J. supervised the study.

Declaration of Competing Interest

The authors report no declarations of interest.

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