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Articles

**Adaptive Working Memory Training and Functional Outcomes Post-Stroke: A Randomized Trial**

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**Abstract**

*Background:* Cognitive deficits following ischemic stroke significantly impair functional independence, particularly in instrumental activities of daily living. Previous research highlights working memory as a key target for rehabilitation, but the effectiveness of adaptive working memory training in improving functional outcomes remains underexplored. This study draws on the theoretical framework linking cognitive reserve and neuroplasticity to post-stroke recovery, hypothesizing that targeted cognitive interventions can enhance both working memory and instrumental activities of daily living performance.

*Materials and Methods:* A randomized controlled trial was conducted with 32 participants who experienced ischemic stroke. Participants were randomly assigned to an intervention group (n=16), receiving adaptive working memory training, or an active control group (n=16), engaged in non-adaptive cognitive activities. Independent variables included the type of intervention (adaptive vs. standard), while dependent variables measured instrumental activities of daily living (Lawton-Brody Scale) and working memory (Working Memory Questionnaire, Working Memory Index, Corsi Block Tapping Test). The intervention entailed 25 sessions over 12 weeks, tailored to participant performance to maximize cognitive engagement.

*Results:* The intervention group demonstrated a significant improvement in Working Memory Index compared to the control group, suggesting a stronger effect of adaptive training on cognitive outcomes. However, no significant differences were observed in instrumental activities of daily living performance between groups, raising questions about the transferability of cognitive gains to functional tasks.

*Discussion:* These findings support the theoretical premise that adaptive working memory training enhances cognitive performance post-stroke but highlight limitations in its direct impact on functional independence. Future research should explore the conditions under which such interventions effectively translate cognitive improvements into practical gains, considering factors such as intervention duration, intensity, and individual differences (e.g., baseline performance, motivation, and genetic predispositions). The study underscores the need for refined intervention designs to bridge the gap between cognitive training and functional rehabilitation outcomes.

Clinical Trial registration: RIDIE-STUDY-ID-5e61da9608f23.

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## 1. Introduction

Stroke is a neurological deficit attributed to an acute focal injury of the central nervous system (CNS) by a vascular cause, including cerebral infarction, intracerebral hemorrhage, and subarachnoid hemorrhage, and is a major cause of disability and death worldwide (Sacco et al., 2013). Stroke has also significant and varied effects on mental health, with elevated risks for several psychiatric conditions. Mood disorders, particularly depression, are the most common, with a one-year risk difference of 7.3% compared to the general population and 4.9% when compared to myocardial infarction patients. Organic brain disorders, including dementia and delirium, follow closely with a one-year risk difference of 1.4% relative to the general population and 1.0% compared to myocardial infarction. Although less prevalent, substance abuse disorders and neurotic disorders, driven by anxiety and stress, also exhibit increased risks, with one-year differences of 0.8% and 0.5%, respectively, when compared to the general population. These risks are particularly pronounced within the first year poststroke, with hazard ratios ranging from 2- to 4-fold for mood, organic brain, and neurotic disorders, although they decline over time (Landínez & Montoya, 2019).

Recent research has found that among poststroke survivors more than 20% experience limitations in activities of daily living (ADL) and over 30% in Instrumental Activities of daily living (IADL), with these percentages increasing in the years following the stroke event (Einstad et al., 2022; Gil-Salcedo et al., 2022). Working memory (WM) plays a critical role in IADL and may predict poor cognitive recovery after stroke (Fitri et al., 2020; Landínez Martínez & Montoya Arenas, 2021a). Therefore, it is crucial to improve this function. WM training offers several benefits, such as increased accessibility, individualized training, increased intensity, enhanced motivation, objective monitoring, cost-effectiveness, improved outcomes, convenience and standardization (Lundqvist et al., 2010; Zhou et al., 2022). Moreover, studies have shown that WM training improves specific aspects of daily living, such as telephone use and medication management in stroke survivors compared to control groups (Kamal et al., 2015;

Landínez Martínez & Montoya Arenas, 2021b). It is important to note that while WM training holds promise, potential limitations in its implementation in the poststroke population should be considered for a more comprehensive understanding of its impact.

So far, the available evidence for the effectiveness of WM training in improving IADL and WM after stroke is inconclusive. Thus, there are some limitations and potential flaws to consider (Peers et al., 2022; Ripp et al., 2022). Firstly, a lack of standardized protocols for WM training, makes it challenging to compare studies and determine the most effective methods (Velugoti et al., 2022). Larger randomized controlled trials are needed to provide more robust evidence for the effectiveness of WM training after stroke (Lugtmeijer et al., 2021). Moreover, many studies lack a control condition or include only passive (non-treated) control conditions. In studies with active control (i.e. mock training) groups, computer-based training has failed to outperform mock training (Melby-Lervåg & Hulme, 2013; van de Ven, Murre, et al., 2017). Similarly, other studies did not statistically adjust for multiple testing, despite including a large number of outcome measures, making them prone to type 1 error (i.e., report of positive results where there are none) (Soveri et al., 2017; van de Ven, Buitenweg, et al., 2017).

Two recent meta-analyses have claimed that WM training can be effective in enhancing cognitive skills in adulthood (Au et al., 2015) and stemming cognitive decline in old age (Karbach & Verhaeghen, 2014). However, these conclusions can be questioned due to the failure to account for baseline differences when calculating effect sizes. Relying solely on post-test differences can lead to biased effect-size estimates, especially in a field with small sample sizes and studies that exhibit imbalances at baseline.

For instance, four studies measuring memory using tests like the forward Digit Span, Letter-Number Sequencing, and Digital Span tests revealed a moderate effect size favoring the intervention group (SMD = 0.49, 95% CI [0.27–0.72],  $I^2 = 0\%$ ) (Bo et al., 2019; Bunketorp-Käll et al., 2017; Cho et al., 2015; Yoo et al., 2015). However, subgroup analysis indicated that interventions lasting longer than six months did not sustain this effect (SMD = 0.32, 95% CI [–0.03 to 0.67],  $I^2 = 0\%$ ). For spatial and visual memory, two studies reported a favorable effect (MD = 0.98, 95% CI [0.33–1.64],  $I^2 = 0\%$ ) (Cho et al., 2015; Yoo et al., 2015). In contrast, no significant effects were observed for general cognitive function (MD = 1.20, 95% CI [–0.28 to 2.67]), attention (MD = 0.01, 95% CI [–0.08 to 0.11]), perception (SMD = 0.14, 95% CI [–0.16 to 0.45]), depression (SMD = –0.26, 95% CI [–0.57 to 0.06]), or quality of life (SMD = 0.19, 95% CI [–0.24 to 0.63]). Similarly, no evidence of benefit was found for neglect when compared with an active control (MD = 4.98, 95% CI [–33.29 to 43.24]).

Four studies evaluating functional status through the Barthel Index, modified Barthel Index, and Functional Independence Measure found a small but significant effect favoring multiple-component interventions over a standard control (SMD = 0.33, 95% CI [0.05–0.62],  $I^2 = 61\%$ ). However, subgroup analysis revealed no significant effects for interventions applied either within three months poststroke or beyond six months poststroke. These findings suggest that while multiple-component interventions may improve functional status overall, their timing relative to the stroke event is critical, with no clear benefit observed in early or late poststroke periods (Brainin et al., 2015; Jiang et al., 2016; Kongkasuwan et al., 2016; Yoo et al., 2015).

The aim of the current study was to test the hypothesis that three months of computer-based, WM training improves both IADL and WM after stroke, while addressing the methodological issues highlighted above. We additionally conducted within-group analyses similar to those used in a previous study, to assess inferences about transfer effects when comparisons to proper control groups are missing (das Nair et al., 2016). Participants trained three times per week during 50 minutes over 12 weeks, a regimen expected to trigger restitution-based recovery of IADL and WM. Task difficulty was adapted individually to participants' performance (Buitenweg et al., 2012). An active control group (i.e. mock training) was included to control for nonspecific effects. We expected that the WM training would result in more pronounced transfer effects on IADL and WM compared to the mock training.

## **2. Materials and methods**

### **2.1 Trial design**

This was a randomized controlled trial (RCT) with an experimental intervention group and an active control group carried out by a researcher blind to both the intervention and the pre-intervention scores. Participant IDs were randomized prior to recruitment by a statistician, with the allocation of each individual becoming known to the research team only at the end of the initial assessment.

### **2.2 Participants**

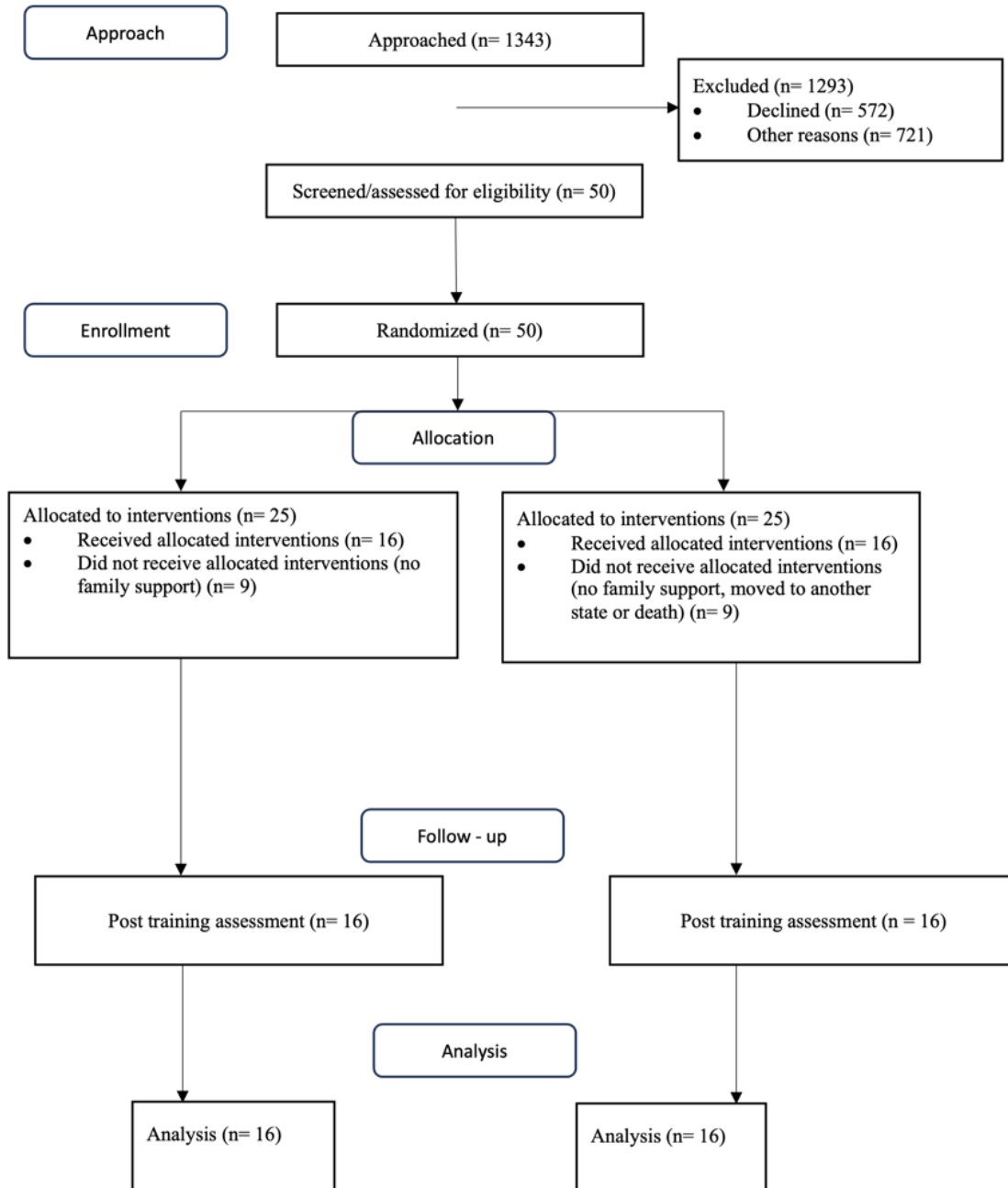
One thousand three hundred and forty-three stroke survivors were referred by therapists at Instituto neurológico de Colombia. Of these, 50 were finally randomized into the trial (see Figure 1 for details). The groups differed significantly in time after stroke (11 months to 10.5 years; mean time since injury = 41.8 months  $\pm$  70.2 months), (see Table 1). Written consent was obtained from each participant. The research procedure was evaluated by Instituto neurológico de Colombia (Medellín, Colombia) ethical committee who issued approval number: 449011-19.02-013 (see our Ethics Approval Statement).

The study recruited outpatients from the Neurological Institute of Colombia diagnosed with ischemic vascular disease between October 2017 and November 2019. Eligible participants were adults aged 50 to 79 years who had experienced a first-time ischemic vascular event at least one year prior to the evaluation, confirmed by computed tomography (CT) or functional magnetic resonance imaging (fMRI). Participants were required to have completed at least primary education and to meet the diagnostic criteria for mild neurocognitive disorder, determined by a Montreal Cognitive Assessment (MoCA) score of 21–22 for those with 5–10 years of education or 23–24 for those with 11 or more years. Additional eligibility criteria included access to a computer with an internet connection, the availability of a primary caregiver, and no current participation in a rehabilitation program. Exclusion criteria encompassed significant upper limb motor impairment affecting computer use, clinically relevant depressive symptoms (Yesavage Geriatric Depression Scale score  $\geq 10$ ), psychiatric disorders, aphasia, major neurocognitive disorder, or inability to comprehend and provide informed consent. While detailed information on lesion location and extent was available for some participants, there was considerable inconsistency across the group and hence these details are not included here due to the large number of necessary omissions.

For replication purposes, we provide an example of both pre-test and post-test: Once online, the neuropsychologist, patient, and primary caregiver shared an access link for the sociodemographic interview, the IADL scale (Neuronorma version), and the working memory questionnaire. The caregiver's support was requested to share the patient's screen, and the caregiver was also asked to refrain from assisting the patient unless specifically requested by the neuropsychologist on the team. This marked the end of the first session. For the second session, a new meeting room was created on the Google Meet platform, and the link was sent to the email provided by the patient and caregiver. On the scheduled day for the second assessment, the patient accessed the Google Meet platform to be assisted by a neuropsychologist. Once online, the neuropsychologist, patient, and primary caregiver administered the working memory index. The caregiver was asked to refrain from assisting the patient unless requested by the neuropsychologist. Once this task was completed, the evaluation continued with the Corsi Blocks test.

The evaluation was conducted as follows: the participant was asked to access the link generated for the administration of the test. Then, the presence of the primary caregiver was requested to share the patient's screen. Once the neuropsychologist accompanying the patient was able to view the patient's screen, the task was authorized to begin, starting with a demonstration of the

task. The neuropsychologist recorded the patient’s performance. The caregiver was instructed to refrain from assisting the patient unless specifically requested by the neuropsychologist on the team. Once the task was completed, the session was concluded.



**Figure 1.** CONSORT-SPI 2018 diagram showing flow of patients through the study

**Table 1.** Comparison of the two groups on sociodemographic and clinical measures at baseline

Variable	Active Control Group (n=16)	Experimental Group(n=16)	<i>p</i>	
Age +	59.3 (4.9)	62.0(6.2)	0.185	
Years of education. <sup>△</sup>	11.0 (11-14)	12.0 (6.7-14.5)	0.923	
Time after stroke (months) +	41.7 (25.7)	70.1 (36.1)	<b>0.016</b>	
MoCA <sup>△</sup>	24.0 (23.7-24.2)	24.0 (23.0-24.0)	0.348	
Yesavage <sup>△</sup>	2.5 (0.7-4.7)	1.5 (1.0-2.25)	0.319	
Lawton-Brody <sup>△</sup>				
	Number of activities performed without difficulties	10.5 (9-13)	10.5 (7.7-12)	0.543
	Number of activities performed with difficulties. No help needed	1.5 (0.75-4.25)	2.0 (0.75-3.0)	0.878
	Number of activities performed with help	0.0 (0.0-1.25)	1.0 (0.0-2.2)	0.503
LBI1	You are capable of walking independently outside	3.0(2-3)	3.0(2-3)	0.782
LBI2	You are capable of walking around the rooms of your house	3.0(3-3)	3.0(2.7-3.0)	0.693
LBI3	You operate the telephone on own initiative- looks up and dial numbers	2.0(2-3)	2.0(2-3)	0.785
LBI4	You take care of all shopping needs independently	2.5(2-3)	2.5(1-3)	0.758
LBI5	You take medications in correct dosages at correct time	3.0(1.7-3.0)	2.0(1-2)	0.089
LBI6	You open and close windows independently	3.0(3-3)	3.0(3-3)	0.575
LBI7	You manage financial matters independently	3.0(2.7-3.0)	3.0(3-3)	0.390
LBI8	You can turn on/off the TV	3.0(3-3)	3.0(3-3)	1.0
LBI9	You can turn on/off the lights	3.0(3-3)	3.0(3-3)	1.0
LBI10	You plan, prepare and serve adequate meals independently	3.0(2.7-3.0)	3.0(2-3)	0.594
LBI11	You can open/close the door with the keys	3.0(3-3)	3.0(3-3)	0.308
LBI12	You can trim your nails	3.0(2.7-3.0)	3.0(2.7-3.0)	1.0

Variable		Active Control Group (n=16)	Experimental Group(n=16)	p
LBI13	You maintain the house alone or with occasional assistance (light work domestic help)	3.0(3-3)	3.0(3-3)	0.955
LBI14	You maintain the house alone or with occasional assistance (Hard work domestic help)	3.0(2.7-3.0)	3.0(2.0-3.0)	0.594
WMQ+*	Storage	14.1(5.9)	15.3(7.5)	0.618
	Attention	13.0(6.1)	13.1(6.5)	0.955
	Executive	9.0(5.6)	10.1(7.0)	0.621
	Total	36.3 (15.2)	38.7(18.7)	0.687
	Raw score digits forward	6.62(1.7)	6.93(1.3)	0.616
	Raw score digits backward	6.43(1.5)	6.43(1.5)	1.0
	Raw score sequential digits	5.37(1.0)	6.50(1.8)	0.051
	Total Raw score digits	18.4(3.5)	19.8(2.8)	0.217
Percentile WMI+**	Scaled score: digits	8.0(2.2)	8.9(1.8)	0.200
	Raw score: Arithmetic	10.0(1.8)	10.3(2.2)	0.732
	Scaled score Arithmetic	8.0(1.5)	8.2(1.7)	0.750
	Percentile: Working memory index	27.4(13.8)	34.0(16.7)	0.231
Corsi block tapping test <sup>▲</sup>	Total: Corsi block tapping test: Forward	4.0 (3.0-4.0)	3.5 (3.0-4.0)	0.233
	Total: Corsi block tapping test: Backward	3.0 (3.0-4.0)	3.0 (3.0-3.0)	0.123

**Note.** + Mean (Standard Deviation); <sup>▲</sup> Median (Interquartile range Q1-Q3); -LBI (#): Lawton-Brody Item (#); \* WMQ: Working memory Questionnaire; \*\*Percentile WMI: Percentile Working memory index. Variables following normal distribution (t de Student) are conveyed using mean scores and standard distribution. Variables following non-normal distribution (U de Mann-Whitney) are conveyed using median and Interquartile ranges.

### 2.3 Interventions

The intervention group received adaptive computerized working memory training, and it was compared to a non-adaptive working memory training via a preexisting brain training website, <https://braining.me>. Both interventions were developed in-house and had the same basic format and look. Both included six tasks designed to train working memory and provided trial-by-trial feedback, feedback on overall progress but only the adaptive working memory training incrementally adapted by increasing task difficulty as trainees' performance improved (between 1 - 15 stimuli). The non-adaptive working memory training kept a low level of stimulation (between 1 – 5 stimuli).

Both working memory training sessions took approximately 50 min to complete each day, with participants starting the subsequent day's tasks at the performance level they had achieved at the end of the previous day. The target for both trainings was to complete 25 daily sessions over a 12-week period.

Participants completed the training at home, for the most part on their own computers. During the training period, participants were called weekly by a researcher to complete a semi-structured interview covering perception of changes from the previous week in cognitive, mood and social interactions and, perception of training, technical and other barriers encountered. Technical support was provided if necessary.

### 2.4 Outcomes

Outcome measures were collected in 1–2 sessions at baseline and within 12 weeks of completing training.

#### 2.4.1 Primary outcome measure

For the primary analyses, IADL were measured with two tasks (see Table 2 for outcome measures used per task). These included the Lawton instrumental activities of daily living scale (total score and each question was also analyzed individually) (Lawton & Brody, 1969) and the Working memory Questionnaire (Vallat-Azouvi et al., 2012). Raw scores were corrected for demographics at baseline assessment based on norm scores where available. None of the outcome measures was used in the training program, thus all measured transfer effects.

#### 2.4.2 Secondary outcome measure

The Working memory index and the Corsi block-tapping test were used to examine participants' ability to recall and manipulate (e.g., reverse) strings of numbers or spatial locations of increasing length (see Table 2 for tasks and outcome measures used for working memory).

**Table 2.** Tasks used for every domain

Domain	Task	Outcome measure
<i>Primary outcome measure</i>		
IADL	Lawton Instrumental activities of daily living: ( <b>Cronbach's <math>\alpha = 0.94</math></b> ).	Number of activities performed: <ul style="list-style-type: none"> <li>- without difficulty (1-14)</li> <li>- some difficulty but without help (1-14)</li> <li>- with help (1-14)</li> </ul>
	e.g. Using the telephone	<ul style="list-style-type: none"> <li>- without difficulty (3)</li> <li>- some difficulty but without help (2)</li> <li>- with help (1)</li> </ul>
	Working memory Questionnaire: ( <b>Cronbach's <math>\alpha = 0.89</math></b> ).	30 questions
	e.g. When you shop, do you often spend more than the budget you set for yourself?	Each question was rated on a five-point Likert-type scale, ranging from 0 ("no problem at all") to 4 ("very severe problem in everyday life"). Three sub-scores were computed, for each of the three domains (maximal score 40 for each), as well as a total score (out of 120). Higher scores corresponded to more difficulties/complaints.
<i>Secondary outcome measure</i>		
Working memory	Working memory Index: Arithmetic task, forward, backward and sequencing digit span. ( <b>Cronbach's <math>\alpha = 0.94</math></b> ).	Age-corrected z-scores of total number of correct items
	e.g. There are 25 gum tablets in each package. How many tablets are there in 8 packages?	
	Corsi block-tapping test: ( <b>Cronbach's <math>\alpha = 0.90</math></b> ).	Number of correct items (forward - backward)

**Note.** IADL = Instrumental activities of daily living.

## 2.5 Background measures

The Montreal Cognitive Assessment was administered to all participants to discard dementia (Nasreddine et al., 2005) (**Cronbach's  $\alpha = 0.75$** ). The Geriatric Depression Scale was also used to discard depression (Yesavage et al., 1982) (**Cronbach's  $\alpha = 0.72$** ).

## 2.6 Sample size

G\*Power 3.1 (Faul et al., 2009) was used to calculate the sample size with  $\alpha = 0.05$ , a power = 90% and two measurements (working memory training vs non-adaptive working memory training). The analysis indicated that a total sample size of  $N \geq 30$  was necessary to detect a significant effect in our study.

## 2.7 Randomization

Participants were randomized into two groups, that is, the intervention group (adaptive working memory training), or the active control group (non-adaptive working memory training) by randomization software (Research Randomizer). This assured minimal differences between groups in level of computer experience, age, education, cognitive screening scores, and sex. This was done as soon as the telephone screening had been administered, thus, before medical files had been received. In case the medical file revealed that a participant did not fulfil in- or exclusion criteria, he or she was contacted to notify them about their exclusion and was replaced by a new participant.

Participants were not informed that one of the training programs was a non-adaptive training. Instead, they were told that the study aimed to compare two types of computer-based cognitive training programs. The groups were coded by the research coordinator such that the assessors were blind to which training condition the participant was assigned. At that moment, 25 participants were included in the intervention group and 25 in the active control group.

## 2.8 Statistical analysis

Before and after treatment, the patients' performance was evaluated by comparing the mean scores obtained in the Lawton Instrumental Activities of daily living, Working Memory Questionnaire, the Working Memory Index and the Corsi Block-tapping test. Data were analyzed using RStudio v. 1.4.1106 and the level of significance was set at  $p < .05$  for all tests. The normality of the data was checked using the Shapiro–Wilks test. Descriptive statistics were calculated as a mean or median (with standard deviation, interquartile range), while categorical variables were presented as percentage frequencies. Student's t-test and Mann–Whitney U test were used to test the significant differences in gains between the two groups. The effect size (Cohen's  $d$ ) was calculated to determine the group difference for each outcome measure. Cohen

suggested that  $d = 0.2$  be considered a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size (Gignac & Szodorai, 2016).

### 3. Results

The flow of participants through the study can be seen in the CONSORT-SPI 2018 diagram (Figure 1).

#### 3.1 Baseline characteristics

Out of 1343 potential participants who were screened, 50 passed all in- and exclusion criteria. However, there were 18 dropouts. Finally, 32 patients were included in the final analyses (see Figure 1 for participant flowchart including drop-out reasons). Prior to training, the two groups did not differ in age, educational level, sex or baseline cognitive functioning except for time since stroke (see Table 1 for scores and statistics). Time since stroke was significantly higher in the adaptive training group ( $p < .05$ ) than the non-adaptive training group.

#### 3.2 Primary outcome measures: active control group

The analysis showed significant differences in the IADL (activities performed without difficulty) after the non-adaptive intervention (Mdn = 10.5, IQR = (9-13); Mdn = 14.0, IQR = (12.5-14.0) ( $p = 0.002$ ), ( $d = 0.79$ )). The study also found significant differences in IADL (activities performed with some difficulty but without help), after the intervention (Mdn = 1.5; IQR = (0.75-4.25); Mdn = 0.0; IQR = (0-1) ( $p = 0.003$ ), ( $d = 1.07$ )). Significant differences were reported when questions were analyzed separately: e.g., using the telephone (Mdn = 2.0, IQR = (2-3); Mdn = 3.0; IQR = (3-3) ( $p = 0.003$ ), ( $d = 2.20$ )) (see Table 3).

#### 3.3 Secondary outcome measures: active control group

Significant differences were only found in sequencing digit span ( $M = 5.37$ ;  $SD = 1.0$ ;  $M = 6.81$ ;  $SD = 1.8$  ( $p = 0.014$ ), ( $d = 1.0$ )).

**Table 3.** Longitudinal change during follow-up (3 months) in primary outcomes (Lawton-Brody Scale, Working Memory Questionnaire) and secondary outcomes (Working Memory Index, Corsi block tapping test) in Active Control Group.  $n = 16$

Variables		Active Control Group $n=16$			
		Initial	Final	$p$	$d$
Lawton-Brody <sup>A</sup>	Number of activities performed without difficulties	10.5 (9-13)	14.0(12.5-14.0)	<b>0.002</b>	0.79
	Number of activities performed with difficulties. No help needed	1.5 (0.75-4.25)	0.0 (0-1)	<b>0.003</b>	1.07
	Number of activities performed with help	0.0 (0.0-1.25)	0.0 (0-0.2)	0.496	0.06
LBI1	You are capable of walking independently outside	3.0(2-3)	3.0(3-3)	0.129	0.38
LBI2	You are capable of walking around the rooms of your house	3.0(3-3)	3.0(3-3)	0.148	0.94
LBI3	You operate the telephone on own initiative- looks up and dial numbers	2.0(2-3)	3.0(3-3)	<b>0.003</b>	2.20
LBI4	You take care of all shopping needs independently	2.5(2-3)	3.0(3-3)	0.070	0.50

Variables	Active Control Group n=16				
		Initial	Final	<i>p</i>	<i>d</i>
LBI5	You take medications in correct dosages at correct time	3.0(1.7-3.0)	3.0(2.7-3.0)	0.071	0.14
LBI6	You open and close windows independently	3.0(3-3)	3.0(3-3)	0.345	0.73
LBI7	You manage financial matters independently	3.0(2.7-3.0)	3.0(3-3)	0.890	0.04
LBI8	You can turn on/off the TV	3.0(3-3)	3.0(3-3)	1.0	0.49
LBI9	You can turn on/off the lights	3.0(3-3)	3.0(3-3)	1.0	0.49
LBI10	You plan, prepare and serve adequate meals independently	3.0(2.7-3.0)	3.0(3-3)	0.586	0.17
LBI11	You can open/close the door with the keys	3.0(3-3)	3.0(3-3)	0.345	0.38
LBI12	You can trim your nails	3.0(2.7-3.0)	3.0(3-3)	1.0	0.10
LBI13	You maintain the house alone or with occasional assistance (light work domestic help)	3.0(3-3)	3.0(3-3)	0.345	0.13
LBI14	You maintain the house alone or with occasional assistance (Hard work domestic help)	3.0(2.7-3.0)	3.0(3-3)	1.0	0.08
WMQ+*	Storage	14.1(5.9)	12.4 (34.1)	0.425	0.085
	Attention	13.0(6.1)	9.2 (38.3)	0.087	0.17
	Executive	9.0(5.6)	8.1(28.7)	0.635	0.05
	Total	36.3 (15.2)	29.8(15.7)	0.237	0.42
	Raw score digits forward	6.62(1.7)	6.5(1.3)	0.823	0.08
	Raw score digits backward	6.43(1.5)	6.43(1.4)	1.0	0.00
	Raw score sequential digits	5.37(1.0)	6.81(1.8)	<b>0.014</b>	1.0
	Total Raw score digits	18.4(3.5)	19.7(3.7)	0.319	0.36
Percentile	Scaled score: digits	8.0(2.2)	8.8(2.0)	0.286	0.38
WMI+**	Raw score: Arithmetic	10.0(1.8)	10.9(2.1)	0.225	0.46
	Scaled score Arithmetic	8.0(1.5)	8.7(1.6)	0.237	0.45
	Percentile: Working memory index	27.4(13.8)	35.3(15.6)	0.141	0.53
Corsi block tapping test <sup>△</sup>	Total: Corsi block tapping test: Forward	4.0 (3.0-4.0)	4.0 (4-4.2)	0.064	0.65
	Total: Corsi block tapping test: Backward	3.0 (3.0-4.0)	4.0 (3-5)	0.064	0.49

**Note.** <sup>△</sup> Median (Interquartile range Q1-Q3); LBI (#): Lawton-Brody Item (#); + Mean (Standard Deviation); \* WMQ: Working memory Questionnaire; \*\*Percentile WMI: Percentile Working memory index.

### 3.4 Primary outcome measures: intervention group

The analysis revealed significant differences in the IADL (activities performed without difficulty) after the adaptive intervention (Mdn = 10.5, IQR = (7.7-12); Mdn = 13.0, IQR = (12-14) ( $p= 0.007$ ), ( $d=1.09$ )). Likewise, this study found significant differences in the IADL (activities performed with help) after the intervention (Mdn = 1.0, IQR = (0.0-0.2); Mdn = 0.0; IQR = (0.0-0.2) ( $p= 0.013$ ), ( $d=0.81$ )). Significant differences were also noted when each question was analyzed separately: e.g., using the telephone (Mdn = 2.0, IQR = (2-3); Mdn = 3.0; IQR = (3-3) ( $p= 0.003$ ), ( $d=1.66$ ), shopping (Mdn = 2.5, IQR = (1-3); Mdn = 3.0; IQR = (3-3) ( $p= 0.030$ ), ( $d=0.62$ ) and handling medications (Mdn = 2.0, IQR = (1-2); Mdn = 3.0; IQR = (2.7-3.0) ( $p= 0.003$ ), ( $d=1.29$ ) (see Table 4).

### 3.5 Secondary outcome measures: intervention group

This study found significant differences in the working memory index ( $M = 34.0$ ;  $SD = 16.7$ ;  $M = 57.8$ ;  $SD = 25.4$  ( $p = 0.004$ ), ( $d = 1.13$ ). Besides, differences were noted in forward ( $M = 6.93$ ;  $SD = 1.3$ ;  $M = 8.31$ ;  $SD = 2.1$  ( $p = 0.041$ ), ( $d = 0.81$ ), backward ( $M = 6.43$ ;  $SD = 1.5$ ;  $M = 8.32$ ;  $SD = 2.0$ ) ( $p = 0.005$ ), ( $d = 1.1$ ) and sequencing digit span ( $M = 6.50$ ;  $SD = 1.8$ ;  $M = 8.31$ ;  $SD = 2.1$ ) ( $p = 0.015$ ), ( $d = 0.92$ ). Finally, differences were also found in the forward Corsi block-tapping test ( $Mdn = 3.5$ ;  $IQR = (3-4)$ ;  $Mdn = 4.0$ ;  $IQR = (4-5)$ ) ( $p = 0.001$ ), ( $d = 1.38$ ) and backward version ( $Mdn = 3.0$ ;  $IQR = (3-3)$ ; ( $Mdn = 4.0$ ;  $IQR = (4.0-4.2)$ ) ( $p = 0.000$ ), ( $d = 1.91$ ).

**Table 4.** Longitudinal change during follow-up (3 months) in primary outcomes (Lawton-Brody Scale, Working Memory Questionnaire) and secondary outcomes (Working Memory Index, Corsi block tapping test) in Active Control Group.  $n = 16$

Variables	Experimental Group		<i>p</i>	<i>d</i>
	n=16			
	Inicial	Final		
Lawton-Brody <sup>▲</sup>				
Number of activities performed without difficulties	10.5 (7.7-12)	13.0(12-14)	<b>0.007</b>	<b>1.09</b>
Number of activities performed with difficulties. No help needed	2.0 (0.75-3.0)	0.5(0.0-1.2)	0.084	0.76
Number of activities performed with help	1.0 (0.0-2.2)	0.0 (0.0-0.2)	<b>0.013</b>	0.81
LBI1 You are capable of walking independently outside	3.0(2-3)	3.0(3-3)	0.070	0.54
LBI2 You are capable of walking around the rooms of your house	3.0(2.7-3.0)	3.0(3-3)	0.071	1.13
LBI3 You operate the telephone on own initiative- looks up and dial numbers	2.0(2-3)	3.0(3-3)	<b>0.003</b>	1.66
LBI4 You take care of all shopping needs independently	2.5(1-3)	3.0(3-3)	<b>0.030</b>	0.62
LBI5 You take medications in correct dosages at correct time	2.0(1-2)	3.0(2.7-3.0)	<b>0.003</b>	1.29
LBI6 You open and close windows independently	3.0(3-3)	3.0(3-3)	1.0	0.0
LBI7 You manage financial matters independently	3.0(3-3)	3.0(3-3)	0.586	0.31
LBI8 You can turn on/off the TV	3.0(3-3)	3.0(3-3)	1.0	0.49
LBI9 You can turn on/off the lights	3.0(3-3)	3.0(3-3)	1.0	0.49
LBI10 You plan, prepare and serve adequate meals independently	3.0(2-3)	3.0(2.7-3.0)	0.66	0.20
LBI11 You can open/close the door with the keys	3.0(3-3)	3.0(3-3)	1.0	0.49
LBI12 You can trim your nails	3.0(2.7-3.0)	3.0(3-3)	0.345	0.21
LBI13 You maintain the house alone or with occasional assistance (light work domestic help)	3.0(3-3)	3.0(3-3)	0.423	0.38
LBI14 You maintain the house alone or with occasional assistance (Hard work domestic help)	3.0(2.0-3.0)	3.0(3-3)	0.129	0.49
WMQ+*				
Storage	15.3(7.5)	12.4(59.5)	0.282	0.04
Attention	13.1(6.5)	11.1(39.6)	0.368	0.08
Executive	10.1(7.0)	7.9(27.9)	0.312	0.12
Total	38.7(18.7)	31.5(18.2)	0.276	0.39
Raw score digits forward	6.93(1.3)	8.31(2.1)	<b>0.041</b>	0.81
Raw score digits backward	6.43(1.5)	8.37(2.0)	<b>0.005</b>	1.1
Raw score sequential digits	6.50(1.8)	8.31(2.1)	<b>0.015</b>	0.92
Percentile				
Total Raw score digits	19.8(2.8)	25.0(5.4)	<b>0.003</b>	1.2
WMI+**				
Scaled score: digits	8.9(1.8)	11.6(2.3)	<b>0.000</b>	1.3
Raw score: Arithmetic	10.3(2.2)	12.1(3.6)	0.104	0.62

Variables	Experimental Group				
	n=16		p	d	
	Inicial	Final			
	Scaled score Arithmetic	8.2(1.7)	9.87(2.8)	0.065	0.74
	Percentile: Working memory index	34.0(16.7)	57.8(25.4)	<b>0.004</b>	<b>1.13</b>
Corsi block tapping test <sup>^</sup>	Total: Corsi block tapping test: Forward	3.5 (3.0-4.0)	4.0(4.0-5.0)	<b>0.001</b>	<b>1.38</b>
	Total: Corsi block tapping test: Backward	3.0 (3.0-3.0)	4.0(4.0-4.2)	<b>0.000</b>	<b>1.91</b>

**Note.** <sup>^</sup> Median (Interquartile range Q1-Q3); LBI (#): Lawton-Brody Item (#); + Mean (Standard Deviation); \* WMQ: Working memory Questionnaire; \*\*Percentile WMI: Percentile Working memory index.

### 3.6 Active control Group vs. intervention group: primary outcome measures

For the primary measures in IADL and Working Memory Questionnaire, none of the comparisons between the groups were significant (see Table 5).

### 3.7 Active control group vs. intervention group: secondary outcome measures

The analysis showed that after the training the intervention group improved to a significantly amount in the working memory index compared with the active control group (M = 57.8; SD = 25.4; M = 35.3; SD = 15.6) (p= 0.005), (d=1.09). Similar results were also shown for the forward digit span that the intervention group improved compared with the active control group (M = 8.31; SD = 2.1; M = 6.5; SD = 1.3) (p= 0.009), (d=1.0), backward digit span (M = 8.37; SD = 2.0; M = 6.43; SD = 1.4) (p= 0.004), (d=1.1) and sequencing digit span (M = 8.31; SD = 2.1; M = 6.81; SD = 1.8) (p= 0.017), (d=0.76).

**Table 5.** Comparison of performance in primary outcomes (Lawton-Brody Scale, Working Memory Questionnaire) and secondary outcomes (Working Memory Index, Corsi block tapping test) between the experimental and active control groups at follow-up (3 months) n = 32

Variables		Active control	Experimental	Comparison	d
		Group	Group n=16	(A.C.G vs	
		n=16	n=16	E.G)	
		Follow-up	Follow-up	p	
		Assessment	Assessment		
Lawton- Brody <sup>^</sup>	Number of activities performed without difficulties	14.0(12.5-14.0)	13.0(12-14)	0.598	0.00
	Number of activities performed with difficulties. No help needed	0.0 (0-1)	0.5(0.0-1.2)	0.258	0.20
	Number of activities performed with help	0.0 (0-0.2)	0.0 (0.0-0.2)	0.823	0.19
LBI1	You are capable of walking independently outside	3.0(3-3)	3.0(3-3)	0.742	0.0
LBI2	You are capable of walking around the rooms of your house	3.0(3-3)	3.0(3-3)	1.0	0.0
LBI3	You operate the telephone on own initiative- looks up and dial numbers	3.0(3-3)	3.0(3-3)	0.348	0.49
LBI4	You take care of all shopping needs independently	3.0(3-3)	3.0(3-3)	1.0	0.0

Variables		Active control	Experimental	Comparison	<i>d</i>
		Group n=16	Group n=16	(A.C.G vs E.G)	
		Follow-up Assessment	Follow-up Assessment	<i>p</i>	
LBI5	You take medications in correct dosages at correct time	3.0(2.7-3.0)	3.0(2.7-3.0)	0.861	0.17
LBI6	You open and close windows independently	3.0(3-3)	3.0(3-3)	0.348	0.49
LBI7	You manage financial matters independently	3.0(3-3)	3.0(3-3)	0.279	0.0
LBI8	You can turn on/off the TV	3.0(3-3)	3.0(3-3)	1.0	0.0
LBI9	You can turn on/off the lights	3.0(3-3)	3.0(3-3)	1.0	0.0
LBI10	You plan, prepare and serve adequate meals independently	3.0(3-3)	3.0(2.7-3.0)	0.488	0.09
LBI11	You can open/close the door with the keys	3.0(3-3)	3.0(3-3)	0.348	0.49
LBI12	You can trim your nails	3.0(3-3)	3.0(3-3)	0.676	0.11
LBI13	You maintain the house alone or with occasional assistance (light work domestic help)	3.0(3-3)	3.0(3-3)	0.575	0.21
LBI14	You maintain the house alone or with occasional assistance (Hard work domestic help)	3.0(3-3)	3.0(3-3)	0.889	0.22
WMQ+*	Storage	12.4 (34.1)	12.4(59.5)	1.0	0.00
	Attention	9.2 (38.3)	11.1(39.6)	0.402	0.04
	Executive	8.1(28.7)	7.9(27.9)	0.921	0.00
	Total	29.8(15.7)	31.5(18.2)	0.779	0.10
	Raw score digits forward	6.5(1.3)	8.31(2.1)	<b>0.009</b>	1.0
	Raw score digits backward	6.43(1.4)	8.37(2.0)	<b>0.004</b>	1.1
	Raw score sequential digits	6.81(1.8)	8.31(2.1)	<b>0.017</b>	0.76
	Total Raw score digits	19.7(3.7)	25.0(5.4)	<b>0.003</b>	1.1
Percentile	Scaled score: digits	8.8(2.0)	11.6(2.3)	<b>0.000</b>	1.3
WMI+**	Raw score: Arithmetic	10.9(2.1)	12.1(3.6)	0.274	0.42
	Scaled score Arithmetic	8.7(1.6)	9.87(2.8)	0.189	0.53
	Percentile: Working memory index	35.3(15.6)	57.8(25.4)	<b>0.005</b>	<b>1.09</b>
Corsi block tapping test <sup>Δ</sup>	Total: Corsi block tapping test: Forward	4.0 (4.0-4.2)	4.0(4.0-5.0)	0.661	0.05
	Total: Corsi block tapping test: Backward	4.0 (3-5)	4.0(4.0-4.2)	0.292	0.16

**Note.** <sup>Δ</sup> Median (Interquartile range Q1-Q3); LBI (#): Lawton-Brody Item (#); + Mean (Standard Deviation); \* WMQ: Working memory Questionnaire; \*\*Percentile WMI: Percentile Working memory index.

#### 4. Discussion

The aim of the current study was to evaluate whether a computer-based brain training improves IADL and WM after stroke. With this training program, we found that participants improved on several outcome tasks. Upon comparing the groups, it was found that the intervention group did not exhibit significant improvement in the primary outcome measures compared to the active control group. However, significant differences were observed in the secondary outcome measures. This implies that far transfer effects of training were small and may be explained

largely by variables unrelated to the training, such as the level of engagement and motivation of the participants.

A potential limitation in the WM training field mentioned in the introduction section was whether studies without proper control groups can draw conclusions about transfer effects. The improvements after three months corroborate findings of previous WM training studies for patients with stroke (Lundqvist et al., 2010; Zhou et al., 2022). Therefore, if the results of the intervention group are not compared to those of the active control group, this study would have concluded that the intervention training was effective. This work also showed that a positive within-group effect does not imply an effect of training because the time effect may not differ from the one seen in the active control group. These results highlight the importance of including active control conditions in the study design and analyses.

In the current study, there were baseline differences in the time after stroke variable between both groups. Therefore, we performed a correlation analysis using the Pearson or Spearman test (depending on the normality distribution) to examine the relationship between time after stroke and primary and secondary outcome measures, both at baseline and follow-up. Since none of the comparisons showed significant differences, no further control measures were necessary. It is therefore unlikely that time after stroke accounted for the training effect.

With the same outcome measures as used in the current study, one study did report within-group transfer effects of training to functional independence and WM (van de Ven, Murre, et al., 2017). However, the intervention group did not improve more than the active control group. This suggests that improvement was also due to training unspecific effects (Increased motivation, practice effects, placebo effects, enhanced attention and arousal, social interaction or support, task engagement). A limitation is that only a small number of tasks per cognitive domain was used. It is important, however, to use multiple outcome measures per cognitive domain because an improvement in a small selection of outcome measures taxing the same function is less convincing than improvement on several outcome measures within a function (van de Ven, Buitenweg, et al., 2017).

From a methodological standpoint, it is surprising that only half of the studies in this field compare the effects of the intervention group to an active control group (Au et al., 2020). Therefore, to discuss if an intervention can improve both cognitive and functional skills, the only difference between groups should be the task's level of difficulty (Tam et al., 2022). Furthermore, participants should perceive the alternative intervention as a believable and potentially effective cognitive training. Ideally, training conditions for the different groups should be as similar as possible to control for motivational and psychological effects such as the

Hawthorne effect, which refers to improvements in performance due to increased attention to the participants' behavior (von Bastian & Oberauer, 2014).

The intervention group was exposed to specific tasks aimed at improving WM. Therefore, processing and storage skills were trained to (a) hold information for a limited amount of time and (b) improve problem solving skills (Nikraves et al., 2021). The latter also implies neural plasticity. In fact, CRUNCH theory (The Compensation-Related Utilisation of Neural Circuits Hypothesis) predicts that brain activity in areas related to WM should change due to cognitive training (Jamadar, 2020). Simultaneously, cognitive training (a) reduces brain activation when demand is low and this would explain that compensatory overactivation is useless and (b) brain activity would increase if the demand were high (Lustig et al., 2009).

This work also performed a rigorous cognitive training and participants received feedback according to their performance. Likewise, the design of the training lowered the automation of tasks (Morrison & Chein, 2011) and strengthened skills related to maintaining information when interference takes place (Jaeggi et al., 2017). In the experimental group, the task difficulty was adjusted during training in each trial, the amount of information that the patient had to recall was adjusted to what he/she could actually retrieve. Thus, patients in the experimental group were always involved in each task that were neither too difficult nor too easy (Schmiedek et al., 2010).

This method is different from other studies focused on WM training. For instance, it was not designed to teach explicit strategies like metacognitive strategies (Bozorgian et al., 2020). Besides, computerized tasks can not only be adjusted but also calibrated according to the skills of each participant (Tsolaki et al., 2017).

On the other hand, this study found that both the experimental group and the active control group were equivalent in the sociodemographic and clinical variables reported and no significant differences were found but time after stroke. Others have also reported between groups differences related to time after stroke (Buitenweg et al., 2017). However, when these differences were controlled using similar statistical procedures, they do not explain the findings. Future research should study if there is a time window after stroke when cognitive training is more effective.

#### **4.1 Longitudinal changes in primary outcomes from the active control group**

Regarding the active control group, this study found significant differences both in the number of activities performed without difficulties and the number of activities performed with difficulties, but no help needed. Likewise, these findings show that before the intervention, participants could use the phone with some difficulties, but no help was needed and after the

intervention participants could use the phone without difficulties. This task involves higher cognitive processes to be performed (look up for the desired number, make the call).

Since the active control group was also involved in training, these changes were expected. However, the level of difficulty was lower and progressive than the experimental group. This is a difference with other studies since most works keep a fixed level of difficulty (Brehmer et al., 2012). Based on these findings, even low intensity cognitive training may be beneficial since people after stroke are often restricted in their ability to participate optimally in the community (Verghese et al., 2021). Therefore, this intervention demonstrated substantial efficacy in eliciting far transfer effects in IADL. However, these effects were stronger in the experimental group.

#### **4.2 Longitudinal changes in secondary outcomes from the active control group**

Significant differences were found in the raw score of the sequential digits. This intervention produced benefits in a single subtest that is alike to the cognitive training. Thus, generalization is limited and this might not reflect an increase in the WM general capacity as previously reported (Bergman-Nutley & Klingberg, 2014).

#### **4.3 Longitudinal changes in primary outcomes from the experimental group**

The experimental group reported significant differences in the number of activities performed without difficulties and the number of activities performed with help. Differences were also found in the ability to operate the telephone on own initiative but also to take care of all shopping needs independently and to take medications in correct dosages at correct time. After the intervention, participants performed these activities without difficulties. These findings are consistent with other studies focused on the effects of cognitive training on functional independence (Karbach & Schubert, 2013). Particularly, it was proved that adapting the level of difficulty of the task stimulated brain plasticity mechanisms to strength functional independence (Shipstead et al., 2010). It also promotes cognitive processes related to codification, inhibition, multitasking, set-shifting (Borella et al., 2019), learning and far transfer mechanisms.

In regard to daily living skills, this cognitive training improved problem-solving strategies, monitoring and planning skills (to operate the telephone on own initiative, to take care of all shopping needs independently and to take medications in correct dosages at correct time) (Mograbí et al., 2014). This study supports evidence from previous observations where cognitive training stimulates mechanisms that rely on WM like categorization (Constantinidou, 2019). This skill is related to arranging stimuli to perform a task but also explains how human beings organize and plan information to cope with highly demanding situations (Regev & Josman, 2020).

#### **4.4 Longitudinal changes in secondary outcomes from the experimental group**

This study found significant differences in the WM index and the Corsi block tapping test performance. These findings are consistent with other works that showed that adjusting the level of difficulty of the intervention is key to improve the phonological loop efficiency (storing information) (Spencer-Smith & Klingberg, 2015). This is also a major finding to improve more active components of WM like the central executive (Lee, 2015). Besides, adapted WM training has shown to improve cognitive processes connected to the phonological loop, visuospatial sketchpad and the episodic buffer. This implies a better performance in set-shifting tasks (Saito & Miyake, 2004).

Thereafter, this research evidenced that the adapted cognitive training transfer effects are not restricted to learning a single task. Conversely, it also improved generalization abilities of patients with poststroke cognitive impairment (Etherton et al., 2019). However, this study did not support the findings of previous studies that showed limited improvement to short term retrieval of information despite the similarities of the intervention (McAvinue et al., 2013).

#### **4.5 Comparing active control group with experimental group for examining the effects of working memory training at follow-up**

In this clinical trial, the adapted cognitive training did not improve IADL in adults after stroke when compared to an active control group. However, significant differences were reported in WM tasks, particularly, the experimental group had better performance in the WM index after the intervention. These findings are in line with previous studies that showed better cognitive performance after 5-week training (Westerberg et al., 2007) but do not support others who failed to prove better cognitive performance after 8-week training (Wentink et al., 2016).

On the other hand, our results support near transfer effects after the intervention. These findings clear up the notion that cognitive performance cannot improve after an intervention in stroke populations (Richmond et al., 2011). Instead, this study showed that the lack of near transfer in other studies can be related to the selection of inappropriate measures of WM. A systematic review found three studies that reported little to no near transfer effects after WM training (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008; Li et al., 2015). Thus, this study hypothesizes that near transfer effects are due to a better ability to store and manipulate information in WM after the intervention (Nikraves et al., 2021).

Nevertheless, adapted cognitive training may only be effective under certain circumstances. For instance, some authors suggest that home-based WM training is less effective than lab-based interventions since these involve one-on-one supervision to ensure task completion, technical and emotional support (Lampit et al., 2014). Still, this study verified that technical support, daily

and weekly feedback about individual performance were always available. In fact, throughout the study's progression, no participants withdrew from the research. The lack of significant findings in the primary outcomes agree with others that did not show improvements neither in IADL (Prokopenko et al., 2013) nor quality of life questionnaires (Lundqvist et al., 2010). Most likely, future studies should involve larger, more intensive interventions to show far transfer effects in IADL (van de Ven et al., 2016). For example, a recent study showed significant differences in IADL when comparing an active control group and an experimental group (De Luca et al., 2016). However, the methodology employed in this study, leading to the obtained results, lacks clarity.

Also, adapted cognitive training may be more effective after acute stroke. However, positive findings from the previous study may be the cause of an early assessment after the episode also known as spontaneous recovery (Westerberg et al., 2007).

Finally, to induce far transfer effects in IADL, cognitive training should be coupled with physical activity (Verghese et al., 2021). Previous findings suggest transfer effects in WM but also in functional independence (Joubert & Chainay, 2018). A recent study showed that 62 healthy adults between 65 and 93 years old trained with Cognitifit and physical activity during 4 months and found better performance in WM tasks and other domains in a group of 60 adults that were involved in a single physical activity program (Shatil, 2013).

## **5. Clinical Implications**

This study highlights that adapted WM training fosters neuroplasticity and enhances cognitive processes crucial for functional independence in post-stroke populations. By tailoring task difficulty to individual capacity and integrating feedback mechanisms, the intervention not only strengthened WM capacity but also facilitated far transfer effects, such as improved IADL. These findings underscore the value of personalized cognitive training approaches in stimulating executive functions, problem-solving strategies, and planning abilities essential for daily life. Furthermore, the demonstrated improvements in WM and related cognitive domains align with mechanisms outlined by the CRUNCH theory, suggesting that cognitive interventions can effectively modulate neural activity in response to varying task demands.

Despite the promising results, the study emphasizes the need for larger and more intensive interventions to induce substantial improvements in IADL across broader populations. While near transfer effects were observed, the lack of significant gains in primary outcomes such as overall functional independence aligns with prior research indicating the importance of multimodal interventions. Incorporating physical activity or addressing the timing of cognitive training, particularly during acute recovery phases, may optimize outcomes. These findings suggest that cognitive training should be further refined to maximize its efficacy in supporting

recovery and long-term functional independence in individuals with post-stroke cognitive impairments.

### **Ethical approval**

The study was performed with human subjects in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments and the study procedure was approved by the ethics committee of the Instituto Neurológico de Colombia (reference no. 449011-19.02-013).

### **Informed Consent Statement**

Informed consent was obtained from all subjects involved in the study.

### **Data Availability Statement**

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

### **Conflict of Interest Statement**

The authors declare that the research was conducted in the absence of any potential conflict of interest.

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### **Authors' Contribution**

DL: Conceptualization, methodology, investigation, writing original draft, project administration. DM: conceptualization, resources, writing – review and editing, supervision. AA: Validation, resources, writing – review and editing. JF: Methodology, software, formal analysis, data curation.

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