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Critical Review

Effectiveness of teleneuropsychological rehabilitation: Systematic review of randomized controlled trials

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Abstract

Objective: The effectiveness of neuropsychological rehabilitation is supported by the evidence found in previous reviews, but there is a lack of research regarding the effectiveness of remotely conducted neuropsychological rehabilitation. This review aimed to identify and evaluate the results of studies investigating the effectiveness of teleneuropsychological rehabilitation. **Methods:** Relevant articles were extracted from electronic databases and filtered to include studies published in 2016 or later to focus on recent practices. Data were synthesized narratively. **Results:** A total of 14 randomized controlled studies were included in the synthesis (9 for children/adolescents, 5 for adults). The most common type of intervention was computerized cognitive training with regular remote contact with the therapist (seven studies). Regarding children and adolescents, the evidence for the effectiveness was found only for these types of interventions with improvements in cognitive outcomes. The results regarding the family-centered interventions were mixed with improvements only found in psychosocial outcomes. No support was found for the effectiveness of interventions combining cognitive and motor training. Regarding adults, all included studies offered support for the effectiveness, at least to some extent. There were improvements particularly in trained cognitive functions. Long-term effects of the interventions with generalization to global functioning remained somewhat unclear. **Conclusion:** Remote interventions focused on computerized cognitive training are promising methods within teleneuropsychological rehabilitation. However, their impact on long-term meaningful, everyday functioning remained unclear. More research is needed to reliably assess the effectiveness of teleneuropsychological interventions, especially with more comprehensive approaches.

Keywords: Telerehabilitation; Psychological intervention; Neurocognitive disorders; Cognitive dysfunction; Rehabilitation; Neuropsychology

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Neuropsychological rehabilitation or cognitive rehabilitation aims to assist patients' in recovering or compensating for impaired cognitive functions and in emphasizing meaningful functional activity in everyday life. The holistic approach of neuropsychological rehabilitation emphasizes the interlinked nature of cognition, emotion, and psychosocial functioning (Wilson, 2008). Comprehensive-holistic cognitive interventions are designed to decrease the impact of cognitive deficits and increase the patient's self-awareness of the disability, while supporting their emotional, interpersonal, and psychological functioning through the therapeutic environment (Cicerone et al., 2019; Koehler et al., 2012). In addition, neuropsychological rehabilitation can focus on improving or maintaining the patient's cognitive abilities in specific cognitive areas (e.g., attention, vision and neglect, language and communication skills, memory, executive functioning) (Cicerone et al., 2019). Interventions may include compensatory strategy-based techniques and/or individually adapted cognitive training (Miotto et al., 2008; Mowszowski et al., 2010; Wilson et al., 2017). Furthermore, cognitive interventions may include family-centered or social interventions (De Goumoëns et al., 2018; Shaw, 2016; Robinson et al., 2014).

Cognitive interventions can be utilized with a wide array of patients with neuropsychological impairments, and research has demonstrated its effectiveness in improving cognitive and psychosocial functioning in populations, such as acquired brain injury (ABI), stroke, multiple sclerosis (MS; Cicerone et al., 2011; Cicerone et al., 2019; Turner-Stokes et al., 2015; Resch et al., 2018; Rosti-Otajärvi & Hämäläinen, 2014; Mattioli et al., 2010). Furthermore, systematic reviews have demonstrated some promising findings from technologically-oriented cognitive interventions, such as virtual reality, video games, and computer-based training with persons with various neurological disorders, including autism spectrum disorder, attention-deficit/hyperactivity disorder (ADHD), learning disabilities, Parkinson's disease, dementia, and ABI; however, the results are mixed, particularly for the drill-based cognitive training approaches with issues of generalizability (e.g., there was no clear transfer effect to patient's daily life, or it was not investigated) (Mesa-Gresa et al., 2018; Peijnenborgh et al., 2015; García-Casal et al., 2017; Nousia et al., 2020; Resch et al., 2018; Rivero et al., 2015; Sala et al., 2019; Bogdanova et al., 2016).

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In recent years, telerehabilitation has provided an alternative for patients with neuropsychological impairments to receive rehabilitation remotely at home or in other environments outside the clinic or hospital. Telerehabilitation has the potential to provide flexibility of time and location in rehabilitation (Chen et al., 2015). Remote services can increase access for persons who live in areas where traditional rehabilitation services may be limited (Peretti et al., 2017), and increase accessibility of services for patients who have mobility impairments or difficulties with traveling (Brennan et al., 2009). Telerehabilitation also has potential to be less labor intensive and serve as a lower cost alternative to traditional interventions (Kairy et al., 2009; Kueider et al., 2012), although the results considering cost-effectiveness are still inconclusive (Laver et al., 2020).

Clinician-patient communication in telerehabilitation may be delivered remotely via multiple technologies, such as telephone, videoconference, or e-mail (Peretti et al., 2017; Stephenson et al., 2022). Remote interventions may be delivered synchronously with real-time clinician-patient interaction, asynchronously by using remotely monitored platforms with delayed feedback from a clinician, or using a hybrid approach combining both (Khoshrounejad et al., 2021; Stephenson et al., 2022). Interventions can also include virtual reality (Rogante et al., 2010), digital patient portals (Voigt et al., 2020), or other technologies such as sensory monitors, personal digital assistants, and smart phone applications (McCue et al., 2010). Using a computerized training program can offer a personalized approach to training, such as real-time feedback and automatic adjustments to the user's ability level (Kueider et al., 2012). In this study the term "teleneuropsychological rehabilitation" refers to neuropsychological or cognitive interventions utilizing remote delivery methods involving synchronous or asynchronous interaction between the professional and patient with the aim to assist the recovery or compensation for impaired neuropsychological functioning (McCue & Cullum, 2013; McLellan, 1991; Wilson, 2008) which distinguishes it from completely independently utilized (i.e., without clinician involvement) cognitive training programs or assistive technology (e.g., personal digital assistants).

Although there is increasing evidence demonstrating the potential of telerehabilitation in patients with neuropsychological impairments (e.g., Camden et al., 2020; Laver et al., 2020; Meltzer et al., 2018), the literature of the systematic review of the teleneuropsychological rehabilitation/remote cognitive intervention is sparse. Findings from one systematic review demonstrated that remote interventions could be as effective as conventional rehabilitation to improve cognitive or depressive symptoms after traumatic brain injury (TBI; Betts et al., 2018). One meta-analysis focused on home-based technology interventions in rehabilitation of executive functioning and memory for children and adolescents with ABI (Linden et al., 2016). Results were encouraging, but the quality of evidence for all outcomes was noted to be low. Similarly, a meta-analysis of computer-based remote training programs with behavioral and cognitive focus demonstrated promising results for patients with pediatric ABI (Corti et al., 2019), although high heterogeneity limited the ability to draw definite conclusions from the results. Altogether, even though these cited reviews showed some promising results, the conclusions were limited by with issues of quality of the evidence and methodological heterogeneity. In addition, most of the studies included in the previous reviews were conducted before 2016 and along with RCT's included studies with diverse methodological quality. Given the rapidly evolving field of telehealth, technological development as well as the increasing use of telemedicine during the COVID-19 pandemic (Mann et al., 2020), there is a need for evaluate the current research field and practices of the teleneuropsychological rehabilitation.

Objective

The aim of this systematic literature review was to identify and evaluate the effects of teleneuropsychological rehabilitation on cognitive, behavioral, and socio-emotional functioning in adults and children.

Methods

This systematic review was conducted using the PRISMA reporting protocol (Moher et al., 2009), as this allows for a standardized non-biased approach to the review. The study protocol has been retrospectively published on the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY) with the registration number INPLASY202330093.

Eligibility criteria

Eligible studies included neuropsychological remote interventions for children and/or adults (aged 0–65 years) with neuropsychological impairments or their caregivers. Articles where the mean age of the participants was more than 65 years were excluded due to greater variability in patients' health conditions and its impact on intervention outcomes. Given the scarcity of research on teleneuropsychological rehabilitation, there were no restrictions on duration, intensity, co-interventions, comparators, or outcome measures. In addition, a wide spectrum of neuropsychological rehabilitation approaches was included, such as cognitive retraining (paper-pencil and/or computerized), compensatory strategy training, and neuropsychological counseling or support. Remote interventions involving mainly self-training was included if there was regular involvement (synchronous/asynchronous) of the intervention provider. The goal was to achieve a large sample of studies to assess the current state of the field. The final sample of this study was narrowed to randomized controlled trials (RCTs). Experimental study design was considered necessary to determine the validity of the results and to evaluate the evidence supporting effectiveness. More detailed eligibility criteria are presented in Figure 1.

Information sources

Online literature searches were conducted using MEDLINE (PubMed), Web of Science, Scopus, and PsycINFO electronic databases and filtered to include studies published in 2016 or later to focus on recent telerehabilitation practices. All database searches used the same set of search terms combining words "tele," "remote," "virtual," "distance," "online," and "web-based" with words "rehabilitation," therapy, intervention, and training and words "neuropsychology," "neurology," "neuropsychiatry," "neurodevelopmental," "neurocognitive," and "cognitive." These terms were searched from title, abstract, and keyword fields, if available. In addition, searches were supplemented from relevant Finnish electronic databases (Journal.fi; Helda, psykologia.fi., Julkari) with the same set of search terms. Review articles identified in the searches and the accompanying reference lists were screened using the same criteria. Basic search expression, which was slightly modified according to each database, is presented in Appendix.

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Inclusion criteria

1. Intervention studies addressing teleneuropsychological rehabilitation for participants with neuropsychological impairments
   a) Studies with remotely delivered interventions as well as studies involving more than one delivery mode (e.g., face-to-face and telephone) if most of the sessions (e.g., ≥4 sessions of an 8-session intervention) were delivered remotely
   b) Studies with neuropsychological or cognitive rehabilitation as a part of multidisciplinary rehabilitation if neuropsychological rehabilitation of the intervention was clearly reported
   c) Participants with neuropsychological impairments due to neurological or psychiatric disorder
   d) Studies targeting caregivers or family members of the participants if the aim of the intervention was to support the participant with neuropsychological impairments.
2. Peer-reviewed journal articles

Exclusion criteria

1. Articles not addressing intervention
2. Articles relating to older adults (+65)
3. Theoretical articles or descriptions of rehabilitation programmes without specific intervention
4. Articles without adequate specification of intervention
5. Review articles
6. Articles in which participants had only mild neuropsychological symptoms not affecting their everyday functioning (e.g., subjective memory complaints or mild cognitive impairment)
7. Articles addressing interventions without any synchronous or asynchronous interaction with the provider of the intervention (e.g., therapist, coach, study personnel)

Figure 1. The eligibility (inclusion and exclusion) criteria employed for the systematic review.

Study selection, data collection and extraction

An initial screening of titles and abstracts was carried out to quickly exclude clearly non-eligible articles. If it was unclear whether an article met inclusion or exclusion criterion after review of the title and abstract, the article was passed for full text assessment. Following initial screening, two authors (EN, IS) independently assessed the eligibility of full text articles using the previously described eligibility criteria. The same authors further discussed any article in which they provided discrepant ratings on whether it satisfied eligibility criteria. If there were remaining uncertainties regarding eligibility, the final decision was made based on a group discussion with two additional authors (MP, EP). A data extraction form was used for collecting the following information for each eligible study: (1) baseline information (e.g., demographics, study design), (2) intervention characteristics (e.g., content, duration), (3) outcome measures and their results, (4) effect sizes (ESs) if reported, and (5) main findings, as reported in the study. The data extraction form was developed based on the data extraction template by Cochrane Developmental, Psychosocial and Learning Problems group (available on https://dplp.cochrane.org/data-extraction-form).

Risk of bias assessment

Risk of bias (RoB) of the selected studies was assessed using The Cochrane's RoB tool and by applying the guidelines of The Cochrane Handbook (Higgins et al., 2011; Higgins et al., 2022). One author (EN) completed the ratings independently and categorized the RoB as being low, high, or unclear. When there was uncertainty in the coding of the RoB, three authors (EN, IS, MP) discussed it and decided by consensus.

Data analysis and synthesis

Due to the heterogeneity of the included studies, a meta-analysis could not be undertaken. Thus, a narrative synthesis of quantitative results was used. In addition, for each eligible study, the reported ES was used, wherever effect was statistically significant (p-values < 0.05). If ES was not reported, Hedges' g was computed using R version 3.6.2 (R Core Team, 2019) according to means and standard deviations reported in the study, whenever possible, and the ES's were categorized as small ($g = 0.2$), moderate ($g = 0.5$), or large ($g = 0.8$). However, these categories are somewhat arbitrary and should be interpreted only as rough estimates of the ES. In the case of insufficient information regarding the ES, the authors were contacted. However, no responses were obtained.

Results

Results of the search and study selection

All databases were searched in November 2021. The processes for searching the literature and choosing final articles for this study are shown in Figure 2. There was 85% initial agreement between 2 researchers concerning the eligibility of the 292 studies. Altogether, there were 29 studies considered as eligible. Among these studies, there were 14 RCTs, 4 controlled studies with a pre-post-study design, and 11 intervention studies without a control group. Of the remaining articles, only RCTs were included in the qualitative synthesis based on the predefined criteria.

Intervention findings

Detailed descriptions of the interventions are presented in Table 1. The most used medium for remote communication was telephone ($n = 7$, 50%), followed by videoconference ($n = 5$, 36%). In addition, two studies had e-mail as an alternative to telephone and in two studies, the medium remained unclear. Furthermore, six studies (43%) combined remote sessions with face-to-face meetings. For children/adolescents, the most typical diagnosis was TBI ($n = 6$, 43%). Regarding children, other patient groups were pediatric onset MS or ADHD ($n = 1$), childhood cancer survivors

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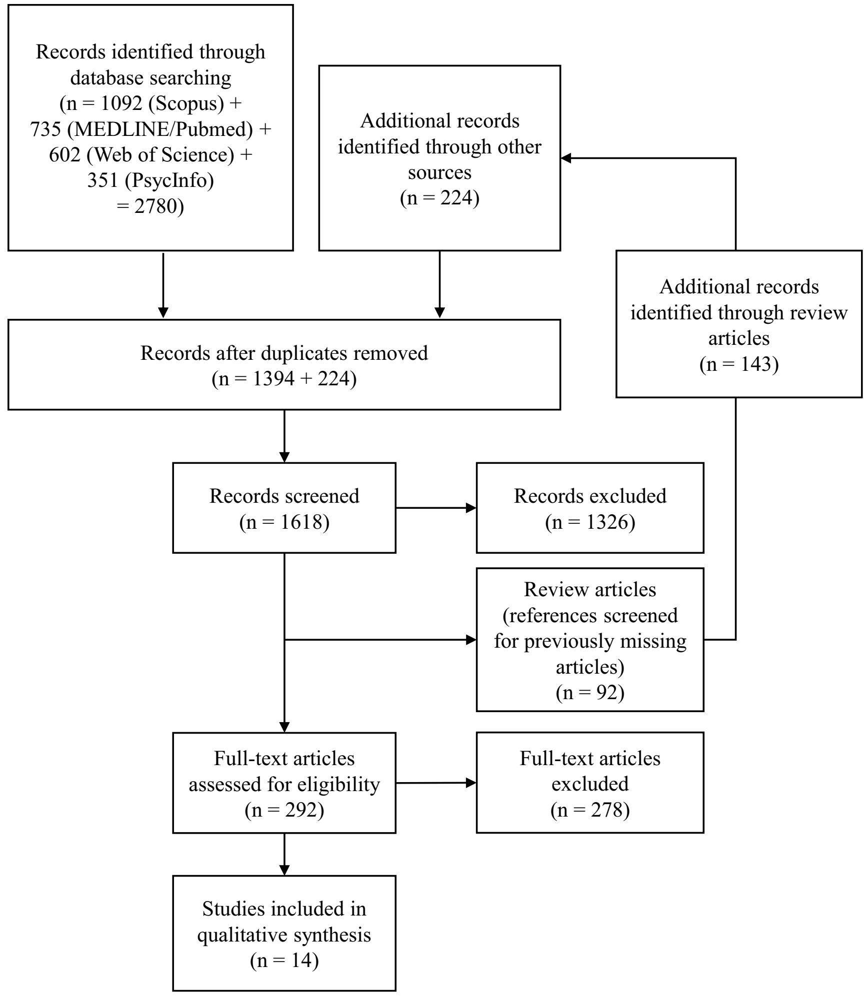

Figure 2. The flow chart of the process of choosing the articles on teleneuropsychological rehabilitation.

(acute lymphoblastic leukemia/brain tumor; $n = 1$) and unilateral cerebral palsy ($n = 1$). The most typical diagnosis for adults was MS ($n = 2$) or stroke ($n = 2$). Additionally, there were one study including patients with epilepsy. The total length of the interventions varied from 5 weeks to 6 months and intensities varied from weekly/biweekly sessions to 6 sessions per week. Next, synthesis of the findings of the studies is summarized in Tables 1 and 2 (total $n = 1063$), with studies with children/adolescents synthesized separately from those with adults. From here on, the term *therapist* refers to the person who provided the intervention independent of his/her exact profession, unless specification is needed.

Telerehabilitation for children and adolescents

There were nine studies evaluating the effectiveness of telerehabilitation for children and adolescents with neuropsychological impairments, comprising a total of 844 participants. Regarding the content, three types of interventions were identified: (1) family-centered interventions with strategy training focused on parenting skills, cognitive, behavioral, or emotional functioning or a combinations of these (studies 1, 4, 11, and 14); (2) computerized cognitive training (studies 3, 7, and 10); and (3) cognitive training combined with motor training (i.e., gross motor, cognitive and upper limb tasks; studies 8, and 9). In all studies of the first intervention type (1), the telerehabilitation included synchronous videoconferencing with self-guided material reviewed between the videoconferencing sessions, with the exception of one study with unclear medium of delivery of the online sessions (study 4). For the second type (2), the cognitive training was home-based self-training with regular phone calls with the therapist. For the third type (3), the mode of the delivery was the same as in the second type.

Evidence for effectiveness was found mainly for the interventions offering computerized cognitive training. These interventions targeted specific cognitive domains (working memory or attention) with improvements in single (study 7) or several (studies 3 and 10) cognitive domains with ESs varying from small to large when compared to active or passive control groups. While there were positive near transfer effects, the sample sizes were relatively small and evidence for transfer of specific training to non-trained domains (e.g., functional cognition) was somewhat mixed. One attention training intervention showed improvements in some non-trained cognitive domains when compared to non-specific training (study 10), although there was no follow-up included. Furthermore, in this study improvements were found only in small group of children with pediatric onset MS, but not in children with ADHD. Regarding the interventions with working memory training, one study had positive long-term changes in some non-trained functions when compared to a passive control group (study 3), and another study showed long-term improvements on a single non-trained task when compared to an active control group

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Table 1. Descriptive summary of the randomized controlled studies on teleneuropsychological rehabilitation included in the analyses

Study number	Description of the study/intervention	Target group	Timing	Outcomes
(1)	**Aguilar et al. (2019):** I-InTERACT and I-InTERACT Express are web-based parenting interventions targeting caregivers of children with moderate to severe TBI aged 3–9 years (Narad et al., 2019). The I-InTERACT program, focusing on behavioral and cognitive effects of TBI, parenting skills, stress/anger management, and family communication strategies, included online intervention carried out by a therapist through Skype, and self-guided psychoeducational modules. The I-InTERACT Express focused exclusively on effective parenting skills. Control condition was IRC group receiving only access to internet content related to TBI and parenting. Both versions of I-InTERACT aimed to reduce problems in executive functioning and internalized behavior.	Children with TBI	**I-InTERACT:** 10 weekly/biweekly core sessions (40–60 min each) and four supplemental sessions based on specific concerns (e.g., sibling issues). **I-InTERACT Express:** 7 weekly/biweekly core sessions and a booster session 8–12 weeks after final core session. **IRC:** Parents were instructed to spend 1 hour or more per week visiting online resources. **Assessment points:** Baseline, follow-up (6 months from baseline)	**Executive functioning:** Behavior Rating Inventory of Executive Functioning – Global Executive Composite (BRIEF – GEC). **Internalizing behavior:** Child behavior checklist (CBCL) – Internalizing problems; CBCL – Anxious/Depressed; CBCL – Withdrawn/Depressed; CBCL – Somatic Complaints
(2)	**Caller et al. (2016):** HOBSCOTCH program for adults (18–65 years old) with epilepsy. The standard HOBSCOTCH program focused on organizational skills, seizure management, and social skills utilizing behavior modification strategies from Memory and Attention Adaptation Training components and Problem-Solving Therapy framework. The main purpose of the HOBSCOTCH programs was to support participants with educational materials and compensatory strategies to solve their cognition related day-to-day problems and worries. In addition, participants in HOBSCOTCH plus condition received daily working memory training implemented in Brain Age© program running on Nintendo DS® handheld console. Both groups received weekly telephone sessions with a therapist between first and last sessions. Control group received care as usual and were waitlisted for memory training intervention.	Adults with epilepsy	**HOBSCOTCH:** Eight weekly sessions (45–60 min each) including two f2f visits (first session as a group visit and last session as a f2f). **HOBSCOTCH plus:** In addition to standard HOBSCOTCH sessions, participants performed working memory training 5 days a week (20–40 min per day) on their own. **Control group:** Waitlist for the memory training alone **Assessment points:** Baseline, post-intervention (6 weeks from baseline)	**Quality of life:** Quality of Life in Epilepsy (QOLIE-31) – Overall score and subscales (Worry, Quality of life, Emotion, Energy, Cognitive, Medication, Social). **Cognitive functioning:** Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) – Total score and subscales (Immediate, Visuospatial, Language, Attention, Delayed); The Functional Assessment of Cancer Therapy – Cognitive scale (FACTCog). **Executive functioning:** Behavior Rating Inventory of Executive Function – Adult (BRIEF-A). **Depression:** Patient health questionnaire (PHQ9); Neurological Disorders Depression Inventory – Epilepsy scale (NDDI-E)
(3)	**Conklin et al. (2017):** The study investigated computerized cognitive training (Cogmed, https://www.cogmed.com) for childhood cancer survivors (ALL or BT, aged 8–16 years). The computerized cognitive intervention focused on improving cognitive outcomes and consisted of working memory exercises in visuospatial and verbal domains. Exercises adapted in difficulty to the participant's performance. While training at home, the progress was monitored over the internet and participants received weekly phone calls for feedback and motivation. Waitlist control group received the same intervention than the intervention group after follow-up assessments.	Children with ALL or BT	25 training sessions over 5–9 weeks, each session approximately 30–45 min. Participants demonstrating slower than desired progress (i.e., score gain of<20 after 20 sessions) were offered five additional sessions. **Assessment points:** Baseline, post-intervention (10 weeks from baseline), follow-up (6 months from baseline)	**Working memory:** WISC-IV – Digit Span Forward; WISC-IV – Digit Span Backward; WISC-IV – Letter Number Sequencing; WISC-IV – Working Memory Index; WISC-IV – Spatial Span Forward; WISC-IV – Spatial Span Backward**. Executive functioning, attention:** Conners 3 Parent – Inattention; Conners 3 Parent – Executive Function; BRIEF – Working Memory; BRIEF – Metacognitive Index; CPT-II – Omissions; CPT-II – Hit RT**. Academic skills:** Wj-III – Reading Fluency; Wj-III – Math Fluency

(*Continued*)

Table 1. (*Continued*)

Study number	Description of the study/intervention	Target group	Timing	Outcomes
(4)	**Kurowski et al. (2020):** The study investigated the comparative effectiveness of three modes of family problem-solving therapy for adolescents (aged 14–19 years) with TBI: (1) f2f intervention, (2) Therapist-guided online intervention, and (3) Self-guided online intervention. The medium used for remote communication in therapist-guided online intervention remained unclear. All three interventions involved one or both caregivers and siblings, when available, in addition to the patient. The content was comparable between all 3 interventions, providing communication and problem-solving strategies for families and executive function heuristics for individuals with TBI.	Adolescents with TBI and behavioral problems	**f2f intervention:** Ten core sessions, 60 min each. **Therapist-guided online intervention:** 10 core sessions, 60 min each. **Self-guided online intervention:** 10 self-guided core sessions. In addition, families in the therapist-guided arms could receive up to four additional meetings with the therapist. The online therapist- and self-guided arms could view 11 supplemental sessions online. The f2f arm participants could complete up to 4 additional sessions with their therapist. **Assessment points:** Baseline, post-intervention (6 months from baseline), follow-up (9 months from baseline)	**Executive functioning:** BRIEF-GEC (parent and self); BRIEF Behavior Regulation Index (BRIEF-BRI; parent and self); BRIEF Metacognitive Index (BRIEF MI; parent and self). **Internalizing and externalizing behavior:** Strength and Difficulties Questionnaire (SDQ) Total; SDQ-Internalizing; SDQ-Externalizing
(5)	**Maresca et al. (2019):** The study examined the effectiveness of a VRRS targeted on adults with aphasia due to stroke. The intervention was ELT containing cognitive and linguistic modules, including exercises on attention, memory, perception, executive functions, and speech/language abilities. The intervention was carried out in two phases. First, while hospitalized, the ELT group received linguistic treatment using VRRS. Second, after hospitalization, the ELT group was provided with a touchscreen tablet and received ELT at home with help from their caregivers. VRRS includes immediate feedback and adjustable difficulty levels. In addition, twice per week a therapist performed a videoconference session with ELT participants to discuss progress and feasibility of the intervention. At the hospital, the control group received similar linguistic treatment as the ELT group but using paper-pencil tools. After hospitalization, the control group underwent conventional speech therapy.	Adults with aphasia due to ischemic or hemorrhagic stroke	Five training days a week, 50 min per session. Whole treatment period lasted 6 months including two phases (12 weeks each). **Assessments points:** Baseline, post-hospitalization (12 weeks after baseline), post-intervention (24 weeks after baseline)	**Receptive language:** Token test (TT). **Language:** Esame Neuropsicologico Per l'Afacia (ENPA); ENPA Comprehension; ENPA Repetition; ENPA Reading; ENPA Naming; ENPA Calculation. **Depression:** Aphasic Depression Rating Scale (ADRS). **Quality of life:** Euro-Qol-5D (EQ-5D). **Psychosocial:** Psychosocial Impact of Assistive Devices Scale
(6)	**Messinis et al. (2020):** The study investigated the effects of HBCACR for adults (25–60 years old) with SPMS. The HBCACR was implemented with RehaCom^{TM} software (RehaCom Cognitive Therapy Software, https://www.rehacom.co.uk) with individualized domain and task-specific sessions under caregiver supervision. During the first session, therapist visited participants' homes to help with the device and execution of cognitive training. Therapist also telephoned participants weekly to encourage adherence and solve possible difficulties. Control group received a sham intervention (non-specific computer-based activities) in addition to standard clinical care.	Adults with SPMS	Three sessions per week, 45 min each, over 8 weeks (24 sessions total) **Assessment points:** Baseline, post-intervention (8 weeks from baseline)	**Processing speed:** Symbol Digits Modalities Test (SDMT). **Memory**: Verbal learning and episodic memory: the Greek Verbal Learning Test (GVLT); Visuospatial memory: The Brief Visuospatial Memory Test-Revised (BVMT-R). **Fatigue:** The Modified Fatigue Impact Scale (MFIS); MFIS Phys; MFIS Cogn; MFIS Psych. **Depression:** The Beck Depression Inventory Fast Screen for Medical Patients (BDI-fast screen). **Quality of life:** Euro-Qol EQ-5D / EQ-5D – visual analog scale (VAS)

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Table 1. (*Continued*)

Study number	Description of the study/intervention	Target group	Timing	Outcomes
(7)	**Phillips et al. (2016):** The study investigated adaptive working memory training (Cogmed, https://www.cogmed.com) for children with TBI (aged 8–15 years). The intervention group received working memory training for verbal and visuospatial information. The difficulty for the training tasks adapted on child's individual working memory span on trial-by-trial basis. The control group was a placebo training group receiving similar training to intervention group with the exception that working memory training was not adaptive and the working memory load of the training tasks remained low all the time. In addition, both groups received weekly phone calls from a certified coach to provide support and enhance motivation.	Children with TBI	Approximately 30–40 min of training five times per week over 5 weeks **Assessment points:** Baseline, post-intervention (5 weeks after baseline), follow-up (3 months after baseline)	**Working memory:** Automated WM Assessment (AWMA) – Phonological loop (Digit recall); AWMA – Visuospatial sketchpad (Dot Matrix); AWMA – CE verbal (Counting Recall); AWMA – CE visual (Mr X)**. Attention:** Test of Everyday Attention for Children (TEA-Ch) – Selective attention (Sky Search: attention score); TEA-Ch – Sustained attention (Score); TEA-Ch – Sustained and divided attention (Sky Search DT); TEA-Ch – Executive control/attention switching (Creature Counting: accuracy score); TEA-Ch – Inhibition (Walk/Don't Walk). **Academic skills:** Wechsler Individual Achievement Tests, Second Edition (WIAT-II) – Word Reading; WIAT-II – Reading Comprehension; WIAT-II – Numerical Operations. **The average index improvement:** Index improvement
(8)	**Piovesana et al. (2017a):** The study examined if a web-based therapy program, "Move it to improve it" (Mitii™; MiTii development, Charlottenlund, Denmark), could improve executive functioning in children with ABI (aged 8–16 years). The Mitii™ intervention was aimed at improving executive functioning using a computer program that included several modules focusing on gross motor, cognitive, and upper limb tasks. A web camera was tracking body movements via bands which were worn on participants' body. The therapists updated the difficulty level of the program weekly. The participants performed training sessions in parental supervision and the therapist contacted them regularly via phone or e-mail to provide feedback and support. In addition to the Mitii™ intervention group, the study utilized a waitlist control group that received care as usual (i.e., physiotherapy, occupational therapy).	Children and adolescents with ABI	30 min per day, 6 days a week for total of 20 weeks. **Assessment points:** Baseline, post-intervention (20 weeks from baseline)	**Executive functioning:** WISC-IV – Digit Span Backwards; WISC-IV – Symbol Search; WISC-IV – Coding; CTMT Trail 2; CTMT Trail 3; CTMT Trail 4; CTMT Trail 5; D-KEFS: CWI – Color naming; D-KEFS: CWI – Word reading; D-KEFS: CWI – Inhibition; TOL Total Correct Score; TEA-Ch Sky Search; TEA-Ch Score; TEA-Ch SkySearch DT; BRIEF-BRI; BRIEF MI; BRIEF-GEC
(9)	**Piovesana et al. (2017b):** The study investigated the effectiveness of a web-based multimodal Mitii™ program to improve executive functioning in children with UCP (aged 8–18 years). The intervention and study design were very similar, overall, to the one described above concerning Piovesana et al. (2017a).	Children and adolescents with UCP	20–30 min per day, 6 days a week for total of 20 weeks. **Assessment points:** Baseline, post-intervention (20 weeks from baseline)	**Executive functioning:** WISC-IV – Digit span Backwards; WISC-IV – Coding; WISC-IV – Symbol Search; Trail Making Test/D-KEFS – Number Letter Sequencing; D-KEFS – Color-word interference (Inhibition); D-KEFS – Tower Test (Tower Achievement Score); BRIEF-BRI; BRIEF MI; BRIEF-GEC

(*Continued*)

Table 1. (*Continued*)

Study number	Description of the study/intervention	Target group	Timing	Outcomes
(10)	**Simone et al. (2018):** The study assessed the efficacy of a home-based computerized program focused on attention training in children (<18 years) with POMS or ADHD. The participants were randomized to either ST or nST group. Participants in the ST group received an Attention Processing Training (APT; Sohlberg & Mateer, 1987) based intervention targeting different domains of attention (focused, sustained, selective, alternating, and divided attention). The training was implemented as a computer program at home after an initial training session conducted in clinic. Participants in nST group received similar intervention, but the training material consisted of a series of non-specific verbal exercises. For participants in both groups, therapist telephoned weekly and met participants and their caregiver every month.	Children with POMS or ADHD	Training twice a week, 1 hour per session. Weekly phone calls. Monthly meetings. Duration of the whole treatment period was 3 months. **Assessment points:** Baseline, post-intervention (3 months from baseline)	**Memory:** Selective Reminding Test Long-Term Storage (SRT-LTS); Spatial Recall Test (SPART); Spatial Recall Test – Delayed (SPART-D). P**rocessing speed, attention:** Symbol Digit Modalities Test (SDMT); Trail Making Test A; Trail Making Test B. **Planning:** Tower of London. **Cognitive functioning:** Cognitive Impairment Index
(11)	**Tlustos et al. (2016):** The study investigated the effects of web-based, family-centered CAPS intervention targeted for adolescents (aged 12–17 years) with TBI. The intervention sessions were carried out via Skype accompanied by self-guided psychoeducational material. The whole family participated in sessions that focused on problem-solving, communication, and self-regulation. The control condition was IRC group receiving only access to websites providing didactic information regarding TBI and modules about working with schools and family advocacy, handling stress, and problem-solving.	Adolescents with TBI	**CAPS:** Weekly or biweekly sessions, followed by up to four supplemental sessions. Duration of the intervention was 6 months. **IRC:** Families were instructed to spend 1 hour or more per week visiting online resources. **Assessment points:** Baseline, post-intervention (6 months from baseline)	**Social competence:** The Social Competence Scale of the Home and Community Social Behavior Scales; The Social Competence subscale of the Child Behavior Checklist (CBCL); The Behavioral and Emotional Rating Scale, Second Edition (BERS-2)
(12)	**Torrisi et al. (2019):** The study investigated the efficacy of a virtual reality based cognitive rehabilitation method for adults with stroke. The intervention utilizing VRRS focused on reasoning and executive abilities, memory functions, and attention processes and spatial cognition. Similar to Maresca et al. (2019), the intervention consisted of two phases, first in hospital and second in home. The system consisted of exercises in two-dimensional (mainly used at home) and three-dimensional (mainly used in hospital) virtual space. Aside from self-training sessions, the second phase consisted of videoconference sessions with a therapist. During hospitalization, the control group received a similar intervention to the experimental group but using paper-pencil tools. During the second phase, the control group received traditional outpatient treatment.	Adults affected by cognitive disorders due to ischemic or hemorrhagic stroke	First phase (at hospital): 5 sessions a week, each session lasting about 50 min. Second phase (at home): 3 sessions a week, each session lasting about 50 min. Total intervention duration 6 months (12 weeks per phase). **Assessment points:** Baseline, post-hospitalization (12 weeks from baseline), post-intervention (24 weeks from baseline)	**Cognitive functioning:** Montreal Overall Cognitive Assessment**. Executive functioning:** Frontal Assessment Battery; Weigl Test**. Attention:** Attentive Matrices; Trail Making Test A (TMT-A); Trail Making Test B (TMT-B)**. Memory:** Rey Auditory Verbal Learning Test Immediate (RAVLT-I); Rey Auditory Verbal Learning Test Differite (RAVLT-D); Digit Span**. Verbal fluency:** Phonemic verbal fluency; Semantic verbal fluency**. Anxiety:** Hamilton Rating Scale for anxiety**. Depression:** Hamilton Rating Scale for depression

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Table 1. (*Continued*)

Study number	Description of the study/intervention	Target group	Timing	Outcomes
(13)	**Vilou et al. (2020):** The study investigated the efficacy of a home-based cognitive rehabilitation program for adults with RRMS. The intervention was implemented on the web-based BrainHQ™ (BrainHQ, Posit Sciences, https://www.brainhq.com) platform, which enables therapist to tailor the intervention content according to the individual needs of the participant. The intervention consisted of training on episodic memory, attention, and processing speed. Also, there was weekly contact from the therapist (for which the medium remained unclear) and biweekly scheduled visits during which the difficulty for BrainHQ™ activities were optimized according to participants' performance. The study reports inclusion of a control group, but it remains unclear if they got any intervention or usual care.	Adults with RRMS	**Intervention group:** Activities twice a week, 40 min per day. Weekly contact with neuropsychologist and scheduled visits every 2 weeks. Total duration 6 weeks. **Assessment points:** Baseline, post-intervention (6 weeks from baseline)	**Processing speed:** Symbol Digit Modalities Test (SDMT). **Visuospatial memory:** Brief Visuospatial Memory Test-Revised (BVMT-R). **Verbal episodic memory:** Greek Verbal Learning Test (GVLT). **Visual attention:** Trail Making Test A (TMT-A). **Divided attention, set shifting (task switching), and cognitive flexibility:** Trail Making Test B (TMT-B). **Reading speed:** Stroop Color Test. **Selective attention and response inhibition:** Stroop Color-Word Test
(14)	**Wade et al. (2018):** The study compared the efficacy of TOPS-Family, TOPS-TO, and IRC for adolescents with TBI (aged 11–18 years). Both interventions had similar content, including training in stress management, problem-solving, self-regulation, communication, and social skills. The interventions included self-guided online modules followed by synchronous videoconferences with a therapist. Supplemental sessions were offered to account for less common individual concerns. The IRC group only received access to online information about brain injury.	Adolescents with TBI	**For both TOPS interventions:** Sessions every 1–2 weeks (and four optional supplemental sessions). **IRC:** Not reported Duration for each intervention was 6 months. **Assessment points:** Baseline, post-intervention (6 months from baseline)	**Externalizing problems:** Child Behavior Checklist (CBCL) – externalizing problems; Youth Self-Report – externalizing problems. **Executive functioning:** Behavior Rating Inventory of Executive Functions global executive composite (BRIEF-GEC); Behavior Rating Inventory of Executive Functions self-report (BRIEF-SR)

Abbreviations for diagnoses: ABI = Acquired brain injury, ADHD = Attention-Deficit/Hyperactivity Disorder, ALL = Acute lymphoblastic leukemia, BT = Brain tumor, POMS = Pediatric onset multiple sclerosis, RRMS = Relapsing-remitting multiple sclerosis, SPMS = Secondary progressive multiple sclerosis, TBI = Traumatic brain injury, UCP = Unilateral cerebral palsy. **Abbreviations for interventions:** CAPS = Communication and problem-solving, ELT = Experimental linguistic treatment, f2f = face-to-face, HBCACR = Home-based computer assisted cognitive rehabilitation, HOBSCOTCH = The HOme-Based Self-management and COgnitive Training CHanges lives, I-InTERACT = Internet-Based Interacting Together Everyday: Recovery After Childhood TBI, IRC = Internet resources comparison, ST = Specific training, nST = Non-specific training, TOPS-Family = Teen Online Problem-Solving with Family, TOPS-TO = Teen Online Problem-Solving with Teen Only, VRRS = Virtual reality rehabilitation system.

Table 2. Summary of the findings of the randomized controlled studies included in the analyses

Study	Study sample and intervention/control groups	Statistical effects*	Main findings
(1) Aguilar et al. (2019)	**Children with TBI (*N* = 117):** I-InTERACT (*n* = 41); I-InTERACT Express (*n* = 37); IRC (*n* = 38)	**BRIEF-GEC (BL-6MF):** g(I-InTERACT) = 0.02 (small), g(Express) = −0.59 (moderate); **CBCL – Withdrawn/Depressed (BL-6MF):** g(Express) = −0.60 (moderate), g(IRC) = −0.10 (small)	Participants receiving I-InTERACT Express intervention demonstrated greater reduction in executive functioning problems when compared to I-InTERACT group and greater reduction in withdrawal behavior compared to the IRC group. However, within the domain of executive functioning, neither intervention group differed statistically significantly from the IRC group. In addition, at follow-up, children receiving I-InTERACT Express whose caregivers had lower educational level showed fewer executive functioning problems than both other groups and less internalizing problems than the IRC group. Similarly, children receiving I-InTERACT Express whose caregivers had depression showed less internalizing problems, withdrawal behavior, and anxiety than IRC group. The results provide partial support for the effectiveness of I-InTERACT Express over I-InTERACT and IRC.
(2) Caller et al. (2016)	**Adults with epilepsy (*N* = 66):** HOBSCOTCH (*n* = 22); HOBSCOTCH plus (*n* = 22); Control group (*n* = 22)	**QOLIE-31 Overall score (PI):** g = 0.60 (moderate); **QOLIE-31 Worry (PI):** g = 0.64 (moderate); **QOLIE-31 Energy (PI):** g = 0.65 (moderate); **RBANS Total score (PI):** g = 0.82 (large); **RBANS Attention (PI):** g = 0.90 (large)	The results indicate that HOBSCOTCH groups improved in quality of life (QOLIE-31 overall score and Worry and Energy subscales) and in cognition (RBANS total score and Attention subscale), whereas Control group demonstrated a decline in all these measures. However, there were no significant differences between intervention and control groups in other domains (depression and functioning in everyday life). HOBSCOTCH and HOBSCOTCH plus did not differ on any outcomes. The results indicate that HOBSCOTCH can be effective in improving quality of life and cognition (especially attention) in adults with epilepsy, but daily working memory training does not add to the effectiveness of the HOBSCOTCH program.
(3) Conklin et al. (2017)	**Children with ALL or BT (*N* = 68):** Computerized cognitive training (*n* = 34); Waitlist (*n* = 34)	**WISC-IV – Digit Span Backward (BL-PI):** g(CCT) = 0.75 (large), g(waitlist) = 0.23 (small); **WISC-IV – Working Memory Index (BL-PI):** g(CCT) = 0.73 (large), g(waitlist) = 0.26 (small); **WISC-IV – Spatial Span Forward (BL-PI):** g(CCT) = 0.96 (large), g(waitlist) = 0.50 (moderate); **WISC-IV – Spatial Span Backward (BL-PI):** g(CCT) = 0.99 (large), g(waitlist) = 0.27 (small); **Conners 3 Parent – Inattention (BL-PI):** g(CCT) = −0.65 (moderate), g(waitlist) = −0.05 (small); **Conners 3 Parent – Executive Function (BL-PI):** g(CCT) = −0.60 (moderate), g(waitlist) = 0.03 (small); **CPT-II – Omissions (BL-PI):** g(CCT) = −0.07 (small), g(waitlist) = 0.46 (moderate); **CPT-II – Hit RT (BL-PI):** g(CCT) = −0.17 (small), g(waitlist) = 0.27 (Small)	The intervention group showed greater improvements in some measures of working memory, attention, and processing speed and greater reductions in parent-reported inattention and executive dysfunction. No other differences were found between the two groups concerning baseline to post-intervention changes. The gains for the intervention group stayed mostly stable during the follow-up period of six months except for a small reduction in a single working memory measure. Taken together, the study provided support for the use of remote computerized cognitive training for children with ALL or BT.
(4) Kurowski et al. (2020)	**Adolescents with TBI and behavioral problems (*N* = 150):** f2f intervention (*n* = 34); Therapist-guided online intervention (*n* = 56); Self-guided online intervention (*n* = 60)	**BRIEF-GEC (BL-6MF):** ES(f2f) = 0.08 (small), ES(therapist-guided) = 0.41 (moderate), ES(self-guided) = 0.50 (moderate); **BRIEF-BRI (BL-6MF):** ES(f2f) = 0.16 (small), ES(therapist-guided) = 0.53 (moderate), ES(self-guided) = 0.50 (moderate)	The authors found no differences among treatment groups in comparative effectiveness. However, in within-group analyses, both online intervention groups demonstrated improvements in parent-reported executive functioning with the self-guided intervention demonstrating increasing effects over the follow-up period after the intervention. No support was found for the efficacy of f2f intervention in any outcome measures. Overall, the study results found relatively similar effectiveness among the three treatment modalities with partial support for benefit of online (especially self-guided) approaches in improving executive functioning.

Table 2. (*Continued*)

Study	Study sample and intervention/control groups	Statistical effects*	Main findings
(5) Maresca et al. (2019)	**Adults with aphasia due to ischemic or hemorrhagic stroke ($N = 30$):** ELT group ($n = 15$); Traditional linguistic treatment control group ($n = 15$)	**TT (PI):** $R^2 = 0.92$; **ADRS (PI):** $R^2 = 0.92$; **EQ-5D – VAS (PI):** $R^2 = 0.84$; **ENPA Reading (PI):** $R^2 = 0.91$; **ENPA Calculation (PI):** $R^2 = 0.98$	Study results demonstrated greater improvements in the ELT group over both intervention phases in the domains of comprehension, repetition, reading, naming, calculation, and psychosocial well-being when compared to the control group. There was no group difference in writing. In addition, the ELT group demonstrated improvement in all of these domains during both phases of the intervention. The control group, in turn, had improvements to a lesser degree in comprehension, repetition, reading, and naming during the first phase, and only in repetition during the second phase. Thus, the study results indicate greater benefit of home-based VRRS over conventional speech therapy in adults with stroke-based aphasia.
(6) Messinis et al. (2020)	**Adults with SPMS (N = 36):** HBCACR (n = 19); Standard care plus sham intervention (n = 17)	**SDMT (PI):** g = 2.980 (large); **GVLT (PI):** g = 2.898 (large); **BVMT-R (PI):** g = 1.699 (large); **MFIS Phys (PI):** g = −0.604 (moderate); **MFIS Cogn (PI):** g = −1.654 (large); **MFIS Psych (PI):** g = −0.940 (large); **BDI-fast screen (PI):** g = −0.519 (moderate); **EQ-5D – VAS (PI):** g = −1.885 (large)	The intervention group showed greater improvements in all domains measured, namely information processing speed/working memory, verbal learning and episodic memory, visuospatial memory, depression, quality of life, and fatigue (physical, psychosocial, cognitive, and general). The results provide evidence in favor of home-based computer assisted cognitive rehabilitation for persons with SPMS when compared to standard clinical care.
(7) Phillips et al. (2016)	**Children with TBI ($N = 27$):** Adaptive working memory training ($n = 13$); Non-adaptive working memory training ($n = 14$)	**AWMA-Visuospatial sketchpad (PI):** $r = -0.58$ (−0.50) (large); **WIAT-II-Reading Comprehension (PI):** $r = -0.39$ (−0.40) (moderate)	Adaptive working memory training resulted in higher gains on a visual working memory task and on some tests of reading from pre- to post-training and from pre-training to follow-up, compared to non-adaptive training. No differences in other working memory tasks or attention tasks were found. The results provide partial support for use of remote adaptive working memory training in children with TBI.
(8) Piovesana et al. (2017a)	**Children and adolescents with ABI ($N = 60$):** Mitii™ intervention ($n = 29$); Waitlist standard care group ($n = 29$)	No statistically significant main results	No differences were found between the Mitii™ intervention group and the care as usual group in executive functioning. Authors concluded that in its current form, Mitii™ is not recommended as an alternative to traditional rehabilitation for this population.
(9) Piovesana et al. (2017b)	**Children and adolescents with UCP ($N = 102$):** Mitii™ intervention ($n = 51$); Waitlist standard care group ($n = 51$)	No statistically significant main results	The study presented no differences between intervention and control groups, indicating that the Mitii™ therapy program is not effective in improving executive functioning in children with UCP.
(10) Simone et al. (2018)	**Children with POMS or ADHD ($N = 36$):** POMS/ST ($n = 8$); POMS/nST ($n = 8$); ADHD/ST ($n = 10$); ADHD/nST ($n = 10$)	**SPART (BL-PI):** g(POMS/Specific training) = 1.86 (large); **SPART-D (BL-PI):** g(POMS/Specific training) = 1.44 (large); **SDMT (BL-PI):** g(POMS/Specific training) = 3.79 (large); **TMT-A (BL-PI):** g(POMS/Specific training) = −0.81 (large); **Tower of London (BL-PI):** g(POMS/Specific training) = 3.47 (large)	The results demonstrated that POMS participants in the ST group had significant improvements in overall cognition, in attention and executive function related domains, and in visuospatial learning and delayed recall, when compared to the nST group. However, ADHD participants in the ST group demonstrated significant improvements only in visuospatial delayed recall and in processing/motor speed. Based on these results, APT seems to have wider effects on cognitive functioning in children with POMS than in children with ADHD.
(11) Tlustos et al. (2016)	**Adolescents with TBI ($N = 132$):** CAPS ($n = 65$); IRC ($n = 67$)	No statistically significant main results	The results failed to show statistical differences between CAPS and IRC groups in any outcome measures, indicating that CAPS participants did not benefit overall from the intervention, at least in the measured domains. In addition, authors did look for effects in subgroups, and found that for younger teens (grades 6–8) with moderate injuries and for older teens (grades 9–12) with severe injuries the CAPS intervention seemed to improve social competence. Overall, the results do not provide clear evidence that the CAPS intervention is effective in improving social competence when compared to IRC, although some specific subgroups might benefit from it.

(*Continued*)

Table 2. (*Continued*)

Study	Study sample and intervention/control groups	Statistical effects*	Main findings
(12) Torrisi et al. (2019)	**Adults affected by cognitive disorders due to ischemic or hemorrhagic stroke (*N* = 40):** Experimental group (*n* = 20); Control group (*n* = 20)	ES or sufficient information for computation not reported (EG and CG at post-intervention differences for Phonemic Fluency ($p = 0.04$) and RAVL.I ($p = 0.03$))	Both groups showed improvements in overall cognitive functioning and depression during the whole treatment period. In addition, during the first phase, the experimental group showed within-group improvements, especially in verbal fluency and anxiety, and partially in attention, whereas the control group did not. During the second phase, similar improvements were found in the experimental group, in addition improved verbal learning. Overall, the results support the use of VRRS both in hospital and home-based cognitive rehabilitation of adults with stroke.
(13) Vilou et al. (2020)	**Adults with RRMS (*N* = 47):** BrainHQ based cognitive rehabilitation (*n* = 23); Control group (*n* = 24)	**SDMT (PI):** $r = 0.26$ (small); **BVMT-R (PI):** $r = 0.38$ (moderate); **GVLT (PI):** $r = 0.60$ (large); **TMT-A (PI):** $r = 0.15$ (small); **TMT-B (PI):** $r = 0.24$ (small); **Stroop Color Test (PI):** $r = 0.30$ (moderate); **Stroop Color-Word Test (PI):** $r = 0.32$ (moderate)	The intervention group demonstrated improvements in verbal learning, visuospatial memory, reading speed and response inhibition, and visual attention. After Bonferroni correction, verbal learning and visual attention remained statistically significant. Both groups showed some improvement in task switching. Taken together, the results support the beneficial effects of semi-assisted home-based cognitive rehabilitation for adults with RRMS.
(14) Wade et al. (2018)	**Adolescents with TBI (*N* = 152):** TOPS-Family (*n* = 49); TOPS-TO (*n* = 51); IRC (*n* = 52)	**BRIEF-GEC (PI):** g between TOPS-Family and TOPS-TO = −0.33 (small–moderate)	Adolescents in the TOPS-Family group improved in parent-reported executive functioning over the TOPS-TO group but not over the IRC group (although the difference approached statistical significance). There were no other statistically significant differences between the three groups. Subgroup analysis revealed that children of lower educated caregivers benefited from TOPS-Family in externalizing symptoms and executive functioning. No other differences between subgroups were found in regard to educational level of the caregivers. The results provided no support for TOPS-TO and just mild support for TOPS-Family (particularly in families with lower educational level) over IRC, indicating low overall support for effectiveness of online problem-solving intervention for children with TBI.

Note: Participants in all studies had cognitive impairments or cognitive symptoms. Sample sizes indicate the number of randomized participants. *Statistical effects are reported only for statistically significant results. (**Study 1)** Effect size (ES) is Hedges' g computed by the authors of the present study based on reported means and standard deviations. (**Study 2)** ES is Hedges' g computed by the authors of the present study based on mean changes in intervention and control groups. (**Study 3)** ES is Hedges' g computed by the authors of the present study based on reported means and standard deviations. (**Study 4)** ES reflect within-group changes derived from the mixed model results and are similar to Cohen's d and Hedge's g. (**Study 5)** ES regarding the linear mixed-effects model between-group differences. The group difference is mostly result of differences between post-hospitalization and post-intervention timepoints. Regarding EQ-5D, statistical effect was found only concerning the visual analogue scale (VAS). (**Study 6)** Hedge's g computed from change scores between groups. (**Study 7)** Mann-Whitney ES r, calculated same way than in Vilou et al. (2020). Intention-to-treat-analysis ES in brackets. (**Study 10)** ES is Hedges' g computed by the authors of the present study based on reported means and standard deviations. (**Study 13)** ES is calculated using $r = Z/\text{sqrt}(N)$, where r is the ES, Z is the score of Mann-Whitney *U* test, and N is the study sample. (**Study 14)** ES is Hedges' g computed by the authors of the present study based on reported unadjusted post-intervention means and standard deviations. This may have little bias on the computed ES, but should be quite good approximate, because the group difference was very small in the baseline [TOPS-Family mean = 57.88 (*SD* = 12.89); TOPS-TO mean = 57.61 (*SD* = 12.81)]. **Abbreviations for diagnoses:** ABI = Acquired brain injury, ADHD = Attention-Deficit/Hyperactivity Disorder, ALL = Acute lymphoblastic leukemia, BT = Brain tumor, POMS = Pediatric onset multiple sclerosis, RRMS = Relapsing-remitting multiple sclerosis, SPMS = Secondary progressive multiple sclerosis, TBI = Traumatic brain injury, UCP = Unilateral cerebral palsy. **Abbreviations for statistical effects:** BL-PI = Within-group effect between baseline and post-intervention, BL-6MF = Within-group effect between baseline and 6 months follow-up, PI = Between-group effect in baseline-adjusted post-intervention scores or in change scores between baseline and post-intervention. **Abbreviations for interventions:** CAPS = Communication and problem-solving, ELT = Experimental linguistic treatment, f2f = face-to-face, HBCACR = Home-based computer assisted cognitive rehabilitation, HOBSCOTCH = The HOme-Based Self-management and COgnitive Training CHanges lives, Computerized cognitive training = CCT, I-InTERACT = Internet-Based Interacting Together Everyday: Recovery After Childhood TBI, IRC = Internet resources comparison, ST = Specific training, nST = Non-specific training, TOPS-Family = Teen Online Problem-Solving with Family, TOPS-TO = Teen Online Problem-Solving with Teen Only, VRRS = Virtual reality rehabilitation system. **Abbreviations for outcome measures:** ADRS = Aphasic Depression Rating Scale, AWMA = Automated Working Memory Assessment, BDI-fast screen = Beck Depression Inventory Fast Screen for Medical Patients, BRIEF-BRI = BRIEF Behavior Regulation Index, BRIEF-GEC = Behavior Rating Inventory of Executive Functioning – Global Executive Composite, BVMT-R = Brief Visuospatial Memory Test-Revised, CBCL = Child behavior checklist, CPT-II = Continuous Performance Test II, ENPA = Esame Neuropsicologico Per l'Afacia, EQ-5D – VAS = Euro-Qol-5D Visual analog scale, GVLT = Greek Verbal Learning Test, MFIS = Modified Fatigue Impact Scale, QOLIE-31 = Quality of Life in Epilepsy, RBANS = Repeatable Battery for the Assessment of Neuropsychological Status, SDMT = Symbol Digits Modalities Test, SPART = Spatial Recall Test, SPART-D = SPART Delayed, TMT = Trail Making Test, TT = Token test, WIAT-II = Wechsler Individual Achievement Tests II, WISC-IV = Wechsler Intelligence Scale for Children IV.

(study 7). None of these studies included psychosocial or emotional outcome measures.

In relation to other types of telerehabilitation, the evidence supporting the effectiveness of family-centered interventions was somewhat mixed. No significant differences were found when cognitive outcomes across treatment groups and active or passive control groups were compared. For one family-centered intervention, there were significant improvements with moderate ES only for the psychological outcome (withdrawn/depressive behavior) compared to active control group (study 1); however, some significant changes were found for family-centered interventions compared to the active control group when subgroup analyses were applied. There were improvements in executive functioning and psychological outcomes in children and adolescents of lower educated caregivers (studies 1 and 14). In addition, children of caregivers with greater symptoms of depression benefitted from the intervention (study 1). Furthermore, improvements were found in social competence depending on age of adolescent and severity of TBI (study 11). Finally, there was no evidence of an effect of home-based cognitive training combined with motor training on cognitive or psychosocial functioning (studies 8 and 9).

Telerehabilitation for adults

There were five studies evaluating the effectiveness of telerehabilitation for adults with neuropsychological impairments, comprising a total of 219 participants. The content of the rehabilitation was focused on home-based computerized cognitive training with regular contact via videoconferencing or telephone with the therapist (studies 5, 6, 12, and 13). Considering the method of delivery of these interventions, the intervention was mainly comprised of self-administered cognitive training with at least weekly contact with the therapist by telephone (study 6) or via videoconferencing (study 5); the contact modality was unclear in one study (study 13) and in another study, contact via videoconference was mainly for monitoring (study 12). In addition to these interventions, one intervention included training of cognitive and self-management strategies with or without computerized cognitive training by telephone with the therapist (study 2).

All studies with adults offered support for the effectiveness of telerehabilitation, at least to some extent. Interventions including computerized cognitive training significantly improved specific or various domains of functioning with ESs varying from small to large, although for one study there was insufficient information to calculate ESs (study 12). In addition, sample sizes of these studies were relatively small and long-term effects remained unclear, as no follow-up was included. Regarding the transfer effect, three studies showed positive post-treatment changes in some psychosocial domains (i.e., quality of life, depression), in addition to the positive near transfer effects on cognitive domains, when compared to face-to-face rehabilitation (studies 5 and 12) or non-specific training (study 6). In one of these studies, the target of the intervention was mainly verbal skills (study 5); however, the ES's (measured with R-squared) of this study were unusually large for psychological research, which should be interpreted with caution. The interventions of two other studies (studies 6 and 12) were targeting various cognitive domains. Additionally, one study with an intervention targeting multi-domain cognition showed improvements in trained domains when compared to a passive control group without psychosocial or emotional outcome measures included (study 13). Finally, the only intervention with compensatory cognitive strategy training over telephone (study 2) demonstrated significantly improved post-treatment quality of life and cognitive functioning when compared to usual care, suggesting some immediate far transfer effects.

Risk of bias

The detailed figure of risk of bias (RoB) assessment is available in the Supplementary Material 1. The most common (100%) methodological flaw was the blinding of participants and personnel. Regarding the random sequence generation, 71% of studies reported it adequately. In one study, the randomization was done based on participants' distance from the hospital, which was assessed as a high RoB. The allocation concealment was reported adequately in 50% of studies (e.g., sealed envelopes), whereas 50% of studies did not report it. In 57% of studies, the blinding of outcome assessors was successful, but in some studies (29%) this was not reported, or the assessors were aware of the randomization (14%). The attrition bias (incomplete outcome data) was assessed as low for 71% of studies (e.g., adequate intent-to-treat analyses, attrition rates equally distributed across groups). This information was unclear for 21% of studies. In addition, the attrition rates of one study were unbalanced across groups reflecting high RoB. In regards to selective outcome reporting, most of the studies (93%) did not report a protocol for the study, or it was too imprecise for determining the RoB.

Regarding other potential bias, there were no other sources of bias found in 29% of the studies; however, this remained unclear for 43% of studies that did not report the compliance of the planned intervention (studies 2, 5, 6, 10, 11, and 12). Furthermore, the compliance of intervention was weak for three studies with participants reaching the planned training dosage poorly (studies 8, 9, and 13), which should be considered as possible RoB (Munder & Barth, 2018). In addition, in one study, intervention and control groups differed in ethnicity (study 4).

Discussion

This systematic review included 14 RCT studies with varying interventions, comparators, as well as participants' characteristics and outcome measures, which reflects the cross-disciplinary nature of neuropsychological rehabilitation (Wilson, 2008). Heterogeneity of studies has been common in previous systematic reviews on telerehabilitation as well (e.g., Amatya et al., 2015; Betts et al., 2018; Camden et al., 2020). Most of the identified articles focused on children with TBI (six studies), followed by adults with MS (two studies) or stroke (two studies). Most typical intervention type was computerized cognitive training with regular contact with a therapist via telephone or videoconferencing (seven studies), or family-centered strategy training via videoconferencing (four studies). In line with this study, previous reviews focusing on neuropsychological or cognitive rehabilitation have found a growing trend to utilize computerized programs in interventions involving cognitive training (Rosti-Otajärvi & Hämäläinen, 2014; Cicerone et al., 2019; Resch et al., 2018). However, a shift toward integrating emotional and cognitive interventions in face-to-face neuropsychological rehabilitation has also been detected (Cicerone et al., 2019; Wilson, 2008).

Effectiveness of telerehabilitation

There was some support for the effectiveness of telerehabilitation in home-based computerized cognitive training with regular contact with the therapist via telephone or videoconferencing for children (studies 3, 7, and 10) and adults (studies 5, 6, 12, and 13). All of these interventions targeting specific or various cognitive domains improved single or several domains of cognitive functioning when compared to active or passive control groups, with ESs varying from small to large. In this review, improvements were found particularly in immediate trained cognitive functions suggesting near transfer effects with only few studies (3 and 7) showing long-term improvements in non-trained cognitive domains. Only few studies incorporated emotional and/or psychosocial outcome measures (5, 6, and 12) or included follow-up (3 and 7). The results showing effects mainly in trained skills with a lack of generalizability are in line with previous studies on the effectiveness of computerized cognitive interventions (Melby-Lervåg et al., 2016; Diamond & Ling, 2016; Lynch, 2002; Sigmundsdottir et al., 2016; Mingming et al., 2022; Zucchella et al., 2014). However, previous studies have also demonstrated promising findings on far transfer effects when computerized training is implemented with face-to-face interaction with the professional (Cicerone et al., 2019; De Luca et al., 2014; Fernández et al., 2012). For adults (studies 5, 6, and 12), there were some immediate improvements in emotional and psychosocial functioning (e.g., quality of life). Even though the sample sizes were relatively small, these indications of some far transfer effects are promising, since previous systematic reviews on computerized-cognitive rehabilitation for similar populations have demonstrated mixed evidence of training effects on emotional or psychosocial functioning (Lampit et al., 2019; Zhou et al., 2021).

Altogether, most of the studies on remote computerized interventions for children or adults focused mainly on impairment level of functioning with scarce evidence of the long-term meaningful, everyday functions of cognition, mood, behavior, or participation (e.g., social, educational, vocational). Finally, only two studies (study 5 and 12) compared the intervention to face-to-face rehabilitation, therefore more research is also needed to evaluate whether telerehabilitation can be used as an alternative to traditional rehabilitation.

Regarding the effectiveness of other types of teleneuropsychological rehabilitation, the results were somewhat mixed. No support was found for the effectiveness of interventions combining cognitive training with motor training aimed for children (studies 8 and 9). These interventions had challenges with treatment compliance and remote technology. In addition, these studies were conducted by the same research group, while the study samples were different. The sole intervention with compensatory cognitive and self-management strategy training with psychoeducation via telephone for adults (study 2) significantly improved post-treatment quality of life and cognitive functioning of participants with epilepsy, suggesting some far transfer effects. Although the evidence for the effectiveness of neuropsychological rehabilitation in epilepsy is limited, the findings of this review are consistent with previous reviews on face-to-face interventions suggesting the usefulness of more comprehensive approach for patients with epilepsy (Farina et al., 2015) as well as strategy-based training for patients with seizure-related deficits (Langenbahn et al., 2013).

Instead, regarding interventions for children, the results of family-centered interventions (studies 1, 4, 11, and 14) showed only tentative support for the intervention improving single psychosocial outcomes. This finding is consistent with prior studies with interventions focused on family members of individuals with TBI, which demonstrated some level of positive outcomes for the telehealth interventions but also a lack of high-quality evidence for the effectiveness of such programs (Brown et al., 2013; Rietdijk et al., 2012). The investigation of effectiveness of the family-centered interventions was based mainly on subjective parent-report outcome measures. This may be problematic due to factors, such as parental mental distress or low socio-economic status of the family, which may impact parental report (Najman et al., 2001; Narad et al., 2019); however, the studies included in this review investigated some of these variables, such as caregivers' education (studies 1, 4, 11, and 14) or parental depression (study 1) and found mixed results: these variables were significant for two studies (1, 14).

Implications for clinical practice

Regarding studies with computerized cognitive training, interventions included varying amount of interaction with the therapist. The content of remote interaction was typically concerning aspects of cognitive training (e.g., motivation) or it was unclear due to vague description in the articles. This type of involvement of the provider of the intervention is quite common in studies concerning home-based computerized cognitive training (Sigmundsdottir et al., 2016). Future studies on remote interventions should describe and evaluate different aspects (e.g., content) of the interaction between the professional and patient more precisely. Individual needs of the patients should be the basis of neuropsychological rehabilitation (Wilson, 2008), and it remained somewhat unclear if these needs were met in the studies described above; however, interventions included specific rehabilitation program with individualized training (e.g., difficulty level adjustments, immediate feedback, systemized delivery), which are found to be advantages of these types of programs for patients with neurological impairments and features in promoting neuroplasticity (Cicerone et al., 2019; Cramer et al., 2011). Along with focusing on cognitive training, interventions aiming to meaningful functional improvements of everyday life may be appropriate approach for many patients.

To keep up with technological development this review focused on recent tele-practices on neuropsychological rehabilitation. The most common methods of delivering telerehabilitation was via telephone followed by videoconferencing. Videoconferencing (Appleby et al., 2019; Camden et al., 2020) or phone calls (Ownsworth et al., 2018; Betts et al., 2018) has been common technology in previous systematic reviews on telerehabilitation for neurological populations, as well. Even though most of the studies showed effectiveness used mainly telephone contact, it is challenging to draw conclusions regarding whether the technology used influenced the outcomes due to the heterogeneity of the studies included in this review. In addition, there could be more relevant factors associated to positive changes. It has addressed that individual preferences and therapy approaches could be key features guiding the choice of technology (Camden et al., 2020; Laver et al., 2020).

Nevertheless, considering the clinical practice, telephone could be used as a delivery method along with videoconferencing. Further, this is notable information considering the telerehabilitation in low-income communities as telephone can offer potential alternative to videoconferencing, which can be inaccessible to many of these communities due to its requirements of fast internet connection (Annaswamy et al., 2020). In addition, previous systematic review focused on TBI (Betts et al., 2018), and now this review found that teleneuropsychological rehabilitation may be suitable delivery method for adults with epilepsy, MS, and stroke as well.

Risk of bias of the included studies

The risk of bias of attrition and randomization process was low for most of the studies, although many studies did not report precise information on allocation concealment. The most common risk of bias was the blinding of the personnel and participants, which is very usual in psychological interventions (Juul et al., 2021). The providers of the intervention must know the type of intervention they deliver, and the participants have opinions about the treatment, as well (Munder & Barth, 2018). Hence, it is almost impossible to fulfill every criterion with neuropsychological rehabilitation interventions; however, there were many studies without information on research protocols (selective outcome bias), or the completion of the intervention as planned. The latter was the case especially for interventions including computerized cognitive training for adults, which would have been important information for potential source of bias and acceptability of the treatment (Higgins et al., 2022; Munder & Barth, 2018), especially since these interventions included primarily self-training.

Limitations

A comprehensive search was performed, and two independent authors evaluated the criteria of eligibility to reduce potential bias in the review process. Nonetheless, a publication bias cannot be excluded with the possibility of some studies being missed. Additionally, relevant studies with unclear or non-significant results may have remained unpublished. Due to heterogeneity of studies included, strong recommendations for specific subgroups could not be made. There were many studies with relatively small sample sizes, particularly for the cognitive training interventions, which can diminish the generalizability of the results. In addition, this review focused on children and adults (0–65 years), hence the findings of this review may not be generalizable to older adults with neuropsychological impairments. Although RCTs provide a strong evidence-base to the results, the inclusion of other designs could have given more information on telerehabilitation. For example, it may be more difficult to conduct RCT for more holistic programs (Khan et al., 2007).

Conclusions

This systematic review found promising preliminary support for the effectiveness of computerized cognitive training with regular interaction with a therapist over telephone or via videoconference; however, it was challenging to draw conclusions on the effectiveness of teleneuropsychological rehabilitation, since interventions and comparators, as well as participants' characteristics and outcome measures, varied significantly. Additionally, only a few of the studies included in this review integrated cognitive, emotional, and psychosocial aspects, and many studies had small sample sizes, as well. Despite these limitations, preliminary support for the effectiveness of computerized cognitive training on impairment level of cognitive functioning was evident for seven out of seven RCTs targeting specific or various cognitive domains with comparators of face-to-face rehabilitation (two studies), non-specific cognitive training (three studies), as well as passive control groups (two studies). However, only few of these studies incorporated follow-up or emotional or psychosocial measures, and their impact on long-term meaningful, everyday functioning remained unclear. For family-centered interventions, the results were somewhat mixed with improvements only noted in single psychosocial outcomes. No support was found for the effectiveness of interventions combining cognitive and motor training.

The field of teleneuropsychological rehabilitation is still evolving alongside the technological development. Thus, including RCT studies published in 2016 or later, this systematic review offers important information on the current state of experimental research as well as the current practices in teleneuropsychological rehabilitation for various patient groups; however, more research is needed, to draw conclusions regarding whether it can be used as an alternative to face-to-face rehabilitation. Furthermore, there is a lack of research investigating the long-term clinical benefits of teleneuropsychological rehabilitation on real-life functioning, which is crucial in the assessment of effectiveness of rehabilitation. Finally, there is also a need for research with more comprehensive rehabilitation approaches to reliably assess the effectiveness of wide spectrum of teleneuropsychological interventions.

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Appendix: Search terms

("Telerehab*" OR "Tele-rehab*" OR "Teletherap*" OR "tele-therap*" OR "Teleintervent*" OR "Tele-intervent*" OR "tele-training" OR "Tele-training" OR "Remote rehab*" OR "Remote therap*" OR "Remote intervent*" OR "Remote training" OR "Virtual rehab*" OR "Virtual therap*" OR "Virtual intervent*" OR "Virtual training" OR "Distance rehab*" OR "Distance therap*" OR "Distance intervent*" OR "Distance training" OR "Online rehab*" OR "Online therap*" OR "Online intervent*" OR "Online training" OR "Web-based rehab*" OR "Web-based therap*" OR "Web-based intervent*" OR "Web-based training") AND ("Neuropsycholog*" OR "Neurolog*" OR "Neuropsychiatr*" OR "Neurodevelop*" OR "Neurocognit*" OR "Cognit*")

These terms were searched from title, abstract, and keyword fields, if available.