Effectiveness of Technology-Based Distance Physical Rehabilitation Interventions for Improving Physical Functioning in Stroke : A Systematic Review and Meta-analysis of Randomized Controlled Trials

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ABSTRACT

Objective: To study the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning in stroke.

Data sources: A systematic literature search was conducted in six databases from January 2000 to May 2018.

Study selection: Inclusion criteria applied PICOS (Patient, Intervention, Comparison, Outcome, Study design) framework as follows: (P) stroke; (I) technology-based distance physical rehabilitation interventions; (C) any comparison without the use of technology; (O) physical functioning; (S) randomized controlled trials (RCTs). The search identified in total 693 studies, and the screening of 162 full-text studies revealed 13 eligible studies.

Data extraction: The studies were screened using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines, and assessed for methodological quality and quality of evidence. Meta-analysis was performed if applicable.

Data synthesis: Thirteen studies were included, and online video monitoring was the most used technology. Seven outcomes of physical functioning were identified – activities of daily living (ADL), upper and lower extremity functioning, balance, walking, physical activity, and participation. A meta-analysis of six RCTs indicated that technology-based distance physical rehabilitation had a similar effect on ADL (standard mean difference (SMD) 0.06; 95%CI: -0.22 to 0.35, p = .67) compared to the combination of traditional treatments (usual care, similar and other treatment). Similar results were obtained for other outcomes, except inconsistent findings were noted for walking. Methodological quality of the studies and quality of evidence were considered low.

Conclusions: The findings suggest that the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning might be similar compared to traditional treatments in stroke. Further research should be performed to confirm the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning of persons with stroke.

Keywords: systematic review, rehabilitation technology, distance physical rehabilitation, stroke

List of abbreviations:

ADL	Activities of daily living
BI	Barthel Index
BBS	Berg Balance Scale
CCRCT	Cochrane Central Register of Controlled Trials
CINAHL	Cumulative Index to Nursing and Allied Health Literature
DVD	Digital versatile disc
EMBASE	Excerpta Medica Database
FAM	Fugl-Meyer Assessment
FONEFIM	Telephone version of the Functional Independence Measure
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
ICF	International Classification of Functioning, Disability, and Health
LLFDI	Late-Life Function and Disability Instrument
MBI	Modified Barthel Index
MeSH	Medical subject headings
MD	Mean difference
Ovid MEDLINE	Database of the National Library of Medicine
PEDro	Physiotherapy Evidence Database
PICOS	Patient, intervention, comparison, outcome, study design
PRISMA	The Preferred Reporting Items for Systematic Reviews and Meta-analysis
PROSPERO	Prospective Register of Systematic Reviews
RCT	Randomized controlled trial
SIS	Stroke Impact Scale
SMD	Standard mean difference
WOS	Web of Science

Introduction

Stroke is one of the leading cause of death and long-term disability worldwide.[1,2] The most important risk factors for stroke have been noted diabetes, hypertension, and smoking.[3,4] Symptoms of stroke vary individually with a wide range of motoric, mental, lingual, sensory, and cognitive impairments that cause functional challenges in daily life and decrease the quality of life.[5–7] Recovery from stroke (i.e., improvement of daily functional activities) is usually very individual and rapid in the acute stage of the disease, but may require several months or years of rehabilitation in some stroke survivors.[8,9] It has been estimated that approximately one-third stroke survivors show low functional performance at five years after stroke onset.[10] Therefore, rehabilitation is an important part of post-stroke care and is highly needed, although substantive advances have been made in acute stroke management.[11]

In previous decades, technology-driven treatments such as virtual reality and robotics have gained popularity in stroke rehabilitation.[11–14] These systematic reviews have reported that the effectiveness of technology-driven treatments is similar to that of traditional treatments in improving the outcomes of physical functioning such as grip strength, gait speed, upper extremity functioning, or global motor functioning in persons with stroke.[11–14] To date, treatments involving virtual reality and/or robotics usually depend on facility requirements, face-to-face interaction between a patient and a healthcare professional, and advanced technology. Moreover, these technologies may not always be user-friendly for participants and exert a considerable economic burden on the healthcare system and institutes.[15,16]

Only few systematic reviews have investigated the effectiveness of distance rehabilitation in persons with stroke.[17–19] Laver et al. (2013) examined the effectiveness of telerehabilitation consisting of 10 randomized controlled trials (RCTs) involving a total of 933 participants.[17] Interventions focused on all types of home-based telerehabilitation using telephone, videoconferencing, desktop videophones, in-home messaging device, or combination of email, online chat programs and virtual online library.[17] This review did not show differences in the activities of daily living (ADL), quality of life, or upper extremity functioning of persons with stroke receiving telerehabilitation and those receiving face-to-face rehabilitation or no rehabilitation. Also, Chen et al. (2013) compared all types of telerehabilitation with that of traditional treatments by assessing seven RCTs and observed no substantial differences in ADL (n = 792), balance (n = 52), or upper extremity functioning (n = 46).[18] A systematic review by Johansson et al. (2011) on all types of telerehabilitation in stroke care involving overall nine RCT-, observational, and qualitative studies concluded that home-based telerehabilitation or technology-based virtual rehabilitation improved the physical health of stroke survivors.[19] However, the same systematic review indicated the need for additional studies on telerehabilitation, especially to determine its cost-effectiveness and resource utilization.[19]

To conclude, there is a call for gathering more evidence on the effectiveness of technology-based distance rehabilitation in stroke, especially focused only on physical rehabilitation interventions. The present study investigated the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning compared to a combination of traditional treatments such as similar treatment, other treatment, and usual care in persons with stroke. In this review, technology-based distance physical rehabilitation interventions were defined as any physical functioning-, activity-, or exercise-promoting interventions that used a technological device that was monitored or guided by a healthcare professional remotely. Additionally, physical functioning refers to the International Classification of Functioning, Disability, and Healthy (ICF) categories of body function, activities, and participation.[20]

Methods

Search strategy

A systematic literature search was conducted using the following databases: Cochrane Central Register of Controlled Trials (CCRCT), Cumulative Index to Nursing and Allied Health Literature (CINAHL), Excerpta Medica Database (EMBASE), Database of the National Library of Medicine (Ovid MEDLINE), Physiotherapy Evidence Database (PEDro), and Web of Science (WOS). The first search was performed for studies published between January 2000 and March 2017. Updated searches were conducted using the same databases for studies published between April 2017 to September 2017 and October 2017 to May 2018. A combined flow chart of study selection is presented in Figure 1. Details of the protocol used for performing this systematic review are registered on Prospective Register of Systematic Reviews (PROSPERO) and can be accessed at www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42017065918.

Inclusion criteria were designed according to the PICOS (i.e., Patient, Intervention, Comparison, Outcome, Study design) framework and were as follows: (P) persons with stroke; (I) any technology (e.g., wearable device, Internet, telephone calls, or smartphone application) used to monitor, promote, or increase physical functioning as a distance physical rehabilitation intervention; (C) any control group not receiving rehabilitation intervention (i.e., wait-list) or receiving rehabilitation intervention without the use of technology (i.e., no rehabilitation, in-person physical rehabilitation interventions, or other treatment for monitoring, promoting, or increasing physical functioning); (O) outcome measures of physical functioning; and (S) RCTs that were published in English, Finnish, Swedish, or German. Literature search was limited also to research in humans. Systematic reviews, non-randomized or non-controlled interventional studies, observational studies, discussion or short reports, abstracts, discussion papers, qualitative studies, and protocols were excluded from the review. Moreover, studies involving other participants with different diagnosis without a separate analysis of persons with stroke were excluded.

A researcher (AR) performed the searches in the selected databases along with other members of the research team (VP and TS) and two information specialists. Search terms included various technology terms and interventional study types (i.e., RCT or clinical trial), comprehensive keywords describing physical rehabilitation interventions (e.g., exercise, exercise therapy, therapies, therapy modalities, rehabilitation, multidisciplinary therapy, motor activity, participation, and physical activity), and stroke-related terms (e.g., stroke, brain infarction, and cerebrovascular disease). The original search strategies are described in Appendix 1. The search strategy used medical subject headings (MeSH) or keyword headings. An additional manual search was conducted using references mentioned in the retrieved studies.

Data extraction

Two reviewers (AR and VP) independently screened the titles and abstracts of the studies in line with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines[21] using the PICOS criteria. Next, relevant studies satisfying the PICOS criteria were independently evaluated for full-text assessment by two reviewers (AR and VP). A third reviewer (SH) evaluated the studies in case of a disagreement. If needed, corresponding authors of the included studies were contacted for obtaining additional information. Agreement level between the reviewers was assessed using Cohen’s Kappa, with a value of 0.62 indicating substantial agreement in the title and abstract screening, and 0.71 indicating substantial agreement in the full-text study screening.[22]

Methodological quality of the studies and quality of evidence

Methodological quality of the included RCTs was assessed independently by two reviewers (AR and VP) using the Furlan method guideline for systematic reviews.[23] A third reviewer (SH) was consulted in case of a disagreement. The 13-item Furlan method guideline for systematic reviews rates RCTs based on (1) adequate randomization, (2) concealment of treatment allocation, (3) blinding of participants, (4) blinding of care providers, and (5) blinding of outcome assessors, (6) described and acceptable rates of drop-out, (7) analysis of participants in allocated groups, (8) suggestion of selective outcome reporting, (9) similarity among groups at baseline, (10) no or similar co-intervention, (11) compliance, (12) timing of outcome assessment, and (13) no other sources of potential bias.[23] An item was scored positive ("*yes*") if the criterion was fulfilled, negative ("*no*") if the criterion was not fulfilled, or unclear ("*unsure*") if required information was inadequately reported. The total score of a study reflected the total sum of positive scores. The maximum score of a study according to the Furlan (2015) method guideline for systematic reviews was 13 points.

The quality of evidence according to the outcomes included in the meta-analyses was evaluated independently by two reviewers (AR and VP) using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) guideline. The quality of evidence was classified as high (i.e., further research is unlikely to change our confidence in the effect estimate), moderate (i.e., further research is likely to have an important impact on our confidence in the effect estimate), low (i.e., further research is highly likely to have an important impact on our confidence in the effect estimate), or very low (i.e., any estimate of the effect is highly uncertain).[24,25] Because this review only included RCTs, evaluation was initiated from the highest quality level. Based on our independent evaluations, we downgraded the quality of evidence depending on the risk of bias, inconsistency, indirectness (e.g., generalizability), imprecision (e.g., insufficient data), or publication bias.[26]

Statistical synthesis

General characteristics for study and participants were extracted and descriptive analysis was performed on all selected outcomes. Outcome measures of physical functioning were linked to the ICF categories of body function, activities, and participation by two researchers (AR and JP), and the ICF categories were used as a tool to capture similar outcomes into meta-analysis or descriptive analysis.[27,28] Meta-analyses were performed separately for captured outcomes of physical functioning that were similar if five or more studies reported meaningful data. Additional subanalyses of used technology were investigated if applicable. If adequate post-treatment values (mean and standard deviation [SD]) were not reported in the original study, a request was sent to the corresponding author of this study. The study was excluded from the meta-analysis if no response was obtained from the corresponding author. If a study reported standard error (SE) values instead of SD values, SD values were obtained from the SE values of the means by multiplying the SE values by the square root of the sample size within a group. Standard mean difference (SMD) between the experimental and control groups was calculated for each study. Mean difference (MD) was calculated if studies in the same meta-analysis used the same outcome assessment. In accordance with the Cochrane guidelines for systematic reviews and meta-analysis, values of outcome were multiplied by -1 if required so that high values reflected better physical functioning.[29] Meta-analyses were performed using a random-effects model. Pooled effect estimates for a combination of single effects of the RCTs were analyzed using Cochrane Collaboration's Review Manager 5.3.5 statistical software analysis package. SMD between the groups was classified as large (> 0.5), moderate (0.3–0.5), small (0.1–0.2) or insubstantial (< 0.1).[30] A study was defined as having a low methodological quality if its score was ≤ 6 points according to the Furlan method guideline. Results of the meta-analyses are presented using forest plots of the SMD or MD. Statistical heterogeneity was evaluated using I^2 statistic, with a value close to 0 indicating low heterogeneity.[31] Possible publication bias was investigated using funnel plots.[32]

Results

The literature search identified 693 studies after removing duplicate studies. Screening of 162 full-text studies revealed 13 studies that fulfilled the inclusion criteria, and these studies were included in quantitative synthesis and descriptive analysis.[33–45] A flow chart of the screening process is presented in Figure 1, and specific details of the included studies are shown in Table 1. A table with the used technologies and the communication between the health care professional and the participant is presented in Appendix 2.

Description of study participants

Selected studies included 605 stroke survivors, of which 304 were included in the experimental group and 301 were included in the control group (Table 1). The mean (SD) age of the study participants was 65.2 (4.2) years. Ten out of 13 studies reported an average disease duration since diagnosis of 10.6 (SD 11.2) months (range, ≤ 1 month to 36 months). Of the 605 study participants, 65 % were men and 87 % had experienced ischemic stroke. Four studies did not report the stroke type.[33,35,39,41] Only six studies reported the affected side of hemiparesis, with majority of participants (53 %) showing left hemiparesis.[33,34,40,42–44] Inclusion criteria of impairment and disability levels due to a stroke were defined across the included studies with measurements of independent walking,[33,42] ADL,[18,36,37,39] or upper extremity functioning.[34,35,40,41,43,44] One study did not report impairment and disability levels as inclusion criteria,[45] and 11 out of 13 studies used cognitive impairment or psychiatric illness as an exclusion criterion.[33,34,36–42,44,45]

Description of technology-based distance physical rehabilitation interventions

The most common technology used for providing distance physical rehabilitation interventions was online video monitoring, which was used in five out of 13 studies.[36,38,39,41,44] Therapists used online video techniques for monitoring physical home exercises, goal settings, or overall treatment.[36,38,39,41,44] However, the frequency of this technology in the interventions was heterogeneous, ranging from three[39,41] to five[36,44] times per week, and one study did not report the frequency of online video monitoring.[38] Three of these five studies used other technologies alongside online video monitoring, such as telephone calls and messaging,[39] gamification,[41] or accelerometer.[36] The second most common technology used for providing distance physical rehabilitation interventions was telephone calls conducted by a therapist or a nurse, which was used in three out of 13 studies.[33,37,42] The frequency of telephone calls varied from only three telephone calls in a six-month study period to one telephone call in a four-week study period.[33,37,42] The remaining five studies used technologies such as exercise videos through an electronic tablet,[40] virtual training program for upper extremity functioning,[34,35] exercises from a digital versatile disc (DVD),[45] or combination of physical exercise programs through the Internet along with gamification.[43]

Eight studies reported that healthcare professionals and participants interacted in real-time through an online video or through telephone calls.[18,33,36,37,39,41,42,44] Only one out of 13 studies used one-way communication where the therapist monitored physical exercise and provided feedback to participants if necessary through the Internet without any real-time communication.[43] Four out of 13 studies did not involve any direct communication or self-monitoring options, because they used a virtual training program without any feedback or exercise videos through an electronic tablet or a DVD.[34,35,40,45]

Content of interventions in the experimental group

Mean (SD) duration of the interventions was 9.2 (6.0) weeks. The content of the intervention in the experimental group was very heterogeneous (Table 1). Four out of 13 interventions focused on overall and individualized physical exercises for improving mobility, strength, balance, walking, and stretching.[38–40,45] Five out of 13 interventions included only upper extremity exercises performed in a virtual environment at home,[34,35,44] balance and body position exercises,[41] or use of orthoses.[43] Two out of 13 interventions focused on lower extremity exercises such as gait-related exercises with balance and coordination exercises.[33,36] Finally, two out of 13 interventions focused on increasing and promoting physical activity.[37,42] Twelve out of 13 interventions were monitored or programmed by a physiotherapist or an occupational therapist, or by both.[33–36,38,39,41–45] Only one intervention was a nurse-led stroke prevention program for improving physical activity.[37]

Effectiveness of technology-based distance physical rehabilitation interventions

Seven outcomes of physical functioning were identified from the selected studies (Table 1 & Table 2). These outcomes were ADL, upper and lower extremity functioning, balance, walking, physical activity, and participation. Descriptive analysis was performed on all of the outcomes and meta-analysis was only conducted from ADL, as for other outcomes there were not enough data to perform meaningful meta-analyses. Metaregression analyses were not performed because of a lack of studies.

ADL. Nine studies investigated ADL of participants receiving technology-based distance physical rehabilitation interventions.[34–36,38,39,41,42,45] ADL was measured using six ADL instruments, namely, the Barthel Index (BI),[34,41] Modified BI,[38,45] Modified Rankin Scale (MRS),[37] telephone version of the Functional Independence Measure (FONEFIM),[39] ADL domain of Stroke Impact Scale (SIS),[42] and the Nottingham Extended ADL Scale (NEADL).[35] ADL instruments were identified for mobility (d4), self-care (d5), and domestic life (d6) in ICF categories of activities and participation.

A meta-analysis was performed from six studies for ADL outcome.[37–39,41,42,45] Technology-based distance physical rehabilitation interventions had a similar effect on ADL when compared to control group with the combination of similar treatment, other treatment, and usual care (SMD 0.06; 95% CI: -0.22 to 0.35, p = .67; Figure 2). Technologies and the content of the interventions in the experimental group were heterogeneous, with most often used technology being online video monitoring to enable physical exercises.[38,39,41] The overall results of the meta-analysis indicated that the included studies were moderately heterogeneous (I^2 = 38 %). Subanalysis of different technologies did not show differences between the groups, but within one technology group there were no heterogeneity observed (Figure 2) Funnel plot did not indicate any publication bias (Appendix 3). Descriptive analysis from all studies indicated similar findings as in the meta-analysis regardless of the used technology or comparison group (Table 2).

Upper extremity functioning. Seven studies investigated upper extremity functioning of participants receiving technology-based distance physical rehabilitation interventions through online video monitoring,[36,39,44] exercise videos,[40] virtual reality training or its combination with gamification (i.e., any game-design elements improving physical functioning),[34,35] or the combination of monitoring through Internet and gamification[43] (Table 1). Outcomes of upper extremity functioning were determined using the Late-Life Function and Disability Instrument (LLFDI),[39] the Fugl-Meyer

Assessment (FMA),[34,43,44] or the Wolf Motor Function Test.[35,40] Outcomes of upper extremity functioning were interpreted for neuromusculoskeletal- and movement-related functions (b7) in the ICF category of body function or for mobility (d4) in the ICF categories of activities and participation, depending on whether the instrument focused only on motor function or on functional capacity. Descriptive analysis revealed similar effects between technology-based distance physical rehabilitation interventions and control groups with combination of usual care[34,35,39,43,44] or similar treatment without the use of technology[40] (Table 2).

Lower extremity functioning. Only two studies investigated lower extremity functioning using lower extremity domains of LLFDI[36] or FMA[39]. Both studies instructed physical exercises such as balance and gait-related physical exercises through telerehabilitation (Table 1). Similar as in upper extremity functioning, instruments assessing lower extremity functioning were interpreted for neuromusculoskeletal- and movement-related functions (b7) in the ICF category of body function and for mobility (d4) in the ICF categories of activities and participation. Descriptive analysis indicated that technology-based distance physical rehabilitation enabled through telerehabilitation had the similar effect on lower extremity functioning when compared with usual care (Table 2).[36,39]

Balance. Balance was assessed in four technology-based distance physical rehabilitation interventions that were enabled through online video monitoring[36,38,41] or telephone calls.[42] All of these four studies used the Berg Balance Scale (BBS) as an outcome for balance,[18,36,41,42] but only three of them reported BBS values. BBS was linked to the domain of mobility (d4) in the ICF categories of activities and participation. Descriptive analysis showed that technology-based distance physical rehabilitation interventions had a similar effect on balance when compared to control group with the combination of usual care, similar or other treatment (Table 2).

Walking. Outcomes of walking was assessed in three studies that compared telephone-enabled distance physical rehabilitation interventions with other treatments (Table 2). Walking tests were performed using a 10-meter walking test.[33,36,42] Walking was linked to the domain of mobility (d4) in the ICF categories of activities and participation. Descriptive analysis showed that two of these three studies had a better improvement on walking ability for participants in the control group receiving either supervised clinic-based treadmill training[33] or leisure-center exercise training[42] compared to technology-based distance physical rehabilitation interventions offering home-based exercises that were monitored through telephone calls. However, Van den Berg et al. (2016) study found similar effect between groups when distance physical rehabilitation interventions enabled by home-based physical exercises through online video monitoring and smartphone application were compared with usual care (Table 2).

Physical activity. Only two studies investigated physical activity on the effectiveness of technology-based physical rehabilitation interventions to either other treatments[42] or physical activity health promotion for nurse-led secondary prevention of ischemic stroke.[37] Physical activity was investigated using the physical activity subscales in SIS[42] and Health Promoting Lifestyle Profile II.[37] We identified physical activity in the domain of self-care (d5) in the ICF categories of activities and participation. Both studies showed similar effects between the groups with respect to the outcomes of physical activity when compared to usual care and other treatments (Table 2).[37,42]

Participation. Four studies investigated participation in technology-based physical rehabilitation interventions enabled through telephone calls (three studies) and website exercises (one study) compared usual care[36,39,43] or other treatment.[42] Studies captured the outcome of participation with either the Stroke Impact Scale (SIS)[36,42,43] or LLFDI.[39] The instruments of participation were identified for mobility (d4), self-care (d5), and domestic life (d6) in ICF categories of activities and participation (Table 2). All studies indicated similar effect on participation between the experimental group compared and usual care[36,39,43] or other treatment (i.e., supervised leisure-center exercise classes for people with stroke).[42]

Methodological quality and quality of evidence

The overall methodological quality of the studies was low (median: 6, interquartile range: 6 to 9) according to the Furlan method guideline (Table 3).[23] The methodological quality was high (> 9/13) in four studies,[33,36,40,42] moderate (7-8/13) in two studies,[38,39] and low (≤ 6/13) in seven studies.[34,35,37,41,43–45] All studies used an adequate randomization method. However, only 38 % studies reported an adequate treatment allocation procedure. Other main methodological faults were observed in the blinding of participants and care providers, reporting of information on selective outcomes, and compliance to the intervention. Moreover, only three studies used intention-to-treat analysis.[36,39,41]

GRADE evaluation was performed using the results of the meta-analysis and descriptive analyses (Table 4).[26] All the outcomes indicated very low quality of evidence. For ADL, downgrading three levels were based on the methodological quality of the studies (risk of bias), clinical heterogeneity (inconsistency), and low number of participants included in the meta-analysis (imprecision). Similar observations were obtained for other outcomes, but only based on descriptive analysis, as meta-analyses were not able to perform due to lack of meaningful data.

Discussion

This systematic review investigated the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning in persons with stroke. Results indicated that technology-based distance physical rehabilitation interventions had a similar effect on physical functioning outcomes of ADL, upper and lower extremity functioning, balance, physical activity, and participation, when compared to the combinations of traditional treatments not involving the use of technology (i.e., similar treatment, other treatment, and usual care). Our findings are consistent with previous systematic reviews that assessed the effectiveness of telerehabilitation in persons with stroke, which reported no significant difference in the improvement of physical functioning between participants receiving telerehabilitation and those receiving traditional treatments.[17–19] However, our study focused only on physical rehabilitation interventions with no technology allowed in the comparison group.

Our meta-analysis involving six studies and 322 stroke survivors showed similar effect of technology-based distance physical rehabilitation interventions on ADL compared to the combination of similar treatment, other treatment, and usual care. ADL improved in both the groups irrespective of the intervention or used technology, which was consistent with previous systematic reviews that investigated all types of telerehabilitation interventions when compared to traditional therapies in stroke.[17,18] Results of our meta-analysis indicated a moderate statistical heterogeneity, which our analysis did not encompass for meta-regression due to lack of studies. Once more studies are published in this field, we might be able to investigate more specific factors that might enhance clinical and statistical heterogeneity, such as personal and clinical characteristics, comparison of different control groups (i.e., usual care, similar, or other treatment), or more wide comparison of different technologies.

Our findings showed inconsistent findings on walking. Two out of three studies showed better improvement on walking for participants who received telephone-based distance physical rehabilitation interventions providing home-based exercises compared to participants receiving supervised clinic-based treadmill training[33] or leisure-center exercise training.[42] Third study found no differences between the groups, when distance physical rehabilitation interventions were instructed through online video monitoring and smartphone application compared with usual care.[36] Evidence of using technology-based physical rehabilitation interventions are still scarce in the research field. However, our findings could indicate that when aiming to improve walking ability in stroke, distance physical rehabilitation might not be an alternative option for stroke survivors. For other physical functioning outcomes (i.e., upper and lower extremity, balance, physical activity, and participation), our descriptive analyses indicated similar effects between technology-based distance physical rehabilitation interventions and the combination of traditional treatments. Unfortunately, we were not able to perform meaningful with meta-analyses from these outcomes due to lack of studies and insufficient data. In previous systematic review with meta-analysis, only two studies showed similar results on upper extremity functioning and balance, when all types of telerehabilitation interventions were compared with traditional treatments in stroke.[18] Although our review was able to solely focus on physical rehabilitation interventions, more evidence is warranted on different technologies and their possible additional values over traditional physiotherapy or other forms of physical rehabilitation when only similar treatments are compared with the distinction only on the use of technology.

The overall methodological quality and the quality of evidence of the included studies were low. The included RCTs had main insufficient methodological quality for treatment allocation procedures, blinding of the participants and care providers, selection bias, prevention of co-interventions, and reporting of intervention compliance. The difficulty in blinding care providers or participants in these study types is understandable. Moreover, it may be difficult to prevent co-interventions completely, especially in the early stage of recovery among persons with stroke. Surprisingly, there was a lack of quality in reporting compliance to interventions. Guidelines such as CONSORT 2010 Statement for reporting a RCT study are strongly recommended to increase transparency and methodological quality of a single RCT study.[46]. GRADE evaluation showed also low quality of evidence, suggesting that the confidence in the effect estimates was low and that future studies may substantially change the effect estimates.

Twelve out of 13 studies reported inclusion criteria of low or intermediate physical disability based on a measure of walking ability, upper extremity functioning, or overall physical functioning and no cognitive deficit at baseline.[33–45] Majority of participants were male with a mean age of 65 years, had a disease duration of 11 months and 87 % of the participants experienced ischemic stroke. These demographic and clinical characteristics suggest that our results can be generalized to elderly male stroke survivors in the subacute stage of a recovery with no cognitive impairment, and who can function independently at least in some levels of their daily life. Approximately from 50 % to 75 % of new stroke survivors develop some level of cognitive impairment.[47,48] From this perspective, the use of technology for providing distance rehabilitation interventions in persons with stroke may not always be suitable, due to the presence of cognitive impairment. Therefore, technology-based distance physical rehabilitation interventions are important to develop towards more stroke-specific, individualized, and user-friendly approaches to recognize who would benefit from the technology approach when focus is to improve physical functioning in daily life.

In this systematic review, technology-based distance physical rehabilitation interventions were defined as interventions that used one or more technological devices in a remote guidance of a healthcare professional, mainly monitored by a physiotherapist. Eight included studies used real-time communication through online video monitoring or telephone calls. However, the included studies used different technologies or a combination of several technologies using different interaction methods, thus making it difficult to determine the advantage of a single interaction approach. Our review also indicated that there is a lack of evidence on the effectiveness of technology-based distance physical rehabilitation interventions in stroke rehabilitation, and the current use of technology and its communication method is scarce in the research field. Future studies are recommended to narrow this gap to understand the benefits of either a single technology or a single interactive method (e.g., self-monitoring vs. interactive communication) enabled through a technology device in a distance physical rehabilitation intervention.

To understand the benefits of using technology in physical rehabilitation interventions, one must understand its benefits in terms of resource utilization and cost-effectiveness.[19] Unfortunately, our systematic review did not observe any indication of these approaches in the included studies, which was consistent with that observed in previous similar systematic reviews.[17–19,49–51] These aspects are crucial for understanding whether technology-driven distance rehabilitation interventions are beneficial for the healthcare system without overlooking the meaningful and goal-orientated rehabilitation of persons with stroke. Therefore, future studies should also focus on the resource utilization and cost-effectiveness of technology-based distance physical rehabilitation interventions compared with traditional or similar treatments.

Study strengths and limitations

The strength of this systematic review and meta-analysis is its focus on technology-based distance physical rehabilitation in persons with stroke, as previous systematic reviews have mainly focused on telerehabilitation.[17–19] In this review, we strictly followed the inclusion criteria based on the PICOS framework to determine the effect of technology-based distance physical rehabilitation interventions in persons with stroke. We only included studies that used technology-based distance physical rehabilitation setting in one intervention group that were administered in the physical absence of a healthcare professional compared to a group that did not use any technology.

However, this systematic review has some limitations. The studies included in our review were heterogeneous with respect to the content of treatments in participants in the experimental and control groups. Heterogeneity was also reported in previous reviews assessing technology-based distance rehabilitation interventions.[49–51] Moreover, substantial variability was observed in technologies in the distance physical rehabilitation interventions. Because of these reasons, the results of this systematic review should be interpreted with caution. Nevertheless, this systematic review provides overview on the type of technologies used to enable distance physical rehabilitation interventions for improving physical functioning in stroke survivors, and hopefully, encourages researchers to conduct more studies in this field.

Conclusions

This systematic review suggests that the effectiveness of technology-based distance physical rehabilitation for improving ADL, upper and lower extremity functioning, balance, physical activity, and participation is similar compared to the traditional treatments in persons with stroke. Contradictory findings were observed for walking. Further research should be performed to confirm the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning of persons with stroke.

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Figure legends

Figure 1. Flow chart of study selection

Figure 2. Meta-analysis and additional sensitivity analysis on ADL compared to control group of similar or other treatment, and usual care without the use of technology. The squares and diamonds represent the test values for individual studies and overall effectiveness; standard mean difference with 95% confidence interval (CI). Footnotes: SD, standard deviation; MBI, Modified Barthel Index; MRS, Modified Rankin Scale; SIS, Stroke Impact Scale; ADL, activities of daily living; FONEFIM, the telephone version of Functional Independence Measure; df, degrees of freedom

Appendix 1: Examples of the search strategies per database.

Appendix 2: Summary of included RCT studies on the used technologies and its communicative interactions thereof in the distance physical rehabilitation interventions.

Appendix 3. Funnel plot of activities of daily living.

Figure 1.

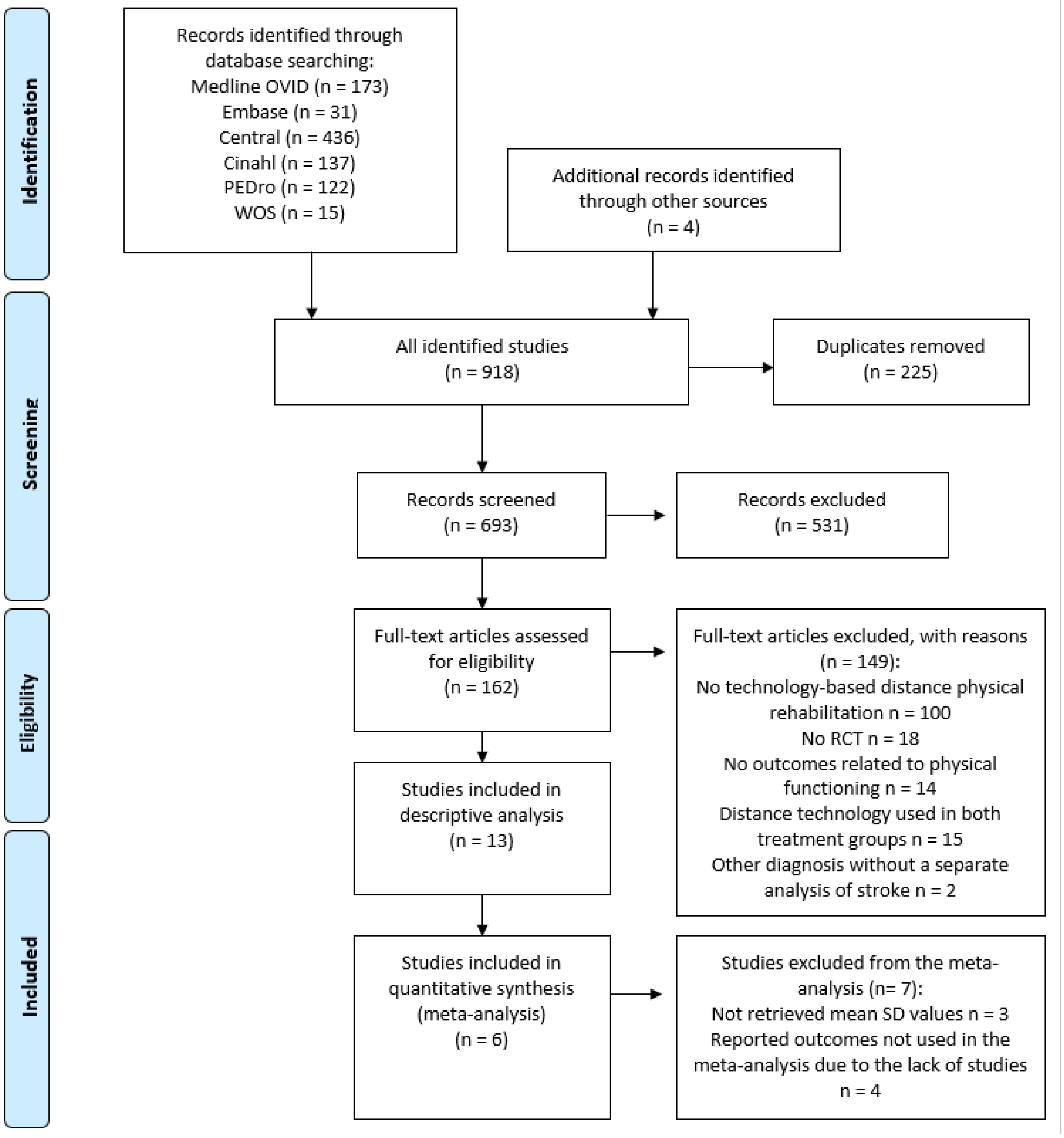
Identification
Screening
Eligibility
Included
Records identified through database searching:
Medline OVID (n = 173)
Embase (n = 31)
Central (n = 436)
Cinahl (n = 137)
PEDro (n = 122)
WOS (n = 15)
Additional records identified through other sources (n = 4)
All identified studies (n = 918)
Duplicates removed (n = 225)
Records screened (n = 693)
Records excluded (n = 531)
Full-text articles assessed for eligibility (n = 162)
Full-text articles excluded, with reasons (n = 149):
No technology-based distance physical rehabilitation n = 100
No RCT n = 18
No outcomes related to physical functioning n = 14
Distance technology used in both treatment groups n = 15
Other diagnosis without a separate analysis of stroke n = 2
Studies included in descriptive analysis (n = 13)
Studies included in quantitative synthesis (meta-analysis) (n = 6)
Studies excluded from the meta-analysis (n= 7):
Not retrieved mean SD values n = 3
Reported outcomes not used in the meta-analysis due to the lack of studies n = 4

Figure 2.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
3.1.1 Online video monitoring or combination with other technology									
Chen et al. 2017; MBI (0-100)	61,4	12,9	27	59,8	12,3	27	17,2%	0,13 [-0,41, 0,66]	2017
Lin et al. 2014; BI (0-100)	57,9	3,1	12	60,8	22,5	12	9,7%	-0,17 [-0,98, 0,63]	2014
Chumbler et al. 2012; FONEFIM (13-91)	82,7	9,7	22	79	15	22	15,0%	0,29 [-0,31, 0,88]	2012
Subtotal (95% CI)			**61**			**61**	**42,0%**	**0,12 [-0,23, 0,48]**	
Heterogeneity: Tau² = 0,00; Chi² = 0,82, df = 2 (P = 0,66); I² = 0%									
Test for overall effect: Z = 0,69 (P = 0,49)									
3.1.2 Only telephone contacts									
Wan et al. 2016; MRS (0-5)	-0,18	0,5	40	-0,4	0,7	40	21,3%	0,36 [-0,08, 0,80]	2016
Moore et al. 2015; SIS/ ADL (0-100)	90	15	20	85	25	20	14,1%	0,24 [-0,38, 0,86]	2015
Subtotal (95% CI)			**60**			**60**	**35,5%**	**0,32 [-0,04, 0,68]**	
Heterogeneity: Tau² = 0,00; Chi² = 0,10, df = 1 (P = 0,76); I² = 0%									
Test for overall effect: Z = 1,73 (P = 0,08)									
3.1.3 DVD exercises									
Redzuan et al. 2012; MBI (0-100)	78,8	20,2	44	86,6	16,3	46	22,6%	-0,42 [-0,84, -0,00]	2012
Subtotal (95% CI)			**44**			**46**	**22,6%**	**-0,42 [-0,84, -0,00]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 1,98 (P = 0,05)									
Total (95% CI)			**165**			**167**	**100,0%**	**0,06 [-0,22, 0,35]**	
Heterogeneity: Tau² = 0,05; Chi² = 8,11, df = 5 (P = 0,15); I² = 38%									
Test for overall effect: Z = 0,43 (P = 0,67)									
Test for subgroup differences: Chi² = 7,19, df = 2 (P = 0,03), I² = 72,2%									

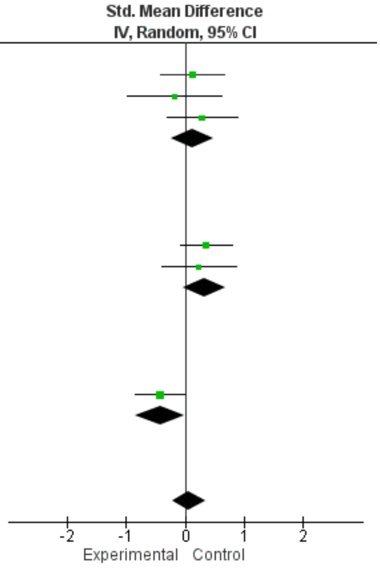

Table 1: Summary of RCTs on technology-based distance physical rehabilitation interventions with outcomes related to physical functioning compared to similar or other treatment, and usual care without the use of technology in stroke.

Study / Year / Country	Duration	Total N (% men)	Experimental N (% men)	Control N (% men)	Age (years) Experimental/ Control	Participants	Intervention in the experimental group	Intervention in the control group	Outcomes
Ada et al. 2003* Australia	4 weeks, FU 12 weeks	27 (70)	13 (69)	14 (71)	66/66	Persons with stroke from general community	Clinic-based treadmill and over-ground walking 3 x week à 45 minutes supervised by a physiotherapist	Home-based exercise program for lower limb muscles, balance, and coordination. Telephone calls once a week with a physiotherapist (total 4x).	10-meter walking test
Ballester et al. 2017 Spain	3 weeks, FU 12 weeks	35 (40)	17 (47)	18 (33)	65/62	Outpatients with stroke from a clinical hospital	Home-based non-supervised Automated Evaluation of Motor Function (AEMF) – virtual training program for the assessment of upper-limb motor functioning. Training comprised 3 tasks: Hit, Grasp, and Place, with a total duration of 20 minutes per training. Occupational therapists did not give any explicit	Usual care of home-based non-supervised upper extremity functioning tasks without the technology	Fugl-Meyer Assessment Barthel Index

							feedback about the performance during the intervention.		
Chen et al. 2017 China	12 weeks, FU 12 weeks	54 (61)	27 (67)	27 (56)	66/66	Persons with stroke as outpatients	Home-based telesupervising rehabilitation including physical exercises and ETNS. Physical exercises included stretching, motor imagery therapy, balance exercises, and walking exercises for 1 hour twice a day (total 60 sessions) with ETNS for 20 minutes twice a day for 12 weeks (total 60 sessions). Therapists supervised the participants to do the physical exercises and ETNS by live video conferencing.	Similar physical exercises and ETNS program without telesupervising	Modified Barthel Index Berg Balance Scale
Chumbler et al. 2012 United States	12 weeks, FU 12 weeks	48 (98)	25 (96)	23 (100)	67/68	Persons with stroke from Veterans Affairs facility center	Multifaceted stroke telerehabilitation intervention to improve functional mobility including individual strength and balance exercises, goal settings, and treatment plan.	Usual care	The Telephone Version of the Functional Independence Measure (FONEFIM)

							Three home video televisits remotely with a teletherapist (physical or occupational therapist) with the help of an assistant at home, five telephone calls, and in-home messaging device between patients and teletherapists.		Late-Life Function & Disability Instrument
Emmerson et al. 2017 Australia	4 weeks, no FU	62 (63)	30 (61)	32 (63)	68/63	Persons with stroke from general community	Home exercise program as video format on an electronic tablet (iPad) with automated reminders. Home exercise program consisted exercises of stretching, range of movement, strength, and fine motor and coordination for 1-2x per day designed by occupational therapists who updated the videos throughout the programme. All participants completed their usual individual and/or group therapy throughout the intervention.	Similar home exercise program without technology (paper-based). All participants completed their usual individual and/or group therapy throughout the intervention.	Wolf Motor Function Test
Lin et al. 2014 Taiwan	4 weeks, no FU	24 (71)	12 (83)	12 (58)	75/76	Persons with stroke living in long-term care facilities	An online web-based telerehabilitation program monitoring the change of body position, standing exercises, environment, and	Usual care	Berg Balance Scale Barthel Index

							the use of upper extremities including animated videos and interactive gaming. The physiotherapist could monitor the sequences and durations with light to moderate exercise intensity (Borg scale 12–14). 3x per week à 50 min for each session, online video monitoring.		
Moore et al. 2015* United Kingdom	19 weeks, no FU	40 (85)	20 (90)	20 (80)	68/70	Persons with stroke from a general community	Supervised leisure-center classes run by a physiotherapist and physical activity instructor for 3x per week à 45-60 minutes. Exercises were targeted to increase functional movement (strength, balance, cardiovascular).	Matched-duration home stretching program with instructions for using a booklet and diary to record stretches and changes in medication, diet, and physical activity. Telephone calls every 2 weeks (total 10x).	10-meter walking test Berg Balance Scale Stroke Impact Scale
Nijenhuis et al. 2017 The Netherlands	6 weeks, FU 8 weeks	19 (53)	9 (78)	10 (30)	58/62	Persons with chronic stroke from rehabilitation center and	Self-administered home-based arm and hand training for 6x per week à 30 minutes, using either a passive dynamic wrist or a	Prescribed conventional exercises from an exercise book	Fugl-Meyer Assessment Stroke Impact Scale

						regional hospitals	hand orthosis combined with computerized gaming exercises designed by a therapist. Therapists monitored progress without real-time supervision, and adjusted training programs remotely via a website.		
Piron et al. 2009 Italy	4 weeks, FU 4 weeks	36 (58)	18 (61)	18 (56)	66/64	Persons with stroke as outpatients	Home-based telerehabilitation program consisting of a virtual environment where a patient conducted motor tasks for upper extremities, coupled with a videoconference tool provided by a physiotherapist for 5 times per week à 60 minutes. Therapist provided real-time feedback to the patient through the videoconferencing system.	Usual care	Fugl-Meyer Assessment
Redzuan et al. 2012 Malyasia	12 weeks, no FU	90 (58)	44 (40)	46 (60)	64/59	Persons with sub-acute stroke	Home-based audiovisual DVD including 45-minute self-instructional therapy with 6 sections: 1) positioning and handling; 2) bed mobility; 3-4) movement, stretching, and	Usual care for weekly therapy (1h/week)	Modified Barthel Index

							strengthening exercises for lower and upper limbs; 5) transfer techniques; and 6) activities of daily living. Content of the DVD was reviewed by physiotherapists, an occupational therapist, and a rehabilitation physician. Additional therapy twice-monthly.		
Standen et al. 2017 United Kingdom	8	27 (64)	17 (47)	10 (80)	59/63	Stroke patients	Home-based virtual reality training employing infrared capture to translate the position of the hand into game play (Nintendo Wii) for 20min/ 3x per day.	Usual care	Nottingham Extended Activities of Daily Living Scale Wolf Motor Function Test
Van den Berg et al. 2016 The Netherlands	8 weeks, FU 4 weeks	63 (64)	31 (66)	32 (61)	65/70	Stroke patients and their caregivers	Telerehabilitation comprised of a caregiver-mediated training program with a support of a customized exercise application loaded into a tablet. Exercises for the patients included gait and gait-related mobility such as standing, turning, or making	Usual care	10-meter walking test Stroke Impact Scale Berg Balance Scale Barthel Index

							transfers for 5 times per week à 30 minutes. Telerehabilitation was conducted via the exercise application and videoconferencing to provide access to the treating physiotherapist. Therapists also had weekly home visits. Patients also wore an activity monitor (the Fitbit Zip) to increase physical activity through real-time feedback.		Fugl-Meyer Assessment
Wan et al. 2016 China	24 weeks, no FU	80 (71)	40 (75)	40 (68)	59/60	Persons with stroke as outpatients	Nurse-lead telephone call intervention for secondary prevention of ischemic stroke. Three telephone follow-up calls at week 1 and at months 1 and 3 after discharge, (à 15-20 minutes) to promote self-management techniques and maintenance of behavioral improvements. Physical activity guideline of moderate to intense exercise 3-5 days per week à 30 minutes.	Usual stroke education for secondary prevention	The Health Promoting Lifestyle Profile II Modified Rankin Scale

FU, follow-up; ENTS, electromyography-triggered neuromuscular stimulation; DVD, digital versatile disc

Table 2: Results of outcome variables concerning technology-based distance physical rehabilitation interventions on physical functioning in stroke

Study, year, and outcome	Experimental			Control			Group differences at end-point	Group differences at end-point
	n	M1 mean (SD)	M2 mean (SD)	n	M1 mean (SD)	M2 mean (SD)	(Effect / Effect size)	p-value (95%CI)
ADL								
Ballester et al. 2017	17			18				
Barthel Index, (0-100)		89.5 (9.4)	Not rep.		84.7 (14.2)	Not rep.	ES = -0.41	.44
Chen et al. 2017	27			27				
Modified Barthel Index, (0-100)		55.6 (12.8)	61.4 (12.9)		54.3 (13.4)	59.8 (12.3)	F = 0.11	.90*
Chumbler et al. 2012	22			22				
FONEFIM, (18-126)		83.5 (9.5)	82.7 (9.7)		81.5 (12.1)	79.0 (15.0)	-	.31*
Lin et al. 2014	12			12				
Barthel Index, (0-100)		52.9 (32.9)	57.9 (3.1)		57.9 (26.7)	60.8 (22.5)	-	.45‡
Moore et al. 2015†	20			20				
Stroke Impact Scale, ADL (0-100)		82.0 (19.0)	85.0 (25.0)		90.0 (17.0)	90.0 (15.0)	-	.39* (-3.0 to 8.0)
Redzuan et al. 2012	44			46				
Modified Barthel Index, (0-100)		46.7 (22.3)	78.8 (20.2)		61.3 (24.3)	86.6 (16.3)	-	Not rep.
Van den Berg et al. 2016	31			32				
Barthel Index, (0-100)		Not rep.	Not rep.		Not rep.	Not rep.	-	.38
Wan et al. 2016	40			40				
Modified Rankin Scale, (0-3)		0.60 (1.0)	0.18 (0.5)		0.70 (1.1)	0.40 (0.7)	F = 0.52	.56*
BALANCE								
Chen et al. 2017	27			27				
Berg Balance Scale, (0-56)		33.1 (4.0)	37.0 (3.8)		31.7 (5.9)	36.1 (5.3)	F = 1.42	.91*
Lin et al. 2014	12			12				
Berg Balance Scale, (0-56)		20.4 (17.0)	24.6 (18.4)		22.4 (18.4)	26.9 (18.0)	-	.83‡

Moore et al. 2015†	20			20				
Berg Balance Scale, (0-56)		50.0 (4.0)	55.0 (2.0)		50.0 (5.6)	52.0 (5.0)	-	<.01* (0.9 to 5.0)
UPPER EXTREMITY FUNCTIONING								
Ballester et al. 2017	17			18				
Fugl-Meyer Assessment, UE (0-66)		42.9 (14.4)	Not rep.		43.4 (13.5)	Not rep.	ES = -0.30	.33
Chumbler et al. 2012	22			22				
Late-Life Function & Disability Instrument, UE (0-100)		64.7 (21.2)	70.1 (19.4)		65.6 (17.2)	64.1 (17.8)	-	.43*
Emmerson et al. 2017	28			30				
Wolf Motor Function Test, (s)		39.0 (44.0)	33.0 (37.0)		49.0 (47.0)	45.0 (44.0)	-	.10 (-11.0 to 1.0)
Nijenhuis et al. 2017	9			10				
Fugl-Meyer Assessment, UE (0-66)		33.0 (20.1)	34.2 (19.9)		32.9 (14.9)	34.9 (15.7)	-	> .05
Piron et al. 2009	18			18				
Fugl-Meyer Assessment, UE (0-66)		48.5 (7.8)	53.6 (7.7)		47.3 (4.6)	49.5 (4.8)	-	Not rep.
Standen et al. 2017	9			9				
Wolf Motor Function Test, (s)		Not rep.	Not rep.		Not rep.	Not rep.	-	Not rep.
LOWER EXTREMITY FUNCTIONING								
Chumbler et al. 2012	22			22				
Late-Life Function & Disability Instrument, advanced LE (0-100)		32.5 (19.0)	40.7 (20.6)		37.9 (17.4)	35.2 (17.8)	-	.20*
Van den Berg et al. 2016	31			32				
Fugl-Meyer Assessment, LE (0-66)		Not rep.	Not rep.		Not rep.	Not rep.	-	.07
WALKING								
Ada et al. 2003†	11			14				
10-meter walking test, (m/s)		0.62 (0.24)	0.75 (0.26)		0.53 (0.30)	0.56 (0.30)	F = 6.53	.02
Moore et al. 2015†	20			20				

10-meter walking test, (m/s)		1.2 (0.4)	1.5 (0.3)		1.2 (0.3)	1.3 (0.3)	-	< .01* (0.1 to 0.3)
Van den Berg et al. 2016	31			32				
10-meter walking test, (m/s)		Not rep.	Not rep.		Not rep.	Not rep.	-	.87
PHYSICAL ACTIVITY								
Moore et al. 2015†	20			20				
Stroke Impact Scale-16, physical total (0-400)		308.0 (92.0)	324.0 (96.0)		336.0 (78.0)	348.0 (64.0)	-	.67* (-15.0 to 24.0)
Wan et al. 2016	40			40				
Health Promoting Lifestyle Profile II, physical activity (1-4)		1.7 (0.7)	2.3 (0.7)		1.8 (0.7)	2.2 (0.7)	F = 0.54	.47*
PARTICIPATION								
Moore et al. 2015†	20			20				
Stroke Impact Scale, participation (0-100)		72.0 (29.0)	76.0 (28.0)		89.0 (18.0)	89.0 (18.0)	-	.31* (-7.0 to 21.0)
Chumbler et al. 2012	22			22				
Late-Life Function & Disability Instrument, overall function (0-100)								
Nijenhuis et al. 2017	9			10				
Stroke Impact Scale, participation (0-100)		57.3 (13.0)	58.9 (11.5)		66.7 (16.0)	67.9 (14.6)	-	> .05
Van den Berg et al. 2016	31			32				
Stroke Impact Scale, participation (0-100)		Not rep.	Not rep.		Not rep.	Not rep.	-	.49

n, study sample; M1, baseline value; SD, standard deviation; M2, post intervention end-point value; p, p-value; 95%CI, 95% Confidential Interval; s, seconds; m/s, meter per second; F, F-statistics; ADL, Activities of daily living; FONEFIM, The telephone version of the Functional Independence

Measure; UE = upper extremity; LE = lower extremity; *, group x time effect; †, control group was treated as experimental group due to using technology-based distance physical rehabilitation intervention; ‡, training x group effect; Not rep., study did not report the values

Table 3: Methodological quality assessment of included RCTs concerning technology-based distance physical rehabilitation interventions on physical functioning in stroke

Study and year	1: randomization method adequate	2: treatment allocation concealed	3: blinding of participants	4: blinding of care provider	5: blinding of outcome assessor	6: drop-outs described and acceptable	7: participants analyzed in the allocated groups	8: free of suggestion of selective outcome reporting	9: group similarity at the baseline	10: co-intervention avoided or similar	11: compliance	12: similar timing of the outcome assessment	13: other sources of potential bias unlikely	Number of "yes" scores (maximun of 13)*
Ada et al. 2013	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	?	Yes	Yes	Yes	9
Ballester et al. 2017	Yes	?	No	?	?	?	No	?	Yes	?	Yes	Yes	?	4
Chen et al. 2017	Yes	No	No	No	Yes	Yes	Yes	?	Yes	Yes	?	Yes	Yes	8
Chumbler et al. 2012	Yes	?	No	?	Yes	Yes	Yes	Yes	Yes	No	?	Yes	Yes	8
Emmerson et al. 2017	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	No	Yes	Yes	Yes	9
Lin et al. 2014	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	?	Yes	6

Moore et al. 2015	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	?	Yes	Yes	Yes	9
Nijenhuis et al. 2017	Yes	?	No	No	No	Yes	Yes	?	No	No	?	Yes	Yes	5
Piron et al. 2009	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	Yes	?	6
Redzuan et al. 2012	Yes	No	No	No	No	Yes	No	?	No	No	?	Yes	Yes	4
Standen et al. 2017	Yes	Yes	No	?	Yes	No	No	?	?	No	?	Yes	Yes	5
Van den Berg at al. 2016	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	9
Wan et al. 2016	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	Yes	?	6

*, the methodological quality of the studies was assessed with Furlan method guideline[23] including 13 items (1–13) rated as positive ("yes"), negative ("no"), or not fulfilled/unsure ("?").

Table 4: Quality of evidence in technology-based distance physical rehabilitation interventions on physical functioning in stroke

Technology-based distance physical rehabilitation

Patient or population: persons with stroke receiving distance physical rehabilitation
Settings: home or rehabilitation care facilities without the present of a healthcare professional
Intervention: technology-based distance physical rehabilitation

Outcomes and number of studies	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Quality of the evidence (GRADE)*	Comments
ADL Nine studies	Study quality by Furlan et al. (2015) 8/13 (moderate) Sufficient information on treatment allocation procedure only in two studies Only 2 studies used ITT analysis	Analysis consisted of subjective and objective ADL measures ADL measures varied (BI, FONEFIM, MBI, MRS, SIS/ADL, NEADL) Technology varied between DVD, video monitoring, virtual training with gamification, or telephone calls Control group was	Stroke survivors with age range of 63 to 75 Mild to moderate physical disability without cognitive deficits	Meta-analysis of six studies with sample size ranging of 24–88 participants (N = 332) indicated no differences Descriptive analysis indicated no differences	No publication bias observed in meta-analysis (Appendix 3)	⨁OOO	Methodological quality indicated somewhat risk of bias Clinical heterogeneity observed in the use of technology and in the treatments in control group Sample size < 400 Only focusing on more elderly persons with stroke with mild impairments without cognitive deficits

		heterogeneous with usual care, similar or treatment Moderate statistical heterogeneity (I^2 = 38%)					
Balance (BBS) Four studies	Study quality by Furlan et al. (2015) 8/13 (moderate) Sufficient information on treatment allocation procedure only in one study Only one study used ITT analysis	Analysis consisted only BBS outcome Technology varied between video monitoring, or telephone calls Control group was heterogeneous with usual care, similar or other treatment	Stroke survivors with age range of 63 to 75 Mild to moderate physical disability without cognitive deficits	Sample size ranged from 24–54 participants Descriptive analysis indicated no differences	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias Clinical heterogeneity observed in the use of technology and in the treatments in control group Subanalysis to assess clinical heterogeneity were not able to perform due to the lack of studies Sample size < 400 Only focusing on more elderly

							persons with stroke with mild impairments without cognitive deficits
Upper extremity functioning Five studies	Study quality by Furlan et al. (2015) 7/13 (moderate) Treatment allocation procedure reported sufficiently only in one study Only one study used ITT analysis	Analysis consisted of objective measures Technology varied from virtual training with gamification, video online monitoring, video online monitoring combined with gamification, or video exercises without monitoring Control group were heterogeneous with similar treatment or usual care	Stroke survivors with age range of 60 to 75 Mild to moderate physical impairments without cognitive deficits	Sample size ranged from 19–58 participants Descriptive analysis indicated no differences	-	⨁OOO	Methodological quality of the studies indicated somewhat risk of bias Clinical heterogeneity observed in the use of technology and in the treatments in the control group Subanalysis to assess clinical heterogeneity were not able to perform due to the lack of studies Sample size < 400 Only focusing on more elderly persons with stroke with mild impairments without cognitive deficits

Lower extremity functioning Two studies	Quality of the study by Furlan et al. (2015) 9/13 (high) Treatment allocation procedure reported sufficiently only in one study	Analysis consisted of objective measures Technology varied from virtual training with gamification, video online monitoring, video online monitoring combined with gamification, or video exercises without monitoring Control group consisted of usual care	Stroke survivors with age of 67 years Mild to moderate physical impairments without cognitive deficits	Sample size N = 48 N = 63 Not enough reported values to conduct meta-analysis Descriptive analysis indicated no differences	-	⨁OOO	Methodological quality of the studies indicated somewhat risk of bias Clinical heterogeneity observed in the use of technology Sample size in total < 400 Only focusing on elderly persons with stroke with mild impairments without cognitive deficits
Walking Three studies	Quality of the study by Furlan et al. (2015) 9/13 (high) Treatment allocation procedure reported	Analysis consisted of objective measures Technology used in the experimental groups were only telephone calls	Stroke survivors with age of 60 and 69 years Mild to moderate physical impairments without	Sample size N = 40 N = 80 Not enough reported values to conduct meta-analysis	-	⨁OOO	Clinical heterogeneity observed in the compared treatments of control groups Sample size in total < 400

	sufficiently in all studies	Control group consisted of usual care (one study) or other treatments (2 studies)	cognitive deficits	Descriptive analysis indicated no differences			Only focusing on elderly persons with stroke with mild impairments without cognitive deficits
Physical activity Two studies	Quality of the study by Furlan et al. (2015) 8/13 (moderate) Treatment allocation procedure reported sufficiently only in one study	Analysis consisted of subjective measures Technology used in the experimental groups were only telephone calls Control group consisted of usual care (one study) or other treatments (1 study)	Stroke survivors with age between 63 and 69 years Mild to moderate physical impairments without cognitive deficits	Not enough studies to conduct meta-analysis	-	⊕OOO	Clinical heterogeneity observed in the compared treatments of control groups Sample size in total < 400 Only focusing on elderly persons with stroke with mild impairments without cognitive deficits
Participation Four studies	Quality of the study by Furlan et al. (2015) 8/13 (moderate)	Self-reported questionnaires Technology varied from telephone calls (three studies)	Stroke survivors with age between 60 and 69 years	Sample size varied between 19 and 63 participants	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias

	Treatment allocation procedure reported sufficiently only in two studies	and website exercises (one study) Control group consisted of traditional treatments (three studies) and other treatment (one study)	Mild to moderate physical impairments without cognitive deficits	Descriptive analysis indicated no differences		Clinical heterogeneity observed in the use of technology Sample size in total < 400 Only focusing on elderly persons with stroke with mild impairments without cognitive deficits

GRADE, Grading of Recommendations, Assessment, Development and Evaluation; ADL, Activities of daily living; BI, Barthel Index, FONEFIM, The telephone version of the Functional Independence Measure; MBI, Modified Barthel Index; MRS, Modified Rankin Scale; SIS/ADL, Stroke Impact Scale ADL subscale; ITT, intention-to-treat analysis; N, study sample; SMD, standard mean difference; 95%CI, 95 % Confidence interval; BBS, Berg Balance Scale; MD, mean difference; *GRADE was considered either high quality (4 plus), we are very confident that the true effect lies close to that of the estimate of the effect; Moderate quality (3 plus), we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different; Low quality (2 plus), our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect; Very low quality (1 plus), we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

Appendix 1: Search strategy

Database: Ovid MEDLINE(R) <1946 to March Week 4 2017>
Search Strategy:
----
1 exercise therapy/ (33186)
2 exercise therapy.tw. (2187)
3 Physical Therapy Modalities/ (32745)
4 physical therapy.tw. (11686)
5 physiotherapy.tw. (12549)
6 functional therapy.tw. (321)
7 Occupational Therapy/ (12632)
8 Neuropsychology/ (2178)
9 dietician.tw. (652)
10 dietitian.tw. (2104)
11 Dietitics/ (0)
12 Occupational Health Services/ (10266)
13 multidisciplinary therapy.tw. (319)
14 physical activity.tw. (67630)
15 Exercise/ (83974)
16 Exercise Movement Techniques/ (547)
17 Motor Activity/ (91252)
18 energy expenditure.tw. (18902)
19 "Delivery of Health Care"/ (76316)
20 public health service$.tw. (5709)
21 Nursing Diagnosis/ (4193)
22 Nursing Informatics/ (1216)
23 Community Health Nursing/ (19236)
24 Nursing/ (50691)
25 Public Health Nursing/ (10062)
26 medical treatment$.tw. (38891)
27 Psychiatry/ (38091)
28 Rehabilitation/ (17670)
29 Health Promotion/ (64237)
30 health counse?ling.tw. (630)
31 directive counse?ling.tw. (136)
32 coaching.tw. (3157)
33 health guidance.tw. (320)
34 "Activities of Daily Living"/ (57898)
35 adl.tw. (7001)
36 participation.tw. (104919)
37 cultural activities.tw. (184)
38 Leisure Activities/ (7552)
39 "Physical Education and Training"/ (13396)
40 Primary Prevention/ (16447)
41 Secondary Prevention/ (17463)
42 Tertiary Prevention/ (123)
43 Sports/ (27823)
44 active lifestyle.tw. (1036)
45 physical lifestyle.tw. (30)
46 Physical Fitness/ (25457)

47 Health Education/ (57740)
48 Patient Education as Topic/ (79380)
49 Behavior Therapy/ (26316)
50 Cognitive Therapy/ (21041)
51 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 (971873)
52 mobile system$.tw. (194)
53 Telemedicine/ (15890)
54 ehealth.tw. (993)
55 mobile health.tw. (858)
56 mhealth.tw. (573)
57 phealth.tw. (31)
58 mobile multimedia.tw. (11)
59 mobile communication$.tw. (521)
60 mobile technolog$.tw. (696)
61 Cellular Phone/ (6815)
62 cellular phone$.tw. (614)
63 cell phone$.tw. (1512)
64 cellular telephone$.tw. (358)
65 mobile phone$.tw. (3942)
66 mobile telephone$.tw. (390)
67 Mobile Health Units/ (3340)
68 Computers, Handheld/ (2988)
69 communication technolog$.tw. (2094)
70 technology integration.tw. (74)
71 web based communication$.tw. (69)
72 web based organi?ation$.tw. (0)
73 virtual communit$.tw. (193)
74 e-learning environment$.tw. (33)
75 User-Computer Interface/ (33427)
76 virtual learning environment$.tw. (149)
77 acceleromet$.tw. (8755)
78 mobile application$.tw. (465)
79 web based interacti$.tw. (158)
80 (mobile adj3 game$).tw. (53)
81 mobile gaming.tw. (6)
82 pervasive game$.tw. (0)
83 Geographic Information Systems/ (6153)
84 global positioning system$.tw. (1046)
85 telerehabilitation.tw. (299)
86 tele rehabilitation.tw. (48)
87 "web 2.0 intervention$".tw. (5)
88 "web 2.0 application$".tw. (30)
89 smart phone$.tw. (411)
90 Remote Consultation/ (4478)
91 sms.tw. (3517)
92 Text Messaging/ (1499)
93 text messag$.tw. (1645)
94 digital learning.tw. (35)

95 52 or 53 or 54 or 55 or 56 or 57 or 58 or 59 or 60 or 61 or 62 or 63 or 64 or 65 or 66 or 67 or 68 or 69 or 70 or 71 or 72 or 73 or 74 or 75 or 76 or 77 or 78 or 79 or 80 or 81 or 82 or 83 or 84 or 85 or 86 or 87 or 88 or 89 or 90 or 91 or 92 or 93 or 94 (86832)
96 Randomized Controlled Trials as Topic/ (111565)
97 Randomized Controlled Trial/ (456758)
98 Random Allocation/ (91691)
99 Double-Blind Method/ (145855)
100 Single-Blind Method/ (24143)
101 Clinical Trial/ (518217)
102 clinical trial, phase i.pt. (18539)
103 clinical trial, phase ii.pt. (29766)
104 clinical trial, phase iii.pt. (13493)
105 clinical trial, phase iv.pt. (1438)
106 controlled clinical trial.pt. (93340)
107 randomized controlled trial.pt. (456758)
108 multicenter study.pt. (223183)
109 clinical trial.pt. (518217)
110 exp Clinical Trials as Topic/ (309655)
111 96 or 97 or 98 or 99 or 100 or 101 or 102 or 103 or 104 or 105 or 106 or 107 or 108 or 109 or 110 (1213187)
112 (clinical adj trial$).tw. (254191)
113 ((signl$ or doubl$ or treb$ or tripl$) adj (blind$3 or mask$3)).tw. (130636)
114 Placebos/ (34752)
115 placebo$.tw. (176629)
116 randomly allocated.tw. (19700)
117 (allocated adj2 random$).tw. (22444)
118 112 or 113 or 114 or 115 or 116 or 117 (470963)
119 111 or 118 (1362773)
120 case report.tw. (213814)
121 letter/ (924107)
122 Historical Article/ (344334)
123 120 or 121 or 122 (1468852)
124 119 not 123 (1330227)
125 51 and 95 and 124 (3317)
126 intervention$.tw,kf. (648169)
127 stroke.mp. or Stroke/ (207599)
128 cardiovascular disease.mp. or Cardiovascular Diseases/ (174150)
129 hemiplegia.mp. or Hemiplegia/ (13843)
130 brain ischemia$.mp. or Brain Ischemia/ (44914)
131 cerebrovascular accident$.mp. (5584)
132 brain infarction/ (3863)
133 cerebrovascular disease.mp. or Cerebrovascular Disorders/ (53477)
134 127 or 128 or 129 or 130 or 131 or 132 or 133 (435463)
135 125 and 126 and 134 (186)
136 limit 135 to (yr="2000 -Current" and (english or finnish or german or swedish)) (186)
137 limit 136 to ("young adult (19 to 24 years)" or "adult (19 to 44 years)" or "young adult and adult (19-24 and 19-44)" or "middle age (45 to 64 years)" or "middle aged (45 plus years)" or "all aged (65 and over)" or "aged (80 and over)") (135)

****

Appendix 2. Summary of included RCT studies on the used technologies and interactions between health care professionals and participants in distance physical rehabilitation interventions.

Study	Technology							Interaction*			Comparison**			Outcomes						
	Telephone	Online video monitoring	Messaging/SMS	Video (e.g., DVD)	Virtual reality or training	Website	Activity monitor	2-way interaction	1-way interaction	Self-monitoring	Other treatment	Usual care	Similar treatment	ADL	Balance	Upper extremity functioning	Lower extremity functioning	Walking	Physical activity	Participation
Ada et al. 2003	X							X			X							X		
Ballester et al. 2017					X					X		X		X		X				
Chen et al. 2017		X						X					X	X	X					
Chumbler et al. 2012	X	X	X					X				X		X		X	X			X
Emmerson et al. 2016				X					X				X			X				
Lin et al. 2014		X						X				X		X	X					
Moore et al. 2015	X							X			X			X	X			X	X	X
Nijenhuis et al. 2017						X			X			X				X				X
Piron et al. 2009		X			X			X				X				X				
Redzuan et al. 2012				X								X		X						
Standen et al. 2017					X					X		X		X		X				
Van den Berg et al. 2016		X					X	X		X		X		X	X	X	X	X		X
Wan et al. 2016	X							X				X		X					X	

SMS = Short Message Service; DVD = digital video disc; ADL = Activities of Daily Living, * = Interaction of communication enabled through the used technologies between participant and the health care professional; ** = Comparison without the use of technology