Effectiveness of telehealth interventions on cognitive function and quality of life in adults with neurological disorders: A systematic review and meta-analysis

Abstract

Objective: Telehealth is an encouraging solution for the remote delivery of cognitive interventions. This review aims to identify the characteristics and effectiveness of telehealth interventions on cognitive functions and related quality of life in adults with neurological disorders.

Design: Systematic review and meta-analysis.

Settings and participants: Community and residential, adults with neurological disorders.

Methods: Six English and two Chinese databases were searched from inception to August 2024. Randomized controlled trials that evaluated telehealth interventions for cognitive function in adults with neurological disorders were eligible. The meta-analysis was conducted using *R* (Version 4.1.3). The Revised Cochrane risk of bias tool for randomized trials (RoB 2) tool was used for risk of bias assessment.

Results: Sixteen studies with 952 participants were included, fourteen of which were eligible for the meta-analysis. Asynchronous telehealth via apps/websites with regular online supervision was the most commonly used format. The pooled results suggested that telehealth interventions could significantly improve global cognitive function (standardized mean difference (SMD)=0.95, 95% confidence interval (CI): 0.06~1.83, *P*=0.035), memory (SMD=0.79, 95% CI: 0.36~1.23, *P*=0.0004), and quality of life (SMD=0.57, 95%CI: 0.14~1.00, *P*=0.01) compared to controls. However, there was no statistically significant effect on attention (SMD=0.12, 95%CI: -0.11~0.35, *P*=0.31), executive function (SMD=0.06, 95%CI: -0.30~0.42, *P*=0.73), or language (SMD=0.44, 95%CI: -0.01~0.89, *P*=0.054).

Conclusions and implications: Telehealth interventions are safe, feasible and acceptable for adults with neurological disorders, and could potentially reduce healthcare cost. They have beneficial effects on global cognitive function, memory, and quality of life. More exercise-based telehealth interventions with adequate statistical power and rigorous designs are needed to evaluate the long-term benefits and financial impact.

Registration: PROSPERO (number blinded for review).

Keywords: Telehealth; Neurological disorder; Cognitive function; Effectiveness; Systematic review; Meta-analysis

1. Introduction

Over the past 30 years, with the growing and ageing population, the total burden of global neurological disorders has been increasing[1]. Cognitive impairment is one of the most consistent complications of acquired and degenerative neurological disorders[2]. Individuals with neurological disorders are more likely to develop dementia than those without[3]. In fact, neurological disorders share some underlying pathophysiological mechanisms for cognitive impairment. As such, neuroinflammation, reduced levels of neurotrophic factors (e.g., brain-derived neurotrophic factor), abnormal amyloid deposition, disruption of the blood-brain barrier, synaptic plasticity damage, impaired nerve conduction, and white matter injury have been implicated in the pathophysiology of many neurological disorders[1,4].

For individuals with neurological disorders, the decline in cognitive function influences the process of treatment and rehabilitation, subsequently affecting their reintegration into society, return to work, and leisure activities[5]. The perceived memory difficulties, poor concentration and impaired problem solving could also have a high impact on their quality of life[2]. Conventional cognitive therapies are commonly carried out in specialized healthcare settings, often in a face-to-face format. However, multiple roundtrips for face-to-face cognitive therapy can impose excessive burdens, especially on individuals who have physical disabilities or mobility impairments, social anxiety, and geographical isolation, thereby hindering their ability to benefit from it[6].

With the rapid development and application of emerging communication technologies, as well as the promotion of the concept of universal health coverage, telehealth has emerged to shape the delivery of medical resources throughout the healthcare ecosystem[7]. Telehealth is defined as the remote delivery and facilitation of health-related services including medical care, rehabilitation, patient education, health information, and self-management using

telecommunication technology[8,9]. Recent studies have increasingly focused on telehealth interventions intended to enhance cognitive function in individuals with neurological disorders, many of which are designed or adapted from non-digital formats[10]. A key advantage of telehealth is its ability to improve access to health care by allowing individuals to receive continuous cognitive interventions in their homes and communities, which makes the care delivered more feasible for those people with neurological disorders. It also helps to reduce potential communication barriers within multidisciplinary teams and facilitates the timely provision of online or offline feedback to patients[11]. This offers healthcare professionals and patients the possibility of selecting the most appropriate interactive approach that could be synchronous, asynchronous or mixed[12]. Furthermore, the professional-led self-training telehealth can effectively reduce the workload of medical staff and address the issue of healthcare resource shortages[13].

Although various telehealth interventions focusing on cognitive function among adults with neurological disorders have emerged in recent years, the evidence for these interventions remains inconclusive, especially regarding the design and delivery of telehealth, as well as its feasibility, acceptability, financial impact, and the specific individuals who would benefit most from this format. Previous reviews mainly focused on the application of telehealth interventions to movement outcomes[14] and physical or psychosocial functions[15,16] among individuals with neurological disorders. To the best of our knowledge, no cognitive function-related review has been published. There is an urgent need for telehealth-delivered cognitive function improvement to be guided by evidence-based recommendations. Thus, this systematic review aimed to: 1) identify the characteristics of telehealth interventions focusing on cognitive function in adults with neurological disorders; 2) determine the feasibility, acceptability, and

financial cost; and 3) analyze the effectiveness of telehealth interventions on cognitive functions and related quality of life.

2. Methods

This systematic review was reported in accordance with the most recent 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement and was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (number blinded for review)[17].

2.1 Eligibility criteria

We defined the eligibility criteria according to the PICOS (population, intervention, comparison, outcomes, and study design) framework.

(1) Population: individuals who were adults with neurological disorders (≥18 years old).

(2) Intervention: the intervention group received telehealth. Telehealth for the purposes of monitoring symptoms or physiological parameters alone (i.e., telemonitoring) without providing training, rehabilitation, or therapy was excluded. Telehealth intervention could be conducted via phone, instant messaging, video call, web-based services, or any other means of remote communication, whether synchronous (e.g., real-time online sessions) or asynchronous (reviewing data at a later point, e.g., recorded video or images)[8].

(3) Comparison: the control group either received a non-telehealth intervention (usual care or any other kinds of intervention without telehealth elements) or no intervention (waitlist control).

(4) Outcomes: global cognitive function and/or specific cognitive domains. Based on the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), the principal domains of cognitive function include attention, executive function, memory, language, perceptual-motor function, and social cognition[18].

(5) Study design: randomized controlled trials (RCTs). Cluster-RCTs were also eligible for inclusion. Cross-over studies that did not report washout effects and could not obtain pre-crossover data were excluded. We also excluded quasi-randomized controlled trials, letters, protocols, reviews, conference abstracts, dissertations, case reports, studies not published in a peer-reviewed journal, and studies with no full text available. Only articles published in English and Chinese were considered.

2.2 Literature search and study selection

Six English electronic databases (The Cochrane Library, PubMed, Embase, Scopus, Web of Sciences, and PsycINFO) and two Chinese databases (China National Knowledge Infrastructure (CNKI) and WanFang) were systematically searched from inception to August 2024. The combinations of key terms surrounding cognitive function, telehealth, and neurological disorders were used for search (see Appendix for the complete search strategy). Reference lists of included studies and relevant reviews were manually screened to identify any additional studies. Searches were imported using Endnote 21.

EndNote 21 was used to automatically remove duplicate entries. Two reviewers (YLH and JYL) independently read the titles and abstracts of the remaining studies and assessed the full texts of potentially eligible articles. The kappa statistic assessed inter-reviewer consistency for abstract/full-text screening. The kappa coefficient (k) determined the agreement level: excellent (> 0.80), good (0.61-0.80), moderate (0.41-0.60), fair (0.21-0.40), or poor (< 0.20)[19]. Any remaining differences of opinion after discussion were resolved by consulting a third reviewer (YL).

2.3 Data extraction

The study characteristics were extracted by using a modified version of the data extraction form based on the Cochrane Handbook[20], including the following information: the first author,

publication year, country, study setting, sample size, characters of participants, types of telehealth interventions, measurement points, results of cognitive outcomes and other outcomes, and cognitive assessment tools. Data on the design, content, and delivery features of telehealth interventions, as well as the feasibility and acceptability, were extracted based on the Template for Intervention Description and Replication (TIDieR) checklist and guide[21]. The indicators of the studies' feasibility include recruitment rates (i.e., the percentage of participants who gave consent after being determined to be eligible) and dropout rates (i.e., the number of participants who dropped out after randomization divided by all participants who agreed to consent)[22]. The following factors indicate the acceptability of studies: (1) adverse events record associated with telehealth interventions; (2) participants' satisfaction with the interventions; and (3) adherence rates: the percentage of participants who completed the interventions as the researchers defined them[22]. Based on the National Quality Forum, which was developed to identify measures and concepts for evaluation of telehealth services, the financial impact/cost took into account the effects on the patient, family, and/or caregiver, the care team, the health system or payer, and society[23].

The data extraction was completed independently by two reviewers (YLH and JYL). The disagreements were resolved by a third reviewer (YL). We contacted the corresponding authors for three articles with insufficient data[24-26], and the author of one study provided the data[25].

2.4 Risk of bias assessment

The Revised Cochrane risk of bias tool for randomized trials (RoB 2) was used for risk of bias assessment in this review by two independent reviewers (YLH and JYL). Any remaining disagreements after the discussion were resolved by consulting a third reviewer (YL). The RoB 2 tool includes the following domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the

158 reported result. This tool classifies the risk of bias for each dimension and the overall outcome
159 into three categories: low, some concerns, and high[27].

160 **2.5 Data synthesis and analysis**

161 The meta package in *R* software version 4.1.3 was used for meta-analysis. *P*-values < 0.05 were
162 considered statistically significant. If two or more studies reported outcomes related to global
163 cognitive function and cognitive domains based on the DSM-5 classification, meta-analyses
164 were conducted. Additionally, we also employed a meta-analysis of the quality of life reported
165 in the included studies. The standardized mean difference (SMD) with 95% confidence
166 intervals (CI) was calculated due to the use of different tools to measure the same variables in
167 the included studies[20]. The effect of intervention was measured by extracting changes in mean
168 and standard deviation (SD) between pre- and post-intervention. The missing SD of changes
169 from baseline was calculated based on the standard error (SE) [20] or the following formula:

170 $$SD_{change} = \sqrt{SD_{baseline}^2 + SD_{final}^2 - (2 \times r \times SD_{baseline} \times SD_{final})}$$

171 Since the correlation coefficient (*r*) between baseline and post-intervention was not reported in
172 the included studies, a conservative estimated value (r = 0.7) was used [28,29]. If the study
173 provided medians, the first and third quartiles, we imputed the means and SDs by using the
174 Excel spreadsheet provided by Wan et al.[30]. For studies that used tools where lower scores
175 reflect "better" outcomes, we multiplied the mean by -1 before standardization, while the SD
176 was left unmodified[20]. According to the Cochrane Handbook, SMD was interpreted as
177 follows: 0.2 represents a small effect, 0.5 a moderate effect, and 0.8 a large effect[8].

178

179 In terms of unit of analysis issues, we planned to analyze data from cluster RCTs after properly
180 adjusting for intracluster correlation. For cross-over trials, only outcomes from the first
181 randomized treatment period were analyzed[20]. We did not, however, find any cluster RCTs or
182 cross-over studies that fulfilled our review criteria. According to Cochrane recommendations,

when a study had more than one eligible group (e.g., a three-arm RCT) and it was not appropriate to pool data, the number of participants in the control group was divided proportionally prior to inclusion in the meta-analysis[20].

Given the expected variability between studies and outcome measurements, the random-effects model was chosen to pool the SMDs across the studies[31]. To explore potential variations in significant efficacy on cognitive function and heterogeneity, the predefined subgroup analyses were conducted based on the type of control group, the type and content of telehealth intervention, the risk of bias, as well as whether cognitive function was the primary outcome. The heterogeneity among the included studies was evaluated using a χ^2 test and a Higgins I^2 value. If the value of I^2 statistics exceeded 50%, heterogeneity was considered to exist[32]. The leave-one-out sensitivity analyses were used to examine the impact of excluding individual studies and explore potential sources of significant heterogeneity[32]. Publication bias was not investigated due to the inclusion of less than 10 studies in each meta-analysis. Narrative synthesis was used for studies that were not pooled for meta-analysis.

2.6 Ethical approval and informed consent

There was no need for ethical approval or informed consent since this was a second study based on the literature.

3. Results

3.1 Search results

Figure 1 shows the flowchart of study selection. There were 4,195 articles identified through searching the specified databases. After removing 932 duplicates and screening by title and abstract, 278 articles remained, with an inter-rater reliability of k=0.82. After a full review of

the remaining articles, 263 articles were excluded, with an inter-rater reliability of k=0.90. Moreover, one article that met the eligibility criteria was obtained through a manual citation search. In total, sixteen articles were finally included in this systematic review.

3.2 Study characteristics

The characteristics of the included studies are shown in Table 1. This review included 16 RCTs conducted in eleven countries or regions: Italy (n=4)[12,25,33,34], China (n=2)[35,36], the Netherlands (n=2)[24,37], Turkey (n=2)[38,39], New England (n=1)[40], Finland (n=1)[41], Spain (n=1)[26], Korea (n=1)[42], North America (n=1)[43], and one multi-country study in the United States and Canada[44].

3.2.1 Participants' characteristics

The included studies covered the following neurological disorders: multiple sclerosis (n=4)[12,38,40,43], stroke (n=3)[35,36,44], traumatic brain injury (n=1)[41], brain tumor (n=1)[24], Alzheimer's disease (n=2)[25,42], epilepsy (n=1)[40], Parkinson's disease or multiple sclerosis (n=1)[33], Parkinson's disease (n=2)[26,34], and traumatic brain injury or stroke (n=1)[37]. The participants in three studies were postoperative or in the early stages of rehabilitation[24,35,36]. Five studies excluded patients with moderate or severe cognitive impairments[33-35,38,41], while three excluded patients with motor impairments that restrict the use of devices[26,41] or neuropsychological assessment[24]. The sample size of the included studies ranged from 20 to 150, with a total of 952 individuals.

3.2.2 Intervention characteristics

Classifications, technology and delivery of telehealth interventions

As shown in Table 2, there were online sessions (n=5; 31.3%), digital gaming (n=2; 12.5%), virtual reality-based telehealth (n=4; 25.0%), and other types of telehealth (n=5, 31.3%). Modes of intervention delivery included applications (App) (n=7; 43.8%)[12,24,25,33,34,42,44],

websites (n=5; 31.3%)[26,35,36,41,43], and phone/video calls (n=4; 25.0%)[37-40]. At baseline, six studies (37.5%) assessed the accessibility of intervention devices and the digital literacy of participants and/or caregivers[25,26,37,38,40,41], while six (37.5%) provided training on the use of devices[25,37,38,41,42,44]. As for delivery type, five studies (31.3%) used synchronous telehealth[36-38,40,43], while ten conducted asynchronous telehealth (62.5%)[12,24-26,33-35,39,41,44]. Moreover, one study conducted mixed telehealth, specifically combining asynchronous self-training with weekly real-time classes[42]. As for asynchronous ones, eight studies (50%) gave offline (delayed) monitoring through the access of recorded information from the software while providing regular telephone support[12,24-26,34,39,41,44]. All the synchronous telehealth[36-38,40,43] and one asynchronous exercise training[39] were health professional-led interventions. Eight studies adjusted the intervention intensity to meet the practice needs of patients, with five of them automatically upgrading by using software algorithms[25,26,35,42,44], while three relied on the judgment of intervention providers[38-40]. The intervention duration ranged from 1 to 6 months, with half in the 6-8 week range[12,25,33,34,37,38,41,42]. Five times per week was the most common intervention frequency[12,25,33,42,44]. Six studies reported post-intervention follow-up, and the periods ranged from six weeks[37] to ten months[25].

Content and theoretical foundations of telehealth interventions

Nine studies with 11 telehealth groups primarily focused on cognitive function[24,25,34,35,40-44]. Among them, six telehealth groups conducted single-domain training (cognitive intervention (n=5)[24,34,40,41] and physical activity improvement (n=1)[43]). And the five cognitive interventions include two types of digital gaming[41], a non-immersive virtual reality cognitive training[34], psychoeducation, strategy training, and attention retraining games[24], and a cognitive self-management program [40]. The last one was based on problem-solving therapy, aiming to assist participants in coping with cognitive impairment[40]. The physical activity

improvement project was designed based on social cognitive theory[43]. There were five telehealth groups that implemented multi-domain interventions including cognitive and language therapies (n=2)[35,44], cognitive and exercise training (n=1)[25], cognitive and socio-cognitive training (n=1)[34], and comprehensive cognitive training including motivation, cognitive improvement, healthcare, emotional support, and caregiver sections (n=1)[42].

There were seven studies that measured cognitive function as the secondary outcome[12,26,33,36-39]. Among them, four studies conducted single-domain training: motor training (n=2; i.e., the motor imaging training based on the PETTLEP (Physical, Environment, Task, Timing, Learning, Emotion, Perspective) model[38,45] and the structured home-based exercise program[39]), online cognitive behavioral therapy for insomnia (n=1)[37], and post-discharge personalized rehabilitation (n=1)[36]. Three studies delivered cognitive and motor training by using virtual reality technology[12,33] or serious games[26].

3.3 Risk of bias

The RoB 2 assessment of the included studies is shown in Figure 2. There were nine studies identified as having a high overall risk of bias[24,26,37-39,41,43,44,46], four with some concerns about the overall risk of bias[25,34,36,42], and three exhibiting a low overall risk of bias[12,33,35]. Seven studies were rated as having some concerns about the randomization process for limited details about the concealment of the allocation sequence[26,36,37,43,44] or not addressing intergroup baseline differences pertaining to cognitive function[34,38]. Three studies were at high risk of bias from deviations from intended interventions, as some participants did not receive the allocated intervention due to technological problems[24,26,41]. Six studies were rated as having some concerns in this domain, as some participants did not comply with their assigned intervention[25,38-40,43,44]. The missing outcome data were rated as some concern[25] or

high[24,26,38,39,41,43,44,46] in the majority of studies for not adopting appropriate methods for assessing or handling missing data. One study was rated as high risk about the measurement of outcome, as participants self-assessed their subjective cognitive function while aware of the group assignment[37]. And four failed to mention the blinding of outcome assessors, which led to some concerns about the measurement process[26,34,36,42]. As for the selective reporting, two studies were rated as having some concerns as the study protocols were not available[36,37].

3.4 Feasibility, acceptability, and financial cost of telehealth intervention

Half of the studies reported the recruitment rate[12,24,37,38,40-42,44], ranging from 32.6%[41] to 92.1%[12] (median value 78.4%). The dropout rates of the telehealth groups ranged from 0%[26,34-36,42] to 38.5%[40] (median value 10.5%), and those of the active control groups ranged from 0%[34,35] to 28.6%[39] (median value 12%). Six studies documented instances of intervention discontinuation due to technological problems[24,41], internet connectivity[12,26,42], or a lack of caregiver assistance for technological issues[25]. Regarding the occurrence of adverse events, one study reported an increase in depressive symptoms after rehabilitation gaming[41]. The adherence rates of the telehealth groups ranged from 70%[24] to 100%[38,41]. Most studies reported a high degree of participant satisfaction. The participants demonstrated a good-to-excellent level of system usability[12,25]. Two studies provided financial cost data. One study concluded that 3-month rehabilitation costs for participants in the telehealth group were € 2,243.07 compared with € 5,108.26 in the traditional rehabilitation group[26]. The other study revealed that the control group spent more on the epilepsy-related blood tests during the 3-month intervention period than the intervention group ($p = 0.04$)[40].

3.5 Effectiveness of telehealth interventions

3.5.1 Primary outcomes-Cognitive function

As shown in Table 1, eight studies (50.0%) compared telehealth groups to active control groups[12,25,33-35,37,39,44], while others compared them to non-active control (usual care or waitlist control)[24,26,36,38,40-43]. The included studies reported the effects of telehealth interventions on global cognitive function and four specific cognitive domains (attention, executive function, language, and memory).

Global cognitive function

Eleven studies reported post-intervention results for global cognitive function[12,24-26,33,34,36,39,40,42,44]. Among them, there was a three-arm RCT involving two types of telehealth interventions[34]. Due to a lack of data for syntheses, two studies were not included in the meta-analysis, and qualitative analysis was performed[24,44]. One study indicated that tablet-based cognitive rehabilitation did not significantly improve global cognitive function in postoperative brain tumor patients compared to the control group[24]. The other one implementing virtual language therapy for post-stroke aphasia patients also reported similar results[44]. The pooled results from the remaining nine studies ($n_{participants}$=512) suggested that telehealth interventions could significantly improve global cognitive function (SMD = 0.95, 95% CI: 0.06~1.83, P = 0.035) when compared with control groups (Figure 3).

The level of heterogeneity (I^2) was 93%. The SMD of Xie et al.[36] deviated the most from the overall effect size. Leave-one-out sensitivity analysis showed that after excluding Xie et al.[36], the heterogeneity decreased from 96% to 67% without altering the direction of the results, suggesting that this study may be the source of heterogeneity (Figure S1, Appendix). And the subgroup that did not include Xie et al.[36] showed no significant heterogeneity (Table S1,

Appendix). As for the results of subgroup analyses, app/website-based delivery modes were more beneficial in improving global cognitive function (SMD = 0.92, 95% CI: 0.45~1.39).

Attention

Six studies with 304 participants were included to assess the effectiveness of telehealth interventions on attention post-intervention[12,25,34,38,41,43]. Among them, two studies conducted three-arm RCTs, and both involved two types of telehealth interventions[34,41]. The included studies exhibited no statistically significant heterogeneity (I^2 = 0%, P = 0.91, Figure 4). The pooled results indicated no significant improvement in attention with telehealth interventions compared to controls (SMD = 0.12, 95%CI: -0.11~0.35, P = 0.31). The sensitivity analyses proved the robustness of the findings (Figure S2, Appendix).

Executive function

Three studies with 135 participants were included to assess the effectiveness of telehealth interventions on executive function post-intervention[25,34,41]. Among them, two studies conducted three-arm RCTs, and both involved two types of telehealth interventions[34,41]. There was no statistically significant heterogeneity between the included studies (I^2 = 0%, P = 0.54, Figure 5). The pooled results revealed no evidence of significant improvement in executive function with telehealth interventions compared to controls (SMD = 0.06, 95%CI: -0.30~0.42, P = 0.73). The sensitivity analyses proved the robustness of the findings (Figure S3, Appendix).

Language

Four studies reported post-intervention results for language[24,25,35,44]. Due to a lack of data for synthesis, one study was qualitatively analyzed and showed that tablet-based cognitive

rehabilitation did not yield a significant improvement in language for postoperative brain tumor patients compared to the control group[24]. Among the three remaining studies ($n_{participants}$=79) included in the meta-analysis, no statistically significant heterogeneity was observed (I^2 = 0%, P = 0.92). The pooled results revealed no evidence of significant improvement in language compared to controls (SMD = 0.44, 95%CI: -0.01~0.89, P = 0.054) (Figure 6). The sensitivity analyses proved the robustness of the findings (Figure S4, Appendix).

Memory

Three studies ($n_{participants}$=94) reported post-intervention results for memory[25,34,38]. One of them conducted a three-arm RCT involving two types of telehealth interventions[34]. There was no statistically significant heterogeneity between the included studies (I^2 = 0%, P = 0.73, Figure 7). Pooled results showed that telehealth interventions could significantly improve memory compared to controls (SMD = 0.79, 95%CI: 0.36~1.23, P = 0.0004). The sensitivity analyses proved the robustness of the findings (Figure S5, Appendix). In terms of the results of subgroup analyses, significant effects were observed in studies that conducted exercise-related telehealth (SMD = 0.66, 95%CI: 0.14~1.19). Compared to active control groups, telehealth groups still significantly improved memory (SMD = 0.72, 95%CI: 0.17~1.26). App/website-based delivery modes were more effective at improving memory (SMD = 0.72, 95%CI: 0.17~1.26) (Table S2, Appendix).

3.5.2 Secondary outcome-Quality of life

Seven RCTs assessed the post-intervention effects of telehealth interventions on quality of life. As lacking data for synthesis, one study was qualitatively analyzed and reported a significant improvement in quality of life among adults with Parkinson's disease following motor and cognitive serious games-based telehealth intervention. Conversely, the control group exhibited no significant differences[26]. The pooled results from the remaining six RCTs ($n_{participants}$=280)

suggested that telehealth interventions focusing on cognitive function could also significantly improve quality of life (SMD = 0.57, 95%CI: 0.14~1.00, $P = 0.01$) when compared with control groups (Figure 8). Pagliari's study significantly contributed to the heterogeneity in the meta-analysis of quality of life, resulting in a change in effect size to 0.39 (95%CI: 0.11~0.67, $I^2 = 0\%$; Figure S6)[12].

4. Discussion

This systematic review is the first known one to evaluate the effectiveness of telehealth interventions for cognitive function among adults with neurological disorders. It is noteworthy that there is a scarcity of studies in this field in comparison to studies focusing on physical and psychosocial health issues. Given the diverse cognitive domains being covered and the unclear or high risk of bias present in many of the included studies, the results should be interpreted with caution.

Characteristics of targeted populations and telehealth interventions

The included studies targeted mostly adults with mobility impairments. Mobility impairment is prevalent among adults with neurological disorders and represents a significant risk factor for cognitive impairment and low quality of life[47]. Compared to roundtrips for face-to-face therapy, telehealth makes the care delivered more feasible for this population. Asynchronous telehealth intervention via apps or websites with regular online supervision was the most commonly used implementation delivery. This type of telehealth modality has also been widely used in mental health care[48]. Compared to synchronous modality, it could ensure safe intervention while freeing the temporal limitations and improving the flexibility of interaction between patients and providers[48]. Among the included studies, recruitment eligibility typically requires reasonable levels of digital literacy and device accessibility. Välimäki M et al.

excluded individuals with physical impairments that may restrict the use of computer game control systems unaided (e.g., hemiplegia and dysfunction of the central vestibular system)[41]. In this study, the elderly with traumatic brain injuries showed resistance to long-term cognitive gaming[41]. For individuals with less ability to use technology (e.g., the elderly or those with motor impairments), telehealth interventions that are excessively novel or complex may not be appropriate. Furthermore, it is suggested to provide targeted training related to device usage. Braley et al. reported that, after providing technological guidance and support, even elderly individuals in their 80s can access and manipulate virtual language therapy systems[44]. Providing necessary technical support could minimize the potential lack of familiarity with technology, thus enhancing human-technology interaction[25].

Effectiveness of telehealth interventions

The pooled results reflected a significant effect of telehealth interventions on global cognitive function and memory in adults with neurological disorders, with a large effect size. And compared to traditional cognitive therapies, telehealth interventions lead to similar benefits for global cognitive function and even superior outcomes for memory. Impaired memory is one of the most consistently observed cognitive symptoms of neurological disorders[49]. The hippocampus is a critical brain structure involved in learning and memory formation[50]. Neuroimaging evidence indicates that adults with neurological disorders with memory impairments exhibit structural abnormalities or sclerosis in the hippocampus[49]. The meta-analysis results showed that telehealth interventions, especially exercise-related telehealth, have a significant impact on improving memory. These exercise-related telehealth interventions specifically included digital platform-based cognitive and exercise training as well as motor imagery training through online sessions[25,38]. The motor imagery training guided participants to attempt to make their imaginations as similar to the actual executed movements as possible, thereby inducing neural and autonomic changes similar to those

executing real movements[38]. Similar to physical exercise, motor imagery has been preliminarily shown to boost cognitive function by increasing activity in the hippocampus and prefrontal cortex associated with memory[38]. Moreover, combining exercise has the potential to enhance the effects of cognitive rehabilitation due to its ability to increase cerebral blood flow and oxygen supply, thereby promoting the neural plasticity necessary for effective cognitive rehabilitation[25]. Therefore, telehealth interventions including exercise could be a potential way to improve the cognitive function for this population.

Another possible reason for the positive outcomes is the advantages of telehealth as a modality compared to traditional face-to-face therapy. On the one hand, telehealth can increase the accessibility of intervention and reduce travel burdens for individuals with neurological disorders and their families. This could not only ensure treatment continuity but also alleviate the fatigue caused by traveling to and from settings[8]. On the other hand, cognitive intervention is a long-term and progressive process. Compared to traditional therapy, telehealth can facilitate more frequent interactions, optimize the intensity of interventions, and flexibly adjust the difficulty of interventions as the process advances by using software algorithms, thereby enhancing engagement with the therapy process[41]. Among the included studies that reported global cognitive function, Xie et al.'s study had a significantly larger effect size than others[36]. This may be attributed to the implementation of a personalized online rehabilitation that was developed based on the progression of patients' conditions. However, the results of this study should be interpreted with caution. This study was rated as having some concerns about the overall risk of bias. Moreover, compared to others, the included participants had poorer cognitive function at baseline, with some individuals identified as having mild cognitive impairment[36]. This may partially explain the large effect size.

Cognitive impairments such as delayed processing speed, poor memory, language, and executive functions are associated with a loss of daily functional living, which influences the quality of life[51]. Similar to the review findings for older adults with frailty, telehealth interventions for improving cognitive function could also be beneficial for the quality of life of adults with neurological disorders[52]. As for the domain-specific cognitive functions, there was no statistically significant effect on executive function, language, or attention. There are some possible explanations for these non-significant findings. First, half of the included telehealth interventions primarily targeted physical or psychosocial functions rather than cognitive function. And some participants in these studies had preserved cognitive function at baseline, which limited the benefits they could derive from telehealth interventions. It also made it difficult to observe statistical or clinical differences after the intervention. Furthermore, some studies assessed cognitive function by using cognitive screening tools such as the Montreal Cognitive Assessment (MoCA), the Mini-Mental State Examination (MMSE), and the Functional Independence Measure (FIM). Compared to multiple neuropsychological tests, these tools have lower sensitivity with a ceiling effect[53]. Thirdly, many of them had small sample sizes, which are thought to be insufficient to detect significant effects of telehealth intervention between controls. Lastly, half of the included control participants received active rehabilitation interventions despite not using telehealth technology, which should also be taken into account when interpreting the pooled results.

Feasibility, acceptability and financial cost

The recruitment rates in some included studies were non-ideal[41, 44]. The heavy symptom burden and disability faced by adults with neurological disorders could partially account for challenges in recruitment[54]. Despite high prevalence of cognitive decline in this population, they may neglect this issues and show less interest in cognitive interventions compared to

physical rehabilitation. The average dropout rate of telehealth interventions was acceptable and was lower than that of active control groups. However, three included studies reported high dropout rates before the telehealth intervention[38,40,41]. Compared to conventional rehabilitation, the effectiveness of telehealth interventions based on emerging communication technologies may be questioned by patients[41]. Thus, the introductory program for telehealth would be a preferable option that needs to be investigated in future studies. The good adherence rates and satisfaction of telehealth interventions were generally reported. And no significant safety concerns were recorded. However, it should be noted that four included studies reported technological problems or poor internet connectivity, leading to reduced engagement with interventions and potentially compromising the intervention's effectiveness[12,24,25,41]. Thus, prior to the intervention, it is essential to conduct comprehensive testing of the devices to prevent technical errors. As for financial costs, only two studies provided related data, indicating that telehealth interventions seem to have a better financial impact[26,40]. However, due to the small sample size and short follow-up duration, it is insufficient to confidently assess the financial costs. More studies are needed to focus on the financial impact and costs of telehealth, as well as its potential to greatly expand access to care.

5. Implications for practice and research

Asynchronous telehealth, which combines cognitive training with exercise-related training, was the most recommended for improving cognitive function among adults with neurological disorders. When implementing telehealth interventions, adding elements such as training results feedback mechanisms, regular supervision, and adjustable training difficulty levels can enhance compliance and improve effectiveness[37,44]. Providing necessary technical support and training is also essential to promoting human-technology interaction.

More telehealth research focusing on cognitive function with rigorous designs is needed. Furthermore, it is recommended to include post-intervention follow-up assessments to evaluate the long-term benefits and financial impact of the interventions. Secondly, the design of the telehealth intervention should take into account the digital literacy and accessibility of the targeted population. When designing intervention strategies, it is advisable to offer targeted training that focuses on the cognitive domains frequently affected in adults with neurological disorders. In addition, to better assess and enhance telehealth programs, it is recommended to provide a comprehensive report on the details, feasibility, acceptability, and financial cost of the interventions.

6. Limitations

The following limitations need to be noted when interpreting the findings. First, it is possible that studies published in other languages or within non-peer reviewed articles may have been overlooked. Secondly, some studies retrieved in the review were underpowered to assess the effectiveness due to the small sample size. Thirdly, the lack of theoretical or model-based justifications and detailed reporting of intervention strategies in certain studies hinders the advancement and replication of telehealth interventions. Moreover, the majority of the included studies reported a high or unclear overall risk of bias.

7. Conclusions

Telehealth interventions could ensure the continuity of treatment and potentially lower health-service costs. They have beneficial effects on global cognitive function, memory, and quality of life in adults with neurological disorders, demonstrating high feasibility and acceptability. When designing telehealth interventions for cognitive function improvement, it is suggested to

obtain exercise-related training and add elements such as training results feedback mechanisms, regular supervision, and adjustable training difficulty levels. This study emphasizes the need for more high-quality cognitive telehealth interventions that specifically target impaired cognitive domains in adults with neurological disorders to evaluate the long-term benefits and financial impact.

Conflict of interest statement

The authors declared no conflicts of interest.

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685 **Table 1.** Study characteristics and findings

Author (year) [Country]	Study population (diagnosis, sample size, age (years, Mean±SD), gender (Males, n (%)))	Intervention types	Control types	Outcome measurement points	Cognitive outcomes and assessment tools; Primary outcome	Other outcomes	Results
Välimäki, M. (2018) [Finland]	Traumatic brain injury; RG: n=29 EG: n=29 CG: n=32; Age: RG: 42.1 ±12.2 EG: 40.9±12.0 CG: 39.3±12.1; Gender: RG:15 (52) EG:13 (45) CG:17 (53)	Digital cognitive gaming: RG, EG	Non-active control: waitlist control	Baseline, post-intervention, 3 months after the intervention ended	1) Processing speed and visuomotor skills: The Trail Making Test, Wechsler Adult Intelligence Scale-Fourth Edition; 2) Attention and executive functions: Simon task; 3) Working memory: Digit span and Paced Auditory Serial Addition Test of the WAIS-IV; 4) Executive functions: Behavior Rating Inventory of Executive Function; Primary outcome	Depression; Self-efficacy	Within-group comparisons, for processing speed, visuomotor skills and working memory, all participants showed significant improvement across the three measurement points. Depression scores increased significantly in the rehabilitative gaming group ($p < 0.05$). No significant differences among the three groups.
van der Linden SD (2021) [Netherlands]	Brain tumor; IG: n=31 CG: n=31; Age: IG: 45.7±11.7 CG: 52.6±10.4; Gender: IG: 6 (26.1) CG: 14 (53.8)	Cognitive telerehabilitation	Non-active control: waitlist control	Baseline, post-intervention, 6 months after the intervention ended	1) Verbal memory, visual memory, processing speed, psychomotor speed, reaction time, complex attention and cognitive flexibility: Computerized neuropsychological test battery Central Nervous System Vital Signs; 2) Working memory: Digit Span Test of the WAIS; 3) Language-verbal fluency: Letter Fluency test; Primary outcome	N/A	Cognitive outcomes did not significantly differ in group means post-intervention.
Braley, M. (2021) [the United States and Canada]	Stroke with aphasia; IG: n=18 CG: n=18; Age: IG: 58.9±10 CG: 64.2±9.9; Gender: IG:10 (58.8) CG: 8 (53.3)	Virtual reality-based language therapy	Active control: homework practice based on paper workbooks for language therapy	Baseline, post-intervention	1) Language and cognitive skills: Western Aphasia Battery, Revised; 2) Global cognitive function: the Brief Test of Adult Cognition by Telephone; Primary outcome	Quality of life: Stroke and Aphasia Quality of Life Scale 39	The IG showed significant within-group differences in language function and quality of life improvement ($p < 0.01$) but no significant between-group differences.

Ford, M. E. (2023) [Netherlands]	Traumatic brain injury or stroke patients with insomnia; IG: n=27 CG: n=25; Age: IG: 53±14, CG: 56±16; Gender: IG:12 (44.4) CG: 8 (32.0)	Online sessions for insomnia therapy	Active control: routine treatment including therapy aimed at cognitive functioning	Baseline, post-intervention, 6 weeks after the intervention ended	Subjective cognitive functioning: the Cognitive Failure Questionnaire Secondary outcome	1) Sleep outcome; 2) Fatigue; 3) Anxiety; 4) Depression; 5) Societal participation after rehabilitation	There were no significant benefits of intervention over usual treatment for subjective cognitive functioning, fatigue, and emotional well-being, either at post-treatment or follow-up versus baseline. The insomnia severity and sleep quality improved significantly more with intervention than with usual treatment as compared to baseline, both at post-treatment (d=0.96, p < 0.003) and at follow-up (d=-0.78, p < 0.03).
Goffredo, M. (2023) [Italy]	Parkinson's Disease or Multiple Sclerosis; IG: n=75 CG: n=75; Age: IG: 58.1±12.4, CG: 61.1±11.1; Gender: IG:29 (44.6) CG:30 (44.8)	Virtual reality-based motor and cognitive telehealth	Active control: conventional rehabilitation including cognitive activities	Baseline, post-intervention	Global cognitive function: MoCA Secondary outcome	Balance; Motor function	The IG showed significant within-group differences in global cognitive function (p=0.003). There were significant between-group differences in balance and motor function, but not in cognitive function.
Kahraman ,T. (2020) [Turkey]	Multiple sclerosis; IG: n=25, CG: n=25; Age: IG: 34.5 (30-38.8) CG: 36 (28-45); Gender: IG: 4 (20.0) CG: 1 (6.7)	Telerehabilitation-based motor imaging training	Non-active control: waitlist control	Baseline, post-intervention	1) Attention: the Symbol Digit Modalities Test; 2) Memory: the Selective Reminding Test; Visual and spatial working memory: 10/36 Spatial Recall Test; Secondary outcome	1) Dynamic balance and gait ability; 2) Walking speed and endurance; 3) Perceived walking ability; 4) Fatigue; 5) Anxiety and depression; 6) Quality of life: Multiple Sclerosis International Quality of Life questionnaire	Compared to the baseline, the IG exhibited significant improvements in most cognitive functions (except for long term memory), dynamic balance during walking, walking speed, perceived walking ability, balance confidence, fatigue, anxiety, depression and quality of life (p<0.05, d>0.80). No significant differences in CG compared to the baseline.
Pagliari, C.(2021) [Italy]	Multiple sclerosis; IG: n=35 CG: n=35; Age:	Virtual reality-based motor and cognitive telehealth	Active control: conventional motor and	Baseline, post-intervention	1) Global cognitive function: MoCA; 2) Attention: the Symbol Digit Modalities Test; Secondary outcome	1) Quality of life: 54-item Multiple Sclerosis Ruality of Life;	No significant between-group differences in cognitive function. IG showed significant improvements in balance and

	IG: 48.3 (9.7) CG: 52.2 (9.3); Gender: IG:12 (40.0) CG:12 (40.0)		cognitive exercises			2) Upper limb motor function; 3) Balance	quality of life (p=0.045, d=1.04) compared to the CG.
Rossetto, F.(2023), [Italy]	Alzheimer's disease; IG: n=15 CG: n=15; Age: IG: 78.2 ± 4.0 CG: 77.1 ± 6.4; Gender: IG: 6 (40.0) CG: 8 (53.3)	Motor and cognitive training telerehabilitation	Active control: conventional motor and cognitive exercises	Baseline, post-intervention, 10 months after the intervention ended	1) Global Cognitive function: MoCA; 2) Language: letter verbal fluencies, categorical verbal fluencies; 3) Executive Functions: the Trail Making Test; 4) Memory: the Free and Cued Selective Reminding Test; Primary outcome	Autonomy in daily living and behavioral symptoms	IG showed significantly higher intervention period delta changes in global cognitive function (p=0.022, d=0.784), language function (p=0.044, d=0.658), attention (p=0.016, d=0.838), and immediate free recall (p=0.020, d=0.448), surpassing those observed in the CG. Better mean adherence was observed in the IG ($p < 0.001$, d=1.42).
Sandroff, B.M.(2014) [North America]	Multiple sclerosis; IG: n=41 CG: n=41; Age: N/A; Gender: IG: 10 (27.0) CG: 9 (23.1)	Internet-delivered and theory-based behavioral online sessions for increasing physical activity behavior	Non-active control: waitlist control	Baseline, post-intervention	Processing speed: The oral version of the Symbol Digit Modalities Test; Primary outcome	Walking performance; Physical activity	No significant between-group differences in processing speed. When considering differences in disability status, significant time x condition x disability group interaction was observed in processing speed and physical activity (p=0.02, partial-η^2=0.08).
Streltzov, N. A. (2022) [New England]	Epilepsy; IG: n=26 CG: n=54; Age: IG: 44.2 ± 9.9 CG: 48.2 ±11.6; Gender: IG: 5 (29.4) CG: 17 (35.4)	Home-based cognitive self-management online sessions	Non-active control: waitlist control	Baseline, post-intervention, 3, 6 and 9 months after the intervention ended	1) Subjective cognitive function: Quality of Life in Neurological Disorders Item Bank v2.0 Cognitive Function; 2) Objective cognition: Brief Test of Adult Cognition by Telephone; Primary outcome	1) Quality of Life: 31-item Quality of Life in Epilepsy; 2) Change in health care utilization; 3) Depression; 4) Self-management practices	IG showed significant post-intervention improvements in quality of life (p<0.001, d=0.504) compared to the CG. No significant between-group differences in cognitive function, depression and self-management after the intervention and at 3 months post-intervention.
Tarakci, E.(2021) [Turkey]	Multiple Sclerosis; IG: n=15 CG: n=15; Age: IG: 39.5 ± 10.6 CG: 41.0 ± 11.1;	Home-based structured exercise telerehabilitation	Active control: structured supervised exercise	Baseline, post-intervention	Global cognitive function: Functional Independence Measure-subscale Secondary outcome	1) Fatigue; 2) Quality of life: quality of life scale	The IG showed significant within-group differences in cognitive function (p=0.028, d=0.27) and quality of life improvement (p=0.009, d=0.46), no significant between-group differences.

	Gender: IG: 4 (26.7) CG: 3 (20.0)						
Zhou, Q.(2018) [China]	Stroke with aphasia; IG: n=10 CG: n=10; Age: IG: 59.8 ± 11.3 CG: 56.5 ± 14.3; Gender: IG: 7 (70.0) CG: 6 (60.0)	Computerized speech-language and cognitive telerehabilitation	Active control group: family topics communication	Baseline, post-intervention	Language: Western Aphasia Battery Primary outcome	Communication skills	The IG showed greater improvement in language function compared to the CG, with a significant group × time interaction ($p < 0.001$, d=2.74).
Xie JX (2023) [China]	Stroke; IG: n=43 CG: n=43; Age: IG: 60.6 ± 5.6 CG: 61.3 ± 4.1; Gender: IG: 29 (67.4) CG: 31 (72.1)	Internet-based continuity of care, online sessions	Non-active control: usual care	Baseline, post-intervention	Global cognitive function: MMSE Secondary outcome	1) Platelet-Related Hematological Parameters; 2) Rehabilitation outcome; 3) Motor function	After the intervention, the cognitive function (p=0.016, d=3.583), motor function, and rehabilitation outcomes of the IG were significantly higher than those of the CG ($p < 0.05$). Hematological parameters were significantly lower in the IG ($p < 0.05$).
Chae, H. J.(2024) [Korea]	Dementia; IG: n=30 CG: n=30; Age: IG: 73.9±6.2 CG: 73.3±6.9; Gender: IG: 10 (33.3) CG: 10 (33.3)	Comprehensive cognitive training including motivation, cognitive improvement, health care, emotional support, and caregiver sections	Non-active control: waitlist control	Baseline, one-month following the intervention, two-month following the intervention	Global cognitive function: MMSE Primary outcome	1) Depression; 2) Quality of life: Euro-Quality of Life-5 Dimension; 3) Balance confidence; 4) Physical ability; 5) Nutritional status; 6) Caregivers' burden	After intervention, the cognitive function ($p < 0.001$, d=1.175), physical ability, and nutritional status of the IG were significantly higher than those of the CG ($p < 0.05$). Depression scores and caregivers' burden were significantly lower in the IG (p=0.001). No significant difference of quality of life between groups.

Del Pino, R.(2023) [Spain]	Parkinson's Disease; IG: n=10 CG: n=10; Age: IG: 64.5±7.9 CG: 69.1±3.5; Gender: IG: 7 (70.0) CG: 7 (70.0)	Motor and cognitive serious games	Non-active control: usual care	Baseline, post-intervention	Global Cognitive function: MoCA Secondary outcome	1) Quality of life: Euro-Quality of Life-5 Dimension; 2) Motor symptoms; 3) Functional disability	After the intervention, IG group showed marginally significant differences in cognitive function (p=0.051), and significant improvements in quality of life, motor symptoms, and functional disability ($p < 0.05$). Participants reported faster subjective processing of speed.
Maggio, M. G.(2024) [Italy]	Parkinson's Disease; IG 1: n=12 IG 2: n=12 CG: n=10; Age: IG 1: 59.7±9.7 IG 2: 63.8±8.3 CG: 66.8±6.5; Gender: IG 1: 8 (66.7) IG 2: 6 (50.0) CG: 9 (90.0)	IG 1: Tele-VR program focusing on cognitive rehabilitation IG 2: Tele-VR program focusing on cognitive and socio-cognitive rehabilitation	Active control: conventional cognitive training	Baseline, post-intervention, 3 months after the intervention ended	1) Global Cognitive function: MoCA, MMSE; 2) Multiple cognitive domains: Frontal Assessment Battery; 3) Immediate and delayed recall: Rey Auditory Verbal Learning test; 4) Attention: Trail Making Test part A; 5) Executive function: Trail Making Test part B; 6) Phonemic Verbal Fluency: Verbal fluency letter test; Primary outcome	1) Depression; 2) Empathy level; 3) Social functioning; 4) Alexithymia	The inter-group comparison showed that both IG1 and IG2 had significantly greater improvements than CG in MoCA score (d_1=1.131, p = 0.014; d_2=1.403, p = 0.004). Both IG1 and IG2 showed a higher improvement in the FAB score, as compared to the CG ($p < 0.05$).

CG: control group; *d*, Cohen's *d*; EG: entertainment gaming; IG: intervention group; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; N/A: not applicable;

NR: not reported; RG: rehabilitation gaming; VR, virtual reality; WAIS: Wechsler Adult Intelligence Scale.

690 **Table 2.** Intervention characteristics-According to the Template for Intervention Description and Replication (TIDieR) checklist and guide

Author (year) [Country]	Intervention types	Design (how)—the modes of delivery	Content (what)—the materials, procedures, activities, and/or processes	Delivery (who, where, when, how much) -format, location, duration of intervention, length of sessions, frequency of sessions, intensity	Feasibility, acceptability and finical cost
Välimäki,M. (2018) [Finland]	Digital cognitive gaming: EG, RG	RG group: Internet browser–based digital brain training program, CogniFit; EG group: Consoles	RG: Participants logged into the cognitive training platform using personal game accounts and selecting exercises from a pool of 33 games. EG: providing participants with a console and installing eight games purchased from the official PlayStation Store. Engagement and compliance were optimized through an introductory meeting, game testing, and weekly follow-up calls.	Format: individual Location: home Intervention time: 8 weeks Follow-up time: 3 months Length: at least 30 min Frequency: every day Intensity: NR	Recruitment rate: 32.6% Dropout rate: RG: 21% EG: 14% CG: 31% Adverse events: Depressive symptoms increased in the RG group. Satisfaction: RG: 68%, EG: 83% Adherence rate: RG: 93%, EG: 100% Finical cost: NR
van der Linden SD (2021) [Netherlands]	Cognitive rehabilitation	The ReMind-app, which could work on iOS systems of iPad devices (Apple Inc)	ReMind includes psychoeducation, strategy training and an attention-retraining game with visual and auditory stimulation. Each module includes compensatory exercises. Patients could send e-mails through the Remind for help. Researchers provided telephone assistance every 2 weeks.	Format: individual Location: home Intervention time: 10 weeks Follow-up time: 6 months Length and frequency: three hours a week Intensity: NR	Recruitment rate: 54.1% Dropout rate: IG: 35.5% CG: 19.4% Adverse events: NR Satisfaction: 90% rated the program as “good” or “excellent”, and 95% would recommend the program to others. Adherence rate: 70% Finical cost: NR
Braley, M. (2021) [the United States and Canada]	VR-based language therapy	Constant Therapy-Research software, iPad tablet	In the Constant Therapy-Research software, participants had the option to select answers and use cues for each trial. Immediate feedback on accuracy was provided. The software utilized the	Format: individual Location: home Intervention time: 10 weeks Follow-up time: none	Recruitment rate: 62.1% Dropout rate: IG: 5.6% CG: 16.7% Adverse events: NR

			algorithm to guide participants through a library of therapy exercises.The software can track program usage. Every two weeks, researchers assessed training progress through video conferences.	Length and frequency: at least 30 min a day, 5 days/week. Intensity: advanced via algorithm	Satisfaction: NR Adherence rate: NR Finical cost: NR
Ford, M. E. (2023) [Netherlands]	Online sessions for insomnia therapy	Smartphone, the Mind district eHealth platform	The program, guided by a healthcare psychologist, covered behavioural and cognitive techniques, including sleep hygiene education, stimulus control, sleep restriction, cognitive restructuring, activation, relaxation, fatigue and stress management. Patients were asked to use a diary app for daily reports of sleep and complete online assignments after each session.	Format: individual+a healthcare psychologist Location: home+research center Intervention time: 6 weeks Follow-up time: 6 weeks Length: NR Frequency: once a week Intensity: NR	Recruitment rate: 91.2% Dropout rate: IG: 11.1% CG: 8.0% Adverse events: NR Satisfaction: NR Adherence rate: 92.0% Finical cost: NR
Goffredo, M. (2023) [Italy]	VR-based motor and cognitive telehealth	A tablet home with the VR telerehabilitation system Inertial sensor	This program featured customized cognitive and motor activities. Inertial sensors captured and processed patient movement during motor activities. The patient received visual and audio feedback in a serious game. Balance and lower limb rehabilitation activities were done.	Format: individual Location: home Intervention time: 6-8 weeks Follow-up time: none Length: 45 min each time Frequency: 5 days/week Intensity: NR	Recruitment rate: NR Dropout rate: IG: 13.3% CG: 10.7% Adverse events: None Satisfaction: NR Adherence rate: NR Finical cost: NR
Kahraman,T. (2020) [Turkey]	Telerehabilitation -based motor imaging training	Via video conferencing using SkypeTM software. Personal computers, a webcam and headphones were provided by the researchers.	Following a 5-minute relaxation exercise, multi-sensory environmental information was provided using auditory, visual, tactile, and olfactory cues. During intervention, patients attempted to make their imaginations as similar to the actual executed movements as possible. Fatigue levels before and after each session were evaluated.	Format: individual+a physiotherapist Location: home+clinic Intervention time: 8 weeks Follow-up time: none Length: 20-30 min/session Frequency: twice a week Intensity: Participants reported their proficiency in the corresponding actualized movement increased.	Recruitment rate: 73.5% Dropout rate: IG: 24.0% CG: 44.0% Adverse event: none Satisfaction: NR Adherence rate: The participants who completed the intervention attended each session. Finical cost: NR

Pagliari, C. (2021) [Italy]	VR-based motor and cognitive telehealth	A tablet home with the VR telehabilitation system and a inertial sensor	The system included digital motor and cognitive rehabilitation activities, which were performed at home by the patient using a dedicated home-based kit in an asynchronous telerehabilitation modality with digital contents and offline remote monitoring by the therapist.	Format: individual Location: home Intervention time: 6 weeks Follow-up time: none Length: 45 min/session Frequency: 5 times/week Intensity: NR	Recruitment rate: 92.1% Dropout rate: IG: 14.3% CG: 14.3% Adverse events: NR Satisfaction: 80% participants reported excellent-to-best level of usability of the system. Adherence rate: 86.7% Finical cost: NR
Rossetto, F. (2023) [Italy]	Exercise and cognitive training telerehabilitation	ABILITY Digital Telerehabilitation Platform, tablet-delivered	1) Delivering tablet-based motor and cognitive activities. The motor activities included home-based aerobic physical exercises with the support of a chair + outdoor aerobic exercise (video tutorials). The content of cognitive intervention involved four domains: language, memory, executive function, and attention. 2) Asynchronously monitoring from remote vital and physical health parameters.	Format: individual Location: home Intervention time: 6 weeks Follow-up time: 42 weeks Length and frequency: cognitive activities 5 days/week (20-30 min/day)+motor exercises 3 days/week (15-25 min/day) Intensity: Five levels of difficulty, with progression to the next level determined by an algorithm.	Recruitment rate: NR Dropout rate: IG: 6.7% CG: 13.3% Adverse events: none Satisfaction: Around 70% participants and caregivers reported good-to-excellent level of usability of the system. Adherence rate: 81% Finical cost: NR
Sandroff, B.M. (2014) [North America]	Internet-delivered and theory-based behavioral online sessions for increasing physical activity behavior	Study website+ Skype™+a Yamax SW-401 Digiwalker pedometer	Internet-based program rooted in social cognitive theory + 15 scheduled Skype™ one-on-one video chat sessions with a behavior-change coach. During these sessions, goal setting and progress review were conducted, alongside discussions on behavioral change strategies and facilitators based the website content. Using the pedometer for recording daily steps, and Goal Tracker software for setting goals and monitoring progress.	Format: individual+ coach Location: home Intervention time: 6 months Follow-up time: none Length: 15 sessions in total Frequency: 7 times during the first 2 month, 4 times during the second 2 month, and 2 during the final 2 months Intensity: NR	Recruitment rate: NR Dropout rate: IG: 9.8% CG: 4.9% Adverse events: NR Satisfaction: NR Adherence rate: 88.6 % Finical cost: NR
Streltzov, N. A. (2022) [New England]	Home-based cognitive self-management	Secure video connection+ telephone+a manual	Participants received 8 sessions based on Problem Solving Therapy mainly focused on memory and attention training. They were taught problem	Format: individual+health care professional Location: home	Recruitment rate: 85.7% Dropout rate: IG: 38.5% CG: 24.1%

	online sessions "HOBSCOTCH"		solving strategies and compensatory mechanisms. Participants received a manual with educational materials, session worksheets, and a toolbox of compensatory memory strategies.	Intervention time: 8-12 weeks Follow-up time: 9 months Length: 45-60 min/session Frequency: NR Intensity: The first session conducted virtually, 3 weekly followed by 3 bi-weekly telephone coaching sessions, and a final session conducted virtually.	Adverse events: NR Satisfaction: 95% affirmed this useful program. Adverse events: NR Satisfaction: NR Adherence rate: NR Finical cost: CG was more likely to have epilepsy-related blood tests between baseline and 3 months than the IG (p=0.04).
Tarakci, E. (2021) [Turkey]	Home-based structured exercise telerehabilitation	Telephone video calls	The structured exercise program customized for each participant following the initial evaluation. The program consisted of 10 min warm-up, 40 min training, and 10 min cool-down exercises. The exercises included functional stretching, breathing, strengthening, balance and coordination, and ambulation activities. Patients received video calls for consultation, guidance, and program revision 3 times/week.	Format: individual+ physiotherapist Location: home Intervention time: 12 weeks Follow-up time: none Length: 1h/session Frequency: 3 times/week Intensity: progressed gradually during the weeks.	Recruitment rate: NR Dropout rate: IG: 25.0% CG: 28.6% Adverse events: NR Satisfaction: NR Adherence rate: NR Finical cost: NR
Zhou, Q. (2018) [China]	Computerized speech-language and cognitive telerehabilitation	Personal computer or iPad	Family topics communication for 30 min a day+training program adopted from the Wispirit Inc.(66nao.com). The training program comprised speech-language module and non-verbal cognitive training module. Individual language deficit profiles were used to determine the training assignments, while cognitive-language associations were leveraged to assign cognitive training tasks.	Format: individual Location: home Intervention time: 30 days Follow-up time: none Length:30 min a day Frequency: daily Intensity: algorithm-based. Within each task, if there was high accuracy (> 80%), the task was replaced by a harder task from the same domain.	Recruitment rate: NR Dropout rate: IG: 0% CG: 0% Adverse events: NR Satisfaction: NR Adherence rate: NR Finical cost: NR
Xie JX (2023) [China]	Internet-based continuity of care, online sessions	Internet-based home rehabilitation platform, via computer or phone	The patient's basic information, examination reports, and disease progression were used to create a personalized online home rehabilitation plan with exercise and food recommendations. Nurses conducted	Format: individual+nurses Location: home Intervention time: 12 weeks Follow-up time: none Length: NR Frequency: NR	Recruitment rate: NR Dropout rate: IG: 0% CG: 0% Adverse events: NR Satisfaction: NR

			regular video calls to provide health education.	Intensity: NR	Adherence rate: NR Finical cost: NR
Chae, H. J.(2024) [Korea]	Mobile application-based comprehensive cognitive training	Tablet, mobile application “Smart Brain”	The Smart Brain program is largely divided into motivation, cognitive improvement, healthcare, emotional support, and caregiver sections. Researchers could encourage patients by viewing the day’s to-do list or goal achievement status on the administrator’s server. Participants could communicate with others and share their daily life.	Format: individual+researchers Location: home Intervention time: 8 weeks Follow-up time: none Length: 30-50 min Frequency: 5 times/week Intensity: automatic adjustment according to the participant's cognitive function	Recruitment rate: 83.3% Dropout rate: IG: 0% CG: 0% Adverse events: none Satisfaction: NR Adherence rate: NR Finical cost: NR
Del Pino, R.(2023) [Spain]	Motor and cognitive serious games	The vCare system, stalled on the tablet+ a TV connected with a 3-dimensional camera	The vCare telerehabilitation followed a routine of clinical condition monitoring, risk prevention, and motor and cognitive rehabilitation synchronized by an intelligent system with an avatar, which scheduled the rehabilitation based on the plan established by the clinicians responsible for the patient. The system continuously reported on the patient's clinical condition and response to rehabilitation.	Format: individual+virtual coach Location: home Intervention time: 4 months Follow-up time: none Length: 30 min Frequency: 4 times/week Intensity: automatic adjustment according to the participant's progress	Recruitment rate: NR Dropout rate: IG: 0% CG: 20.0% Adverse events: none Satisfaction: Participants highlighted the perspicuity of the intervention system, its stimulation, and the novelty of the system. Adherence rate: ＞90% Finical cost: IG's 3-month rehabilitation costs were lower than CG's.
Maggio, M. G.(2024) [Italy]	IG 1: Tele-VR program focusing on cognitive rehabilitation IG 2: Tele-VR program focusing on cognitive and socio-cognitive rehabilitation	Smartphone, non-immersive VR applications;	Participants conducted cognitive rehabilitation (comprehensive brain training) or cognitive and socio-cognitive rehabilitation (social activity training) via non-immersive VR applications. All participants received weekly phone calls for support.	Format: self-training Location: home Intervention time: 6 weeks Follow-up time: 3 months Length: 30 min Frequency: 3 times/week Intensity: NR	Recruitment rate: NR Dropout rate: IG: 0% CG: 0% Adverse events: none. Satisfaction: NR. Adherence rate: NR Finical cost: NR

CG: control group; EG: entertainment gaming; IG: intervention group; N/A: not applicable; NR: not reported; RG: rehabilitation gaming; VR, virtual reality.