Journal of Stroke and Cerebrovascular Diseases 35 (2026) 108640

Contents lists available at ScienceDirect

Journal of Stroke and Cerebrovascular Diseases

journal homepage: www.elsevier.com/locate/jstroke

# Telerehabilitation vs face-to-face computer-based cognitive training in stroke patients: a randomized controlled trial

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ARTICLE INFO

*Keywords:*
Cerebrovascular accident
Cognitive rehabilitation
Telemedicine
Home-based rehabilitation
Cognition disorders

ABSTRACT

*Introduction:* Cognitive deficits are common after stroke, significantly affecting functional independence, quality of life, and long-term outcomes. Computer-based cognitive rehabilitation has shown efficacy in improving attention, memory, and executive functions, but access to in-person therapy is often limited. Telerehabilitation can be a practical alternative by enabling participants to perform tailored exercises remotely while clinicians monitor progress.

*Objectives:* This single-blind randomized controlled trial investigated the effectiveness of computer-based cognitive training delivered remotely (telerehabilitation) versus the same intervention delivered face-to-face in subacute post-stroke participants.

*Methods:* Thirty-nine participants were enrolled and randomized into one of the two groups. All participants underwent 3-hours/week rehabilitation over eight weeks using a technology device for cognitive rehabilitation. Cognitive outcomes were assessed at baseline, post-treatment, and two-month follow-up using cognitive tests (Trail Making Test, Rey Auditory Verbal Learning test, Rey-Osterrieth Complex Figure test, Memory with Interference test, and Dual Task), mood and quality of life questionnaires.

*Results:* Comparable improvements in visual attention, verbal and visuo-spatial long-term memory were observed for both groups at post-treatment and follow-up. Working memory and dual-task performances did not show significant changes. Anxiety, depressive symptoms, and quality of life remained unchanged after intervention.

*Conclusion:* These findings suggest that telerehabilitation may yield cognitive improvements similar to those of face-to-face treatment. Nonetheless, telerehabilitation appears to be a feasible and accessible option for post-stroke patients.

## Introduction

Stroke is a clinical syndrome characterized by the sudden onset of a focal (rarely global) neurological impairment that persists for >24 h or leads to death and is caused by the closure (ischemic stroke) or rupture (hemorrhagic stroke) of a cerebral artery.[1] Following the acute event, various disorders may emerge, impairing functional capacity. Among the leading causes of disability after a stroke, cognitive deficits play a significant role. The most affected functions include executive functions with a prevalence ranging from 25 to 75 % of patients,[2] memory and attention with an incidence ranging from 23 % to 55 % and from 24 % to 51 %, respectively.[3,4] Cognitive deficits after stroke are linked to worse long-term outcomes, including dependence, depression, and mortality.[5] They can limit the patient's ability to resume work and daily activities and create a significant burden on patients, families and society.[5–7]

Non-pharmacological approaches play a key role in the recovery of these disorders, including cognitive rehabilitation.[8] A lot of studies indicated positive effects of cognitive rehabilitation on

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https://doi.org/10.1016/j.jstrokecerebrovasdis.2026.108640
Received 23 February 2026; Received in revised form 13 April 2026; Accepted 20 April 2026
Available online 20 April 2026

neuropsychological functions by addressing skills with specific exercises and activities in domains such as attention, memory, and executive functioning, which directly influence safety and performance in everyday and instrumental activities of daily living (e.g., managing medications, finances, and appointments).[9] Despite the critical role of cognitive rehabilitation in post-stroke recovery, its accessibility remains limited. The healthcare system primarily supports patients during the initial stages of recovery, often leaving the long-term rehabilitation process in the hands of patients and their families.[10] In this context, telerehabilitation represents a viable solution, offering remote access to rehabilitation services and enabling continuous monitoring of patients beyond the acute phase.[11] In other conditions, such as chronic heart failure, neck pain, or fibromyalgia, asynchronous telerehabilitation, in which patients independently perform prescribed cognitive exercises via digital platforms, while clinicians review progress and provide feedback at a later time, further enhanced sustainability by reducing economic and personnel resource demands, while maintaining effectiveness and cost-efficiency.[12–14] Systematic reviews and meta-analyses have indicated that telerehabilitation provides advantages such as improved quality of life during the discharge phase for stroke survivors and their caregivers,[11] including motor,[15] and cognitive function.[10,16] The literature on the effectiveness of telerehabilitation on cognitive functions is still limited,[17] and most research on stroke patients primarily focuses on motor telerehabilitation, evaluating its impact on motor function, while its effects on cognitive abilities are considered only as a secondary outcome.

Moreover, most studies compare standard in-person treatment with telerehabilitation without directly assessing the efficacy of using the same device in person versus remotely and asynchronously. Computer-based cognitive rehabilitation makes it possible to deliver the same treatment across different contexts. In the last decade there has been increasing interest in the development and implementation of computer-based cognitive rehabilitation, and this approach has shown positive effects in recovering attention, memory, and executive functions in stroke patients.[18–22] This approach also demonstrated greater effectiveness in individual cognitive domains and overall functioning than standard cognitive treatment.[23,24] This is likely due to several advantages of computer-based rehabilitation: the possibility of automatic adaptation of task difficulty according to patients' performance, immediate and quantitative feedback on performance, higher engagement and adherence to the treatment thanks to the interactive features and standardized delivery.[17] Based on what was previously discussed, the study aims to evaluate whether computer-based cognitive rehabilitation delivered via telerehabilitation for post-stroke participants leads to cognitive improvements similar to those achieved with the same intervention delivered face-to-face.

## Material and methods

### *Study design*

A single-blind randomized controlled trial (RCT) was conducted in a cohort of stroke participants in the subacute phase. All participants were informed about the study procedures and provided written informed consent before taking part in the study. The study was carried out according to the Declaration of Helsinki and was approved by the Local Ethics Committee on 9th March 2022 (approval number 3623CESC). The study was reported in accordance with the CONSORT guidelines, and the protocol was registered on Clinical Trials (NCT06795672).

### *Subjects*

Participants with ischemic or hemorrhagic stroke referred to the Neurorehabilitation Unit of the University Hospital of Verona were included in the study. They were recruited from March 2022 to November 2023. The inclusion criteria were: age between 18 and 90 years; first stroke event; time from onset between 30 and 180 days (subacute phase); adequate level of comprehension defines as a score = 3 on the semantic trial assessed by Oxford Cognitive Screen (OCS);[25] presence of attention, and/or memory, and/or executive functions impairments assessed by OCS; availability of internet access at the patient's home necessary for telemedicine procedures. Exclusion criteria were: other neurological disorders; history of dementia; psychiatric diseases not pharmacologically compensated; alcohol and/or drug abuse; visual or auditory impairments that preclude the administration of the scales. A total of 39 participants was enrolled at baseline; 32 completed the post-treatment assessment and 23 the follow-up. A flow diagram of the study is shown in Fig. 1.

### *Randomization, allocation, and blinding*

Participants were randomly allocated to one of two groups: the Experimental Group (EG) or the Control Group (CG) using a 1:1 randomization sequence. Allocation to the intervention arms was performed by an external investigator (V.V.) according to a balanced software-generated randomization scheme (www.randomizer.org).

### *Intervention and procedures*

Both groups underwent cognitive treatment for 3 h per week for a total of eight weeks (24 h of rehabilitation intervention), using the computerized tool Neurotablet®.[26] Neurotablet® is a multi-platform neurocognitive rehabilitation software distributed by Neurab S.R.L. (Rovereto, Italy) and preinstalled on a Samsung Tab A tablet. It is CE (Conformité Européenne) marked and registered as a medical device.[26] The device contains a variety of customizable exercises (e.g. type and number of stimuli) by the therapist based on participants' impairments, divided into six cognitive domains: attention, memory, executive functions, language, perception, and neglect.

#### *Experimental group (EG)*

The EG performed independent and remote computer-based cognitive treatment (telerehabilitation) with the device. Each patient received an electronic device and login credentials to access their account. They engaged in various cognitive exercises remotely programmed and updated remotely every week by a neuropsychologist (Y.G.) based on the patient's specific therapy goals and progress, modifying the level or type of exercises. The exercises, which targeted memory, attention, and executive functions, consisted of multiple trials lasting approximately one minute, with a total duration of about 10 min per exercise. During each rehabilitation session, participants completed six exercises, using the device for a total of one hour per session, three times per week.

#### *Control group (CG)*

The CG received face-to-face computer-based cognitive treatment with the electronic device for 1 h per session, three times per week under the supervision of a neuropsychologist (Y.G. or R.B.). The therapist selected exercises for each session, adjusting activities and difficulty levels in real-time based on participants' specific therapy goals and progress.

### *Data collection and assessment procedures*

The evaluation protocol was administered by a blinded observer to group assignment (E.E.) before (T0), after 8 weeks of treatment (T1), and two months after the end of the treatment (T2).

#### *Primary outcome*

The primary outcome was the Trail Making Test part B (TMT B), which evaluates the ability to switch attention between two rules or tasks. The time taken to complete the trials was recorded (shorter time indicates better performance).[27] This test was chosen as the primary

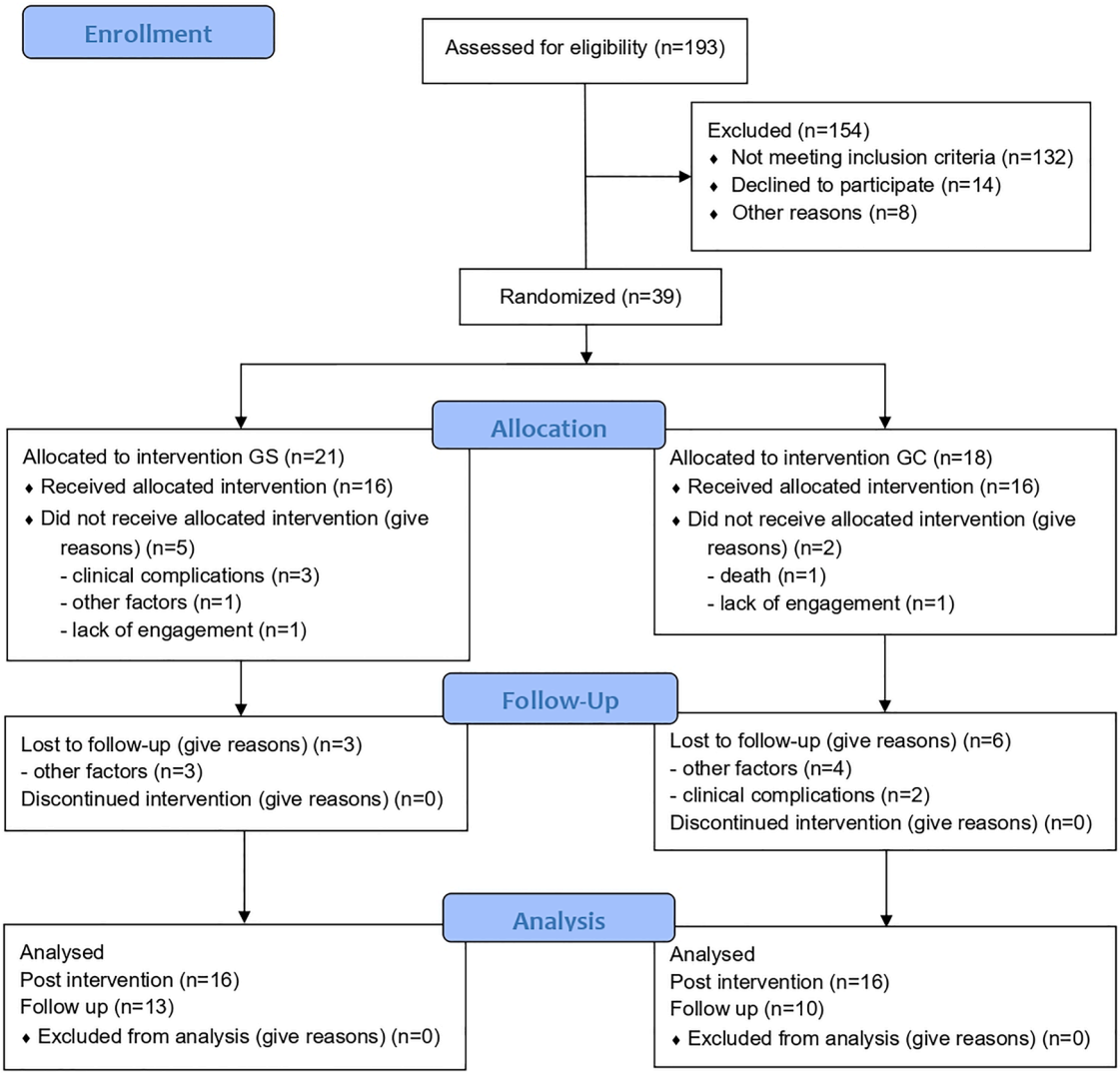


**Fig. 1.** .Flow diagram.

outcome because executive functions strongly predict functional recovery and independence after stroke, compared to other cognitive domains, making them particularly relevant from a clinical perspective.[28,29] Specifically, the Trail Making Test–Part B was selected as it is one of the most widely used and well-established measures of executive functioning at different stages of stroke recovery.[30]

*Secondary outcomes*

Other cognitive measures were chosen as secondary outcomes.

Trail Making Test A (TMT A) evaluates attentional ability, selective attention, psychomotor speed, and sequencing skills. The time taken to complete the trials was recorded (shorter time indicates better performance).[27]

Rey Auditory Verbal Learning test (RAVL) evaluates learning (RAVL-I) and long-term delayed recall (RAVL-D) of verbal information. The number of recalled words was recorded (higher scores indicate better performance).[31]

The Rey-Osterrieth Complex Figure Test (ROCF) assesses constructional praxis skill and visuospatial memory abilities. Participants copy a complex figure (ROCF-I) and later reproduce it from memory (ROCF-D); the score, reflecting drawing accuracy, is recorded (higher scores indicate better performance).[32]

Memory with Interference Test (MI) (30 s version) evaluates working memory, the ability to hold information (string of three letters) while performing a distracting task lasting 30 s (counting by twos starting from a number that will vary each time). The number of correctly recalled letters in the correct order is recorded across three trials (higher scores indicate better performance).[33]

Dual Task (DT) evaluates attention ability and divided attention. An index score comparing single-task and dual-task performances was calculated (higher scores indicate better performance).[34]

In addition, questionnaires were administered to explore mood and quality of life.

Hospital Anxiety and Depression Scale (HADS) evaluates the presence and severity of depression and anxiety, with higher scores indicating an improvement (cut-offs: 0–7=normal, 8–10=mild impairment, 11–14=moderate impairment, 15–21=severe impairment).[35]

Short Form Health Survey 36 (SF-36) evaluates health-related quality of life. It consists of 36 questions grouped in 8 subscales (physical functioning - 10 items, disadvantages due to physical health - 4 items, limitations due to emotional problems - 3 items, energy and fatigue - 4 items, emotional well-being - 5 items, social activities - 2 items, pain - 2 items, perception of general health - 5 items) (higher scores indicate a better quality of life).[36] In this study, we have considered only the subscale perception of general health.

*Statistical analysis*

Data were analyzed using IBM SPSS software version 26.0 for Macintosh (IBM Corp., Armonk, NY, USA). Normal distribution of data was determined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The normally distributed variables were analyzed with two-way mixed ANOVA with a between-individual factor "group" and a within-individual factor "time" (pre-treatment, post-treatment, and follow-up).

The other variables were analyzed with non-parametric tests. The Mann–Whitney U-test was used to compare the effects of treatment between the two groups, and with the Wilcoxon signed-rank test for within-group comparison.

Statistical significance was set at $p < 0.05$. Significant effects were followed by Bonferroni-corrected for post hoc pairwise comparisons. Given the two planned contrasts (pre-treatment vs. post-treatment; pre-treatment vs. follow-up), the adjusted alpha level was set at $p < 0.025$.

## Results

A total of 39 individuals (29 men, 10 women, age: 61,79 ± 12,77 years; education: 10,05 ± 4,41 years) presenting with stroke (time from event: 96,67 ± 57,05 days; type of lesion: ischemic (n = 30), hemorrhagic (n = 9); location: right hemisphere (n = 18), left hemisphere (n = 21)) were recruited among 294 individuals referred to the Neurorehabilitation Unit of University Hospital of Verona, Italy, between March 2022 and November 2023. Thirty-two individuals completed the training program and post-treatment evaluation, and 23 participants completed follow-up assessment. A flow diagram of the study is shown in Fig. 1.

*Baseline*

Among outcome measures: RAVL-I, RAVL-D, ROCF-I, ROCF-D, DT, SF-36 scores were normally distributed (Kolmogorov–Smirnov and Shapiro–Wilk tests, $p > 0.05$). There were no statistically significant differences in age (years, p = 0,40), education (years, p = 0,59), and time from onset (days, p = 0,17) between the two groups before treatment. There were no statistically significant differences in primary (TMT B, p = 0,12) and secondary outcome measures (TMT A p = 0,29; RAVL-I p = 0,06; RAVL-D p = 0,22; ROCF-I p = 0,84; ROCF-D p = 0,86; MI p = 0,72; DT p = 0,23; HADS p = 0,57; SF-36 p = 0,89) between the EG and the CG before treatment.

*Primary outcome*

Analysis revealed no statistically significant differences between the EG and the CG after treatment (TMT B p = 0.252, z=−1,184) and at follow-up (TMT B p = 0,083, z=−1,734). Within-group comparison showed no significant changes in the TMT B scores pre-treatment versus post-treatment for both groups (EG, p = 0,972, z=−0,35; CG, p = 0,123; z=−1,540) and pre-treatment versus follow-up for both group (EG, p = 0,236, z=−1,186; CG, p = 0,027; z=−2,207).

*Secondary outcomes*

For the secondary outcome measures analyzed with non-parametric tests, the between-group comparison showed no statistically significant differences in TMT A, MI and HADS between the EG and the CG after treatment. No statistically significant differences between the EG and the CG groups were found in TMT-A, MI, and HADS at pre-treatment and follow-up. For the outcome measures analyzed with parametric tests, ANOVA revealed no group effect for RAVL-I (F = 2,587; p = 0,127), RAVL-D (F = 2,28; p = 0,151), ROCF-I (F = 0,008; p = 0,931), ROCF-D (F = 0,528; p = 0,478), DT (F = 0,708; p = 0,413), SF-36 (F = 0,421; p = 0,526).

The within-group comparison for non-normally distributed measures showed significant changes in pre-treatment versus post- treatment scores for the EG and CG in the TMT A. Table 1 presents the group data and results of the within-group comparison for outcome measures analyzed with non-parametric tests.

ANOVA revealed a principal significant effect of "time" for RAVL-I (F = 13,591; p = 0,000; $\eta$=0,555), RAVL-D (F = 12,982; p = 0,000; $\eta$=*0,556*), ROCF-I (F = 3,635; p = 0,038; $\eta$=0,185), and ROCF-D (F = 9,276; p = 0,001; $\eta$=0,367).

Post hoc comparisons revealed significantly higher scores at post-treatment compared to pre-treatment for RAVL-I, RAVL-D, and ROCF-D in both the CG and the EG group, with both groups improving significantly also at follow-up. No significant differences in ROCF-I performance were observed across time points.

Table 2 presents the group data and results for outcome measures analyzed with parametric tests.

## Discussion

In this single-blind randomized controlled trial, we compared changes in cognitive domains' scores after computer-based cognitive treatment delivered via telerehabilitation or face-to-face in post-stroke subjects. Specifically, the objective of the study is to assess whether a cognitive treatment administered through telerehabilitation is comparable to the same treatment administered face-to-face.

Results show an overall overlap between the two intervention modalities, suggesting a similar effect on cognitive function in subacute post-stroke participants who received a computer-based cognitive treatment delivered either via telerehabilitation or through face-to-face modalities. These findings are consistent with evidence from systematic reviews and meta-analyses indicating that telerehabilitation offers several advantages, including improvements in quality of life during the post-discharge phase for stroke survivors and their caregivers,[11] as well as benefits in cognitive functioning.[10,16] Moreover, previous studies have demonstrated the efficacy of telerehabilitation across specific cognitive domains, such as visual selective attention,[37] verbal memory,[16–39] and visuospatial long-term memory.[40] However, literature remains limited for other domains, such as praxis abilities. Despite this, taken together with the existing evidence, our findings suggest that telerehabilitation and face-to-face interventions may be comparable in their overall effectiveness.

Concerning the attentional domain, both the telerehabilitation and the face-to-face group showed significant improvements in visual selective attention (TMT A) after treatment, which were not maintained at follow-up. In line with our results, a 2019 review found short-term, but non-lasting improvements in attentional functioning following cognitive rehabilitation in post-stroke patients.[37] More recently, a 2023 study reported improvements in visual attention following 60-minute weekly telerehabilitation sessions in a small group.[41]

Similarly to attention, our data showed a significant improvement in the memory domain in both groups. Specifically, participants after treatment increased their long-term verbal memory ability (RAVL-I, RAVL-D). These results are in line with previous literature. The study by Jung et al.[38] showed that computer-based face-to-face cognitive rehabilitation (30 min sessions, 5 times per week) had positive effects on verbal learning and delayed recall in stroke patients. As reported by another study,[39] the improvement in memory abilities was maintained at follow-up in the telerehabilitation group. Furthermore, our data indicated a lasting effect of rehabilitation also in the face-to-face.

Moreover, both groups demonstrated a significant improvement in visuospatial long-term memory (ROCF-D) following the treatment, which was maintained at follow-up. These data are in accordance with other findings, which showed improvement after a computer-based in-person cognitive rehabilitation program (30 min sessions, 5 times per week).[40] To our knowledge, our study is the first one to investigate the effects of cognitive telerehabilitation on visuospatial long-term memory and its maintenance at follow-up.

**Table 1**
Within-group comparisons for outcome measures analyzed with non-parametric tests.

| Outcome | Rehabilitation Program | Pre-Treatment | Post-Treatment | Follow-up | Within-group comparison | |
|---|---|---|---|---|---|---|
| | | | | | post vs. pre-treatment *p-value (95 % CI)* | Follow-up vs pre-treatment *p-value (95 % CI)* |
| TMT B (seconds) mean (SD) | EG | 196,62 (106,32) | 195,06 (116,39) | 140,78 (82,876) | 0,972 (−8,182; 34,404) | 0,236 (−18,056; 65,612) |
| | CG | 257,94 (106,57) | 214,58 (117,06) | 179,38 (122,86) | 0,123 (−3,146; 147,896) | 0,027 (16,402; 182,098) |
| TMT A (seconds) mean (SD) | EG | 71,29 (33,68) | 56,31 (23,38) | 57,7 (34,283) | 0,009* (1,578; 26,422) | 0,306 (−14,488; 27,088) |
| | CG | 87,56 (45,566) | 61,42 (36,122) | 81,51 (72,293) | 0,009* (22,7; 53,55) | 0,161 (−12,437; 58,677) |
| MI (0-9) median (IQR) | EG | 5,21 (4; 7) | 5,27 (4; 8) | 7,6 (7; 9) | 0,823 (−2,478; 2,478) | 0,06 (−2,989; 0,189) |
| | CG | 4,47 (0; 8) | 4,55 (4; 6) | 6,29 (5; 9) | 0,292 (−4,01; 0,867) | 0,042 (−4,533; −0,038) |
| HADS (0-42) median (IQR) | EG | 11,59 (5; 19) | 10,62 (3, 18,5) | 10,4 (4,5; 19) | 0,799 (−5,282; 2,082) | 0,159 (−5,918; −0,518) |
| | CG | 10,36 (5; 15) | 9,4 (1; 15) | 6,71 (1; 12) | 0,779 (−5,729; 2,872) | 0,672 (−4,698; 7,841) |

Abbreviations: SD = standard deviation; IQR = interquantile range; TMT B = Trial Making Test part B; TMT A = Trial Making Test part A; MI = Memory with interference (30 s version); HADS = Hospital Anxiety and Depression Scale; * = = statistically significant ($p < 0.05$ or $p < 0.025$ for Bonferroni correction); CI = Confidence Interval.

**Table 2**
Group data and results for outcome measures analyzed with parametric tests.

| Outcome | Rehabilitation Program | Pre-Treatment | Post-Treatment | Follow-up | Repeated measures ANOVA | | Post-hoc analysis | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Group between-subjects *p value* | Time within-subjects *p value* | Within-group comparison | |
| | | | | | | | post- vs pre-treatment *p value* (95 % CI) | follow-up vs pre-treatment *p value* (95 % CI) |
| RAVL-I (0-75) mean (SD) | EG | 20,38 (9,576) | 35,8 (9,739) | 39,1 (12,405) | 0,127 | 0,000053* | 0,002 (−9,251; −2,47)* | 0,001 (−16,1; −5,425)* |
| | CG | 32,7 (9,615) | 29 (9,547) | 35,5 (15,099) | | | | |
| RAVL-D (0-15) mean (SD) | EG | 5,9 (2,469) | 7,2 (3,967) | 7,4 (3,438) | 0,151 | 0,000074* | 0,001 (−3,316; −0,984)* | 0,001 (−3,931; - 1,319)* |
| | CG | 2,625 (2,615) | 5,625 (2,134) | 6,38 (2,973) | | | | |
| ROCF-I (0-36) mean (SD) | EG | 26,85 (5,385) | 29,05 (6,069) | 28,7 (6,503) | 0,931 | 0,038* | 0,172 (−5,2; 0,688) | 0,157 (−5,873; 0,711) |
| | CG | 26,063 (9,171) | 28,375 (7,401) | 29,375 (7,049) | | | | |
| ROCF-D (0-36) mean (SD) | EG | 14 (6,502) | 15,6 (7,792) | 17,85 (6,733) | 0,478 | 0,001* | 0,025 (−4,729; −0,371)* | 0,002 (−8,117; −2,108)* |
| | CG | 10,25 (7,151) | 13,75 (6,330) | 16,625 (8,622) | | | | |
| DT (%) mean (SD) | EG | 90,05 (18,89) | 93,779 (18,91) | 88,475 (17,66) | 0,413 | 0,399 | / | / |
| | CG | 77,5 (26,13) | 83 (19,85) | 89, 938 (25,02) | | | / | / |
| SF-36 (0-100) mean (SD) | EG | 65,26 (17,361) | 57,58 (22,321) | 54,5 (20,474) | 0,526 | 0,384 | / | / |
| | CG | 52,14 (28,557) | 75,71 (19,669) | 64,43 (19,722) | | | / | / |

Abbreviations SD= standard deviation; RAVL-I = Rey Auditory Verbal Learning Test Immediate; RAVL-D = Rey Auditory Verbal Learning Test Delayed; ROCF-I = Rey-Osterrieth Complex Figure Test Immediate; ROCF-D = Rey-Osterrieth Complex Figure Test Delayed; DT = Dual Task; SF-36 = Short Form Health Survey 36; *= statistically significant ($p < 0.05$ for ANOVA and $p < 0.025$ for Bonferroni-corrected post-hoc comparison); CI = Confidence Interval.

Regarding the executive functions' domain (attentional shifting and cognitive flexibility - TMT B, working memory – MI, and dual task - DT), no significant differences or changes were observed between and within the two groups after treatment and at follow-up.

One possible explanation is that tasks involving executive functions require greater cognitive resources, which may not have been adequately targeted by the computer-based interventions. Indeed, executive functions are more resource-demanding than lower-level cognitive domains (e.g., visual attention, verbal memory).[40] The strongest evidence of the effectiveness of cognitive interventions targeting executive functions comes from protocols that integrate goal management training and problem-solving therapy, often alongside practical exercises aimed at daily living activities. Although some studies have explored computer-based interventions for executive function rehabilitation, results have been inconsistent.[42]

Furthermore, a significant effect of time was observed for constructional praxis skills (ROCF-I), with no group effect. However, post hoc pairwise comparisons, corrected for multiple testing, did not reveal significant differences between specific time points. This pattern may reflect the greater sensitivity of the overall test to detect general trends over time, whereas post hoc analyses are more conservative and may lack power to identify pairwise differences. A previously cited 2025

study reported improvements in praxis skills in face-to-face cognitive treatment, but not in telerehabilitation; however, the literature on ROCF-I remains extremely limited.[39]

Moreover, participants' health perception as measured by the SF-36 remained stable throughout the study, with no significant group or time effects observed. To the best of our knowledge, there are currently no studies specifically examining changes in health perception following a cognitive rehabilitation program. Nevertheless, it is reasonable to hypothesize that improvements in cognitive functioning may be associated with enhanced health perception, given that lower post-stroke cognitive performance is associated with significant reductions in stroke survivor quality of life.[43]

Lastly, regarding the mood domain, anxiety and depressive symptoms (HADS) remained stable over the study period. This data may reflect the need for a targeted psychological intervention to adequately address issues such as depression and/or anxiety. It is also important to consider the baseline characteristics of the sample, as participants may not have exhibited clinically significant psychological symptoms, but this is not our case. CG showed mild and EG showed moderate impairment at T0 (GC HADS T0=10,36, EG HADS T0=11,59).

Although this research yields encouraging outcomes, there are several constraints that need to be recognized. The sample size was small (n = 39) and consisted mostly of male participants (29 M, 10 F). The follow-up period was relatively short (2 months), which limits conclusions regarding long-term effects. Future studies should consider extending the follow-up duration, as done in promising previous research (e.g., 6-month follow-up[39]). Finally, the executive domain was not extensively investigated (TMT B, MI, DT). This could determine an unclear impact of the intervention on these complex cognitive skills.

## Conclusion

In conclusion, our findings suggest that computer-based cognitive treatment administered through telerehabilitation may lead to outcomes similar to those observed with the same treatment delivered face-to-face in sub-acute post-stroke participants. However, non-statistically significant differences observed between groups do not necessarily indicate equivalence between the two interventions. To our knowledge, this is one of the few studies that used the same device for the two interventions. In fact, most of the existing research seems to have concentrated on analyzing the differences between telerehabilitation and conventional face-to-face rehabilitation using different rehabilitation tools. With this study, we also seek to fill the gap in the literature regarding cognitive rehabilitation, which has been overshadowed by the more prominent research on motor rehabilitation. Lastly, many stroke survivors suffer from cognitive dysfunction, which has an impact on quality of life, mood, and overall well-being. Effective computer-based cognitive telerehabilitation could be a significant step forward in stroke care because it could serve as a cost-friendly, practical, and functional substitute for face-to-face treatment, especially since participants can continue their rehabilitation in a familiar setting, which lessens the strain on the healthcare system while still maintaining quality.

Future research should aim at testing a larger sample and assess long-term effects of this approach. Additionally, it could be beneficial to consider the possibility of integrating telerehabilitation with other therapeutic approaches and assessing how advancements in technology, including artificial intelligence, could potentially improve the effectiveness of the treatment. Finally, additional studies should explore how accessible and user-friendly telerehabilitation is for various demographic groups, especially for individuals with limited technological skills or access, to guarantee its broad applicability and effectiveness in a variety of environments.

## Funding

This research was funded by a grant from the Brain Research Foundation Verona (Fondazione Giuseppe Manni) and Joint Research (2021) University of Verona.

## CRediT authorship contribution statement

**Ylenia Gallinaro:** Writing – original draft, Project administration, Investigation. **Rebecca Boarini:** Writing – original draft, Investigation, Data curation. **Elisa Evangelista:** Methodology, Investigation. **Cristina Fonte:** Methodology, Funding acquisition. **Andreas Waldner:** Resources, Funding acquisition. **Julius Michael Waldner:** Resources, Funding acquisition. **Nicola Smania:** Supervision, Funding acquisition. **Mirko Filippetti:** Visualization, Formal analysis. **Alessandro Picelli:** Writing – review & editing, Supervision. **Valentina Varalta:** Writing – review & editing, Project administration, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

The authors acknowledge Giovanni Zingarlini for support in the preparation of the initial draft.

## References

1. Murphy SJ, Werring DJ. Stroke: causes and clinical features. *Med (Abingdon Engl: UK ed,)*. 2020;48(9):561–566. https://doi.org/10.1016/j.mpmed.2020.06.002.
2. Cramer SC, Richards LG, Bernhardt J, Duncan P. Cognitive deficits after stroke. *Stroke*. 2023;54(1):5–9. https://doi.org/10.1161/STROKEAHA.122.041775.
3. Al-Qazzaz NK, Ali SH, Ahmad SA, Islam S, Mohamad K. Cognitive impairment and memory dysfunction after a stroke diagnosis: a post-stroke memory assessment. *Neuropsychiatr Dis Treat*. 2014;10:1677–1691. https://doi.org/10.2147/NDT.S67184.
4. Loetscher T, Lincoln NB. Cognitive rehabilitation for attention deficits following stroke. *Cochrane Database Syst Rev*. 2013;(5). https://doi.org/10.1002/14651858.CD002842.pub2, 2013CD002842.
5. Obaid M, Douiri A, Flach C, Prasad V, Marshall I. Can we prevent poststroke cognitive impairment? An umbrella review of risk factors and treatments. *Br Med J Open*. 2020;10(9). e37982.
6. Gerstl JVE, Blitz SE, Qu QR, Yearley AG, Lassarén P, Lindberg R, Gupta S, Kappel AD, Vicenty-Padilla JC, Gaude E, Atchaneeyasakul KC, Desai SM, Yavagal DR, Peruzzotti-Jametti L, Patel NJ, Aziz-Sultan MA, Du R, Smith TR, Bernstock JD. Global, regional, and national economic consequences of stroke. *Stroke*. 2023;54(9):2380–2389. https://doi.org/10.1161/STROKEAHA.123.043131.
7. Rochmah TN, Rahmawati IT, Dahlui M, Budiarto W, Bilqis N. Economic burden of stroke disease: a systematic review. *Int J Environ Res Public Health*. 2021;18(14):7552. https://doi.org/10.3390/ijerph18147552.
8. Kalaria RN, Akinyemi R, Ihara M. Stroke injury, cognitive impairment and vascular dementia. *Biochim Biophys Acta*. 2016;1862(5):915–925. https://doi.org/10.1016/j.bbadis.2016.01.015.
9. Mulhern M. Cognitive rehabilitation interventions for post-stroke populations. *Del J Public Health*. 2023;9(3):70–74. https://doi.org/10.32481/djph.2023.08.012.
10. Hao J, Pu Y, Chen Z, Siu KC. Effects of virtual reality-based telerehabilitation for stroke patients: a systematic review and meta-analysis of randomized controlled trials. *J Stroke Cerebrovasc Dis: Off J Natl Stroke Assoc*. 2023;32(3), 106960. https://doi.org/10.1016/j.jstrokecerebrovasdis.2022.106960.
11. Bartoli D, Petrizzo A, Vellone E, Alvaro R, Pucciarelli G. Impact of telehealth on stroke survivor-caregiver dyad in at-home rehabilitation: a systematic review. *J Adv Nurs*. 2024;80(10):4003–4033. https://doi.org/10.1111/jan.16177.
12. Isernia S, Pagliari C, Morici N, Toccafondi A, Banfi PI, Rossetto F, Borgnis F, Tavanelli M, Brambilla L, Baglio F, on behalf of the CPTM Group. Telerehabilitation Approaches for people with chronic heart failure: a systematic review and meta-analysis. *J Clin Med*. 2023;12(1):64. https://doi.org/10.3390/jcm12010064.
13. Timurtaş E, Selçuk H, Uğur Canöz E, Inceer M, Batar S, Demirbüken İ, Polat MG. Synchronous and asynchronous telerehabilitation methods produce similar benefits in individuals with non-specific neck pain. *Arch Orthop Trauma Surg*. 2024;144(2):559–566. https://doi.org/10.1007/s00402-023-05083-7.
14. Timurtaş E, Hüzmeli İ, Demirbüken İ, Polat MG. Clinical outcomes of asynchronous telerehabilitation through a mobile app are equivalent to synchronous

telerehabilitation in patients with fibromyalgia: a randomized control study. *BMC Musculoskelet Disord*. 2025;26(1):118. https://doi.org/10.1186/s12891-025-08377-6.
15. Hestetun-Mandrup AM, Toh ZA, Oh HX, He HG, Martinsen ACT, Pikkarainen M. Effectiveness of digital home rehabilitation and supervision for stroke survivors: a systematic review and meta-analysis. *Digit Health*. 2024;10. https://doi.org/10.1177/20552076241256861, 20552076241256861.
16. Torrisi M, Maresca G, De Cola MC, Cannavò A, Sciarrone F, Silvestri G, Bramanti A, De Luca R, Calabrò RS. Using telerehabilitation to improve cognitive function in post-stroke survivors: is this the time for the continuity of care?. International journal of rehabilitation research. Internationale Zeitschrift fur Rehabilitationsforschung. *Rev Int Rech Readapt*. 2019;42(4):344–351. https://doi.org/10.1097/MRR.0000000000000369.
17. Maggio MG, De Bartolo D, Calabrò RS, Ciancarelli I, Cerasa A, Tonin P, Di Iulio F, Paolucci S, Antonucci G, Morone G, Iosa M. Computer-assisted cognitive rehabilitation in neurological patients: state-of-art and future perspectives. *Front Neurol*. 2023;14, 1255319. https://doi.org/10.3389/fneur.2023.1255319.
18. Svaerke K, Niemeijer M, Mogensen J, Christensen H. The effects of computer-based cognitive rehabilitation in patients with visuospatial neglect following stroke: a systematic review. *Top Stroke Rehabil*. 2019;26(3):214–225. https://doi.org/10.1080/10749357.2018.1556963.
19. Sarfo FS, Ulasavets U, Opare-Sem OK, Ovbiagele B. Tele-Rehabilitation after stroke: an updated systematic review of the literature. *J Stroke Cerebrovasc Dis: Off J Natl Stroke Assoc*. 2018;27(9):2306–2318. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.05.013.
20. van de Ven RM, Murre JM, Veltman DJ, Schmand BA. Computer-based cognitive training for executive functions after stroke: a systematic review. *Front Hum Neurosci*. 2016;10:150. https://doi.org/10.3389/fnhum.2016.00150.
21. Pichiorri F, Mrachacz-Kersting N, Molinari M, Kleih S, Kübler A, Mattia D. Braincomputer interface based motor and cognitive rehabilitation after stroke – state of the art, opportunity, and barriers: summary of the BCI meeting 2016 in Asilomar. *Brain-Comput Interfaces*. 2016;4(1–2):53–59. https://doi.org/10.1080/2326263X.2016.1246328.
22. Fonte C, Damora A, Abbruzzese L, Rotundo G, Picelli A, Gallinaro Y, Evangelista E, Mancuso M, Smania N, Varalta V. Self-administered cognitive rehabilitation using an electronic device in subacute stroke patients: a proof-of-concept study on safety, feasibility, and preliminary efficacy. *NeuroSci*. 2025;6(4):109. https://doi.org/10.3390/neurosci6040109.
23. Mingming Y, Bolun Z, Zhijian L, Yingli W, Lanshu Z. Effectiveness of computer-based training on post-stroke cognitive rehabilitation: a systematic review and meta-analysis. *Neuropsychol Rehabil*. 2022;32(3):481–497. https://doi.org/10.1080/09602011.2020.1831555.
24. De Luca R, Calabrò RS, Bramanti P. Cognitive rehabilitation after severe acquired brain injury: current evidence and future directions. *Neuropsychol Rehabil*. 2018;28(6):879–898. https://doi.org/10.1080/09602011.2016.1211937.
25. Mancuso M, Varalta V, Sardella L, Capitani D, Zoccolotti P, Antonucci G, Italian OCS Group. Italian normative data for a stroke specific cognitive screening tool: the Oxford Cognitive Screen (OCS). *Neurol Sci: Off J Ital Neurol Soc Ital Soc Clin Neurophysiol*. 2016;37(10):1713–1721. https://doi.org/10.1007/s10072-016-2650-6.
26. Neurotablet. The technology device for neurocognitive rehabilitation, https://www.neurotablet.com/en, [access 06 February 2026].
27. Siciliano M, Chiorri C, Battini V, Sant'Elia V, Altieri M, Trojano L, Santangelo G. Regression-based normative data and equivalent scores for Trail Making Test (TMT): an updated Italian normative study. *Neurol Sci: Off J Ital Neurol Soc Ital Soc Clin Neurophysiol*. 2019;40(3):469–477. https://doi.org/10.1007/s10072-018-3673-y.
28. Shea-Shumsky NB, Schoeneberger S, Grigsby J. Executive functioning as a predictor of stroke rehabilitation outcomes. *Clin Neuropsychol*. 2019;33(5):854–872. https://doi.org/10.1080/13854046.2018.1546905.
29. Mancuso M, Iosa M, Abbruzzese L, Matano A, Coccia M, Baudo S, Benedetti A, Gambarelli C, Spaccavento S, Ambiveri G, Megna M, Tognetti P, Maietti A, Rinaldesi ML, Gamberini G, Varalta V, Morone G, Ciancarelli I, Group CogniReMo Study. The impact of cognitive function deficits and their recovery on functional outcome in subjects affected by ischemic subacute stroke: results from the Italian multicenter longitudinal study CogniReMo. *Eur J Phys Rehabil Med*. 2023;59(3):284–293. https://doi.org/10.23736/S1973-9087.23.07716-X.
30. Kokkotis C, Serdari A, Tsamakis K, Aggelousis N, Vadikolias K. Processing speed and attentional shift/mental flexibility in patients with stroke: a comprehensive review on the trail making test in stroke studies. *Neurol Int*. 2024;16(1):210–225. https://doi.org/10.3390/neurolint16010014.
31. Carlesimo GA, Caltagirone C, Gainotti G. The Mental Deterioration Battery: normative data, diagnostic reliability and qualitative analyses of cognitive impairment. The Group for the Standardization of the Mental Deterioration Battery. *Eur Neurol*. 1996;36(6):378–384. https://doi.org/10.1159/000117297.
32. Caffarra P, Vezzadini G, Dieci F, Zonato F, Venneri A. Rey-Osterrieth complex figure: normative values in an Italian population sample. *Neurol Sci: Off J Ital Neurol Soc Ital Soc Clin Neurophysiol*. 2002;22(6):443–447. https://doi.org/10.1007/s100720200003.
33. Mondini S, Mapelli D, Vestri A, Arcara G, Gaggi O, Montemurro S, Pucci V, Bisiacchi P. *Esame neuropsicologico breve 3*. Raffaello Cortina Editore; 2022.
34. Baddeley A, Della Sala S, Papagno C, Spinnler H. Dual-task performance in dysexecutive and nondysexecutive patients with a frontal lesion. *Neuropsychology*. 1997;11(2):187–194. https://doi.org/10.1037//0894-4105.11.2.187.
35. Zigmond AS, Snaith RP. The hospital anxiety and depression scale. *Acta Psychiatr Scand*. 1983;67(6):361–370. https://doi.org/10.1111/j.1600-0447.1983.tb09716.x.
36. Ware Jr JE, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care*. 1992;30(6):473–483.
37. Loetscher T, Potter KJ, Wong D, das Nair R. Cognitive rehabilitation for attention deficits following stroke. *Cochrane Database Syst Rev*. 2019;(11). https://doi.org/10.1002/14651858.CD002842.pub3, 2019CD002842.
38. Jung H, Jeong J-G, Cheong Y-S, Nam T-W, Kim J-H, Park C-H, Park E, Jung T-D. The effectiveness of computer-assisted cognitive rehabilitation and the degree of recovery in patients with traumatic brain injury and stroke. *J Clin Med*. 2021;10(24):5728. https://doi.org/10.3390/jcm10245728.
39. Contrada M, Arabia G, Vatrano M, Pucci C, Mantia I, Scarfone F, Torchia G, Quintieri M, Cerasa A, Pignolo L. Multidomain cognitive Tele-neurorehabilitation training in long-term post-stroke patients: an RCT study. *Brain Sci*. 2025;15(2):145. https://doi.org/10.3390/brainsci15020145.
40. Lugtmeijer S, Lammers NA, de Haan EHF, de Leeuw FE, Kessels RPC. Post-stroke working memory dysfunction: a meta-analysis and systematic review. *Neuropsychol Rev*. 2021;31(1):202–219. https://doi.org/10.1007/s11065-020-09462-4.
41. Dutra LS, Scoralich L, Shigaeff N. Remote cognitive rehabilitation of attention: a case series pilot study with post-stroke patients. *Dement Neuropsychol*. 2023;17, e20230045. https://doi.org/10.1590/1980-5764-DN-2023-0045.
42. Skidmore ER, Eskes G, Brodtmann A. Executive function poststroke: concepts, recovery, and interventions. *Stroke*. 2023;54(1):20–29. https://doi.org/10.1161/STROKEAHA.122.037946.
43. Stolwyk RJ, Mihaljcic T, Wong DK, Hernandez DR, Wolff B, Rogers JM. Post-stroke cognition is associated with stroke survivor quality of life and caregiver outcomes: a systematic review and meta-analysis. *Neuropsychol Rev*. 2024;34(4):1235–1264. https://doi.org/10.1007/s11065-024-09635-5.