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REVIEW ARTICLE

USE OF MOBILE/TABLET AND WEB-BASED APPLICATIONS TO SUPPORT REHABILITATION AFTER STROKE: A SCOPING REVIEW

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Objective: **To describe and review evidence of mobile/tablet and web-based applications to support the rehabilitation process after stroke. The secondary aim was to describe participants' stroke severity, and use of applications in relation to, respectively, the setting and phase of the rehabilitation process.**

Methods: **A scoping review methodology was used to identify studies, through databases such as PubMed, CINAHL, Embase and AMED. In addition, grey literature was searched. The studies were categorized according to Wade's model of rehabilitation.**

Results: **The literature search resulted in 12,065 records. Forty-six studies were included, in which applications were used to support: assessment (*n*=16); training (*n*=25); discharge from hospital (*n*=2); and 2 studies were targeted at supporting discharge/education/information and training. One study targeted assessment, discharge support and goal-setting. No studies were related to the element "participation" using Wade's model of rehabilitation. Of the 46 studies, 33 studies included participants with mild to moderate stroke, and 4 studies included participants with severe stroke. In 9 studies the stroke severity was not reported. Twenty-three studies included participants with chronic stroke, 16 acute and/or subacute stroke, and 5 included participants with acute and/or subacute and/or chronic stroke. In 2 studies, stroke onset was not reported. Applications were used in a rehabilitation setting (*n*=21), home setting (*n*=17), and both settings (*n*=3). In 5 studies the setting was not reported.**

Conclusion: **Most studies of applications developed to support the rehabilitation process after stroke have been explorative. They primarily include participants with mild or moderate stroke and focus on a limited aspect of the rehabilitation process, e.g. assessment or training. Future applications to support stroke rehabilitation should accommodate stroke survivors' and significant others' need for solutions, irrespective of stroke severity and throughout the entire rehabilitation process.**

LAY ABSTRACT

Studies have shown that the integration of applications (apps) can support the rehabilitation process after stroke. However, this scoping review found that most existing app solutions have limited usability, providing only 1 aspect of support in the rehabilitation process, such as clinical assessment or a narrow focus on exercises. Furthermore, currently available app solutions mainly target stroke survivors with mild stroke. Stroke survivors and significant others express a need for more comprehensive solutions to support the entire cross-sectorial rehabilitation process. Therefore, there is a need for development of app solutions that support a greater part of the stroke rehabilitation process regardless of stroke severity.

Key words: rehabilitation process; information and communication technology; apps; mobile health; technology support; physiotherapy; occupational therapy; stroke.

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Globally, stroke is a major cause of disability (1). Furthermore, as a consequence of improved medical care, with decreasing mortality rates and an ageing population, the number of people living with the consequences of stroke is likely to increase (2–4). Although most stroke survivors' recovery takes place largely during the first 3–6 months, the impact of the stroke and the need for rehabilitation may continue for years (2, 5). Long-term consequences, such as physical, cognitive, social and emotional deficits, can result in dependence and reduced participation in everyday life (3, 6, 7). Stroke severity can be categorized as mild, moderate, or severe in relation to cognitive, motor, sensory, and speech-related impairments (8).

Rehabilitation after stroke is important to improve functioning in daily activities and increase participation in everyday life (9). Furthermore, it is recommended that rehabilitation is person-centred, based on the needs and preferences identified by the stroke survivor and their significant others (9–13), and its provision should be based on a partnership between stroke survivor, significant others, and health professionals (9, 14). There is a lack of agreement on how to define rehabilitation (9). However, Wade (15) describes rehabilitation as "an educational, problem-solving process that focuses on activity limitations and aims to optimize patient social participation and well-being, and to reduce stress on family". He emphasizes that rehabilitation should start as early as possible, with a smooth transition between sectors, and that patient involvement is essential (9, 15).Wade (15) includes the following elements in his model of the rehabilitation process: *(i)* identify/screen for activity limitations faced by the patient (assessment: cognitive skills (memory, concentration, speech) and motor skills); *(ii)* establish the patient's goals and expectations, both short-term and long-term, especially regarding level of activity and/or participation (goal-setting); *(iii)* undertake the planned interventions (training: training cognitive skills, motor skills, motivation, and strategies to compensate for deficits); *(iv)* provide any support needed to maintain the patient's well-being, including focus on optimizing the patient's social participation; and *(v)* discharge: structure, planning, communication, rehabilitation plan (9, 15, 16). The 5 elements in this framework of a rehabilitation process will be used to categorize the included studies in this scoping review.

Information and communication technologies and mobile apps

Worldwide, information and communication technology (ICT), including mobile phones, tablets and computers are increasingly accessible (17), and society's demand for ICT is also increasing rapidly (18, 19). A myriad of mobile-based and web-based applications (apps), available on smartphones, tablets and computers allow daily activities to be done in novel ways, including reading the newspaper, playing games, and communicating with family and friends (18, 20, 21). Studies have also shown that the integration of apps can support the stroke rehabilitation process, e.g. to deliver health information to patients (22, 23), and to support stroke survivors in independently performing exercises post-discharge (24), thereby promoting their motor abilities (25). By integrating apps in rehabilitation, continuity can be enhanced (12, 26) and stroke survivors are supported to become more active in managing their own health through increased patient motivation, engagement and empowerment (22, 23, 27–31).

Although access to various app solutions has increased, knowledge regarding mobile/tablet apps to support rehabilitation after stroke is limited (5, 29, 31), including which elements, and in which phase and setting of the rehabilitation process the apps are used. Thus, identifying knowledge gaps is important to indicate directions for future development. The aim of this study was therefore to describe and review evidence of mobile/tablet and web-based applications being used to support the rehabilitation process after stroke. The secondary aim was to describe participants' stroke severity, and use of applications in relation to, respectively, the setting and phase of the rehabilitation process.

METHODS

A scoping review design was used to map existing evidence of the use of mobile/tablet and web-based apps in stroke rehabilitation. Scoping reviews include a range of study designs in both published scientific literature and grey literature and are ideal when the aim is coverage of a body of literature on a given topic, beyond those related to intervention effectiveness (32, 33). A scoping review study is less likely to assess the quality of included studies; whereas a systematic review focuses on a well-defined question and a relatively narrow range of quality assessed studies are included (32–34). A scoping review is thereby useful to guide the process of exploring and mapping the body of existing literature regarding apps used to support stroke rehabilitation (33–35).

This scoping review followed the stages, as described by the methodological framework devised by Arksey & O'Malley (34), and Levac et al. (32). The framework consists of 5 stages: *(i)* identifying the research question; *(ii)* searching for relevant studies; *(iii)* selecting studies; *(iv)* charting the data; and *(v)* collating, summarizing, and reporting the results (32, 34).

Stage 1: identifying the research question

First, a research question that was broad, but still specific enough to answer through a scoping review, was identified (32, 34): "What evidence is available regarding the use of mobile/tablet and web-based apps to support stroke rehabilitation, in which phase and setting of the rehabilitation process are the apps used, and what is the stroke severity of the participants?" These questions addressed the research gap that was discovered from initial searches and had clinical relevance. In line with recommendations made by Levac et al. (32), it was essential to define the concept of "rehabilitation", to establish a clear scope for the study, help guide the search strategy and establish parameters around study selection in subsequent stages. Therefore, "rehabilitation" was defined using Wade's model (15), as described earlier.

Stage 2: searching for relevant studies

In the literature search the following electronic bibliographic databases were used: PubMed, CINAHL, Embase and AMED. In addition, grey literature was searched in the following databases and webpages; OpenGrey, Google Scholar, SveMed, Fysio.dk, Den Danske Forskningsdatabase, and bibliotek.dk. The search was conducted between October 2019 and March 2020, with a 10-year restriction to publication date (March 2010 to March 2020) (36). An updated search was performed in November 2021 and January 2022. The search terms and search strategy were customized for each database to ensure precision and accuracy. The search strategy included thesaurus terms (MeSH terms and subject headings) combined with free-text words. Examples of main search terms used were apps, mobile app, health app, mobile health app, smart phone app, mobile application, rehabilitation, stroke, apoplexy and therapeutics. To maximize the search results, multiple sets of search terms were used. The search was performed until an overlap in the identified studies was observed. The literature search was performed with support from an experienced research librarian (see supplementary material). All studies retrieved from the database searches were imported into an Excel spreadsheet.

Stage 3: selecting studies

The inclusion criteria for this scoping review were: *(i)* mobile/tablet and web-based app solutions used to support stroke rehabilitation; *(ii)* studies including stroke survivors; *(iii)* studies published between 2010 and 2021 (36); and *(iv)* studies written in the English language. Primary studies were included, e.g. randomized controlled trials (RCTs), case studies, pilot studies, feasibility studies; thus, systematic reviews were excluded, however, systematic reviews informed the background and discussion section. Criteria for exclusion were app solutions with a primary focus on pharmacology/medications, robot technology, virtual reality or other not easily accessible hardware, electromyography, brain surgery or diagnosis. Furthermore, studies were excluded if they only introduced the interface or internal structure of the apps (e.g. study protocols) or if studies contained several app solutions without defining them. Title and abstract screening were performed independently by 2 authors (MM and HK) and a research assistant using the Excel spreadsheet mentioned earlier. Full-text screening was performed by the first and last author. In case of disagreements, consensus was reached though discussion (32). A flow-chart of the search strategy and selection process is shown in Fig. 1 (39).

Stage 4: charting the data

Two authors (MM and HK) collectively determined which variables to extract from the included articles, with a view to answering the research question. This stage was an iterative process in which the authors continuously extracted data from the included articles and updated the data-charting form (32). The following variables were chosen: *(i)* author, year, country of publication; *(ii)* study design; *(iii)* objective/aim; *(iv)* participants (numbers, stroke onset, stroke severity); *(v)* target of the specific app solution (using Wade's model of rehabilitation); *(vi)* context (rehabilitation setting and duration of the intervention); and *(vii)* key findings. These are shown in Tables I–II. Two authors (MM and HK) independently extracted data from the first 5 included studies using a data extraction form (see Table II) and subsequently discussed and determined whether the approach to data extraction was consistent with the research question and aim (32).

Stage 5: collating, summarizing and reporting the results

This stage had 2 steps. First, a descriptive numerical summary of the variables mentioned in stage 4 was conducted. Secondly, a manifest qualitative content analysis with a deductive approach was performed to find common elements across the dataset and answer the research question (37). By applying the method content analysis, the researchers could include large amounts of text and systematically identify its properties, such as phase and setting of rehabilitation (rehabilitation centre or at-home rehabilitation), stroke severity (mild, moderate, severe), stroke onset of the included participants (acute: 0–24 h after stroke; subacute: 1–90 days after stroke; chronic stroke: 3 months after stroke) (38), and categorize the apps in the studies in relation to Wade's model of rehabilitation (15), thus providing an overview of which elements of the rehabilitation process the app solutions were intended to support.

RESULTS

The initial literature search resulted in 10,142 records, of which 65 were duplicates. Applying the inclusion criteria, all titles were initially screened for relevance to the research question by the first and last author (MM and HK) and a research assistant, and non-relevant titles were removed.

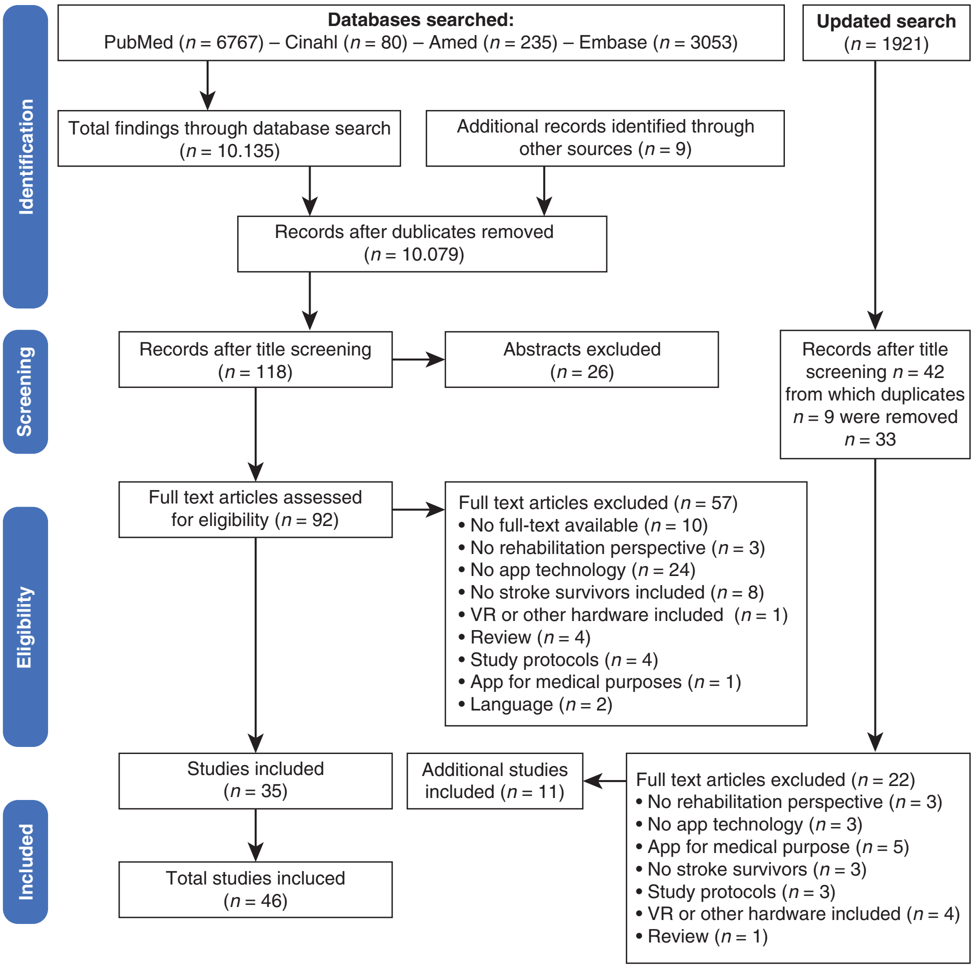

Fig. 1. Prisma flow-chart of search strategy and selection process.

After this selection, a total of 118 studies remained for an abstract review. Of these, 92 abstracts were considered to meet the inclusion criteria and were thus eligible for a full-text reading, which was conducted independently by 2 authors (MM, HK). However, 10 relevant studies were inaccessible and therefore excluded from this study, leaving 82 articles to be read in full text. A search alert was created for the latest published studies in PubMed and CINAHL, which resulted in 1 study (30). Finally, 35 articles were included, with consensus by two authors (MM and HK). Furthermore, an updated search was performed in November 2021 and January 2022 (see supplementary material). When searching only for studies published between 2020 and 2021, 1,921 hits were identified and screened by title, leaving 42 studies

Table I. Characteristics of the included articles (*n* = 46)

Items	Characteristic	Number of articles
Publication type	Primary articles	45
	Conference abstract	1
Study type/data collection method	Feasibility	9 (41–49)
	Pilot	10 (30, 50–58)
	Cohort	2 (40, 59)
	RCT	8 (19, 22, 25, 60–64)
	Case	5 (24, 65–68)
	Case-control	3 (27, 28, 69)
	Comparative	5 (70–74)
	Survey	1 (75)
	Mixed method	1 (76)
	Crossover design	1 (77)
	Qualitative design	1 (78)

(Continued)

Table I. (*contd.*)

Items	Characteristic	Number of articles
Place of origin	Australia	4 (24, 42, 45, 73)
	Belgium	1 (46)
	Brazil	3 (47, 70, 72)
	Canada	3 (49, 54, 66)
	China	2 (43, 62)
	England	3 (58, 59, 77)
	Ghana	1 (57)
	India	1 (76)
	Italy	2 (64, 75)
	Israel	1 (44)
	Latvia	1 (78)
	Netherland	1 (68)
	Korea	8 (19, 25, 27, 51, 56, 61, 63, 74)
	Scotland	1 (28)
	Singapore	1 (69)
	Slovenia	1 (41)
	Spain	2 (48, 60)
	Sweden	1 (40)
	Switzerland	1 (55)
	Taiwan	2 (22, 50)
	USA	6 (30, 52, 53, 65, 67, 71)
Stroke severity	Mild	15 (25, 28, 30, 41, 50, 51, 53, 61–64, 67, 68, 70, 71)
	Moderate	1 (24)
	Mild-moderate	17 (19, 22, 42, 44–46, 48, 54, 56, 57, 60, 65, 66, 72, 74, 76, 78)
	Severe (severe aphasia)	2 (52, 58)
	Mild-moderate-severe aphasia	2 (69, 73)
	Not reported	9 (27, 40, 43, 47, 49, 55, 59, 75, 77)
Stroke onset	Acute	12 (22, 24, 40, 43, 46, 54, 56, 62, 67–69, 76)
	Subacute	2 (25, 64)
	Acute/subacute	2 (30, 45)
	Acute and chronic	1 (73)
	Subacute and chronic	2 (44, 59)
	Chronic	23 (19, 28, 41, 42, 47–51, 53, 57, 58, 60, 61, 63, 65, 66, 70–72, 74, 75, 77)
	Acute, subacute and chronic	2 (27, 78)
	Not reported	2 (52, 55)
Setting of rehabilitation	Hospital/rehabilitation centre	21 (24, 25, 30, 41, 43, 44, 46, 47, 49–51, 54, 56, 60, 61, 63, 68, 70–72, 77)
	At-home	17 (22, 28, 40, 42, 45, 48, 53, 57–59, 62, 65–67, 74, 76, 78)
	Both	3 (69, 73, 75)
	Not reported	5 (19, 27, 52, 55, 64)
Target of app	A: Assessment	16
		Speech (aphasia) ($n=2$) (27, 69)
		Physical activity/function ($n=5$) (30, 41, 47, 70, 72)
		Upper limb ($n=1$) (44)
		Stroke severity ($n=4$) (40, 43, 62, 68)
		Cognitive function 2 (56, 73)
		Pulmonary function 1 (71)
		Unmet needs 1 (75)
	B: Goalsetting	0
	C: Training	25
		Lower limb and balance ($n=9$) (25, 28, 45, 50, 51, 57, 60, 61, 63)
		Fine motor/upper limb ($n=5$) (19, 24, 48, 53, 74)
		Speech (aphasia) ($n=8$) (42, 46, 52, 54, 55, 58, 66, 77)
		Visual therapy ($n=1$) (59)
		Cognitive therapy ($n=2$) (64, 65)
	D: Social participation	0
	E: Discharge (Health information)	2 (22, 67)
	C+E: Exercises (lower limb and balance) and discharge/health information	2 (76, 78)
	A-B-E (assessment, goal-setting, discharge support, information/ education)	1 (49)

for abstract reading. However, 9 studies were already included in the initial search, thus 33 studies were full-text read, from which 11 studies were included using the above-mentioned inclusion criteria. Thus, a total of 46 studies using 1 or more mobile/tablet and web-based app solutions, were included in this scoping review (see fig.1).

Of the 46 included studies, 43 were published from 2016 to 2020, 2 studies were published in 2015 (27, 40) and 1 in 2012 (25). The countries in which

Table II. Overview of main characteristics, target and context of the app solutions and key findings of the included studies

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
1	Ballard KJ et al., 2019 Australia (42)	Feasibility	To assess the feasibility of a newly developed speech therapy application using automatic speech recognition (ASR)-based feedback on performance to improve word production accuracy	5 participants Stroke onset: chronic stroke (more than 6 months) Stroke severity: mild-moderate apraxia of speech plus aphasia deficit	C: Language training	Setting: at-home Duration: 4 weeks, 4 sessions a week +1 face-to-face session each week, (in the clinic or via video calls)	Improvements were maintained 1 month post-treatment. Participants found the app engaging and enjoyed the app-based activities and would continue to use it. However, they wished to maintain regular contact with the speech pathologist.
2	Capela NA et al, 2016 Slovenia (41)	Feasibility	To compare the performance of a smartphone-based wearable mobility monitoring system (WMMS) between able-bodied participants and people who had had a stroke.	15 participants with stroke and 15 able-bodied participants Stroke onset: chronic (mean 9.6 months before) Stroke severity: mild stroke (mean FIM score was 107 points (max. point is 126).	A: Assessment of physical activity	Setting: rehabilitation centre Duration: 30 min	The algorithm performed reasonably well for both stroke and able-bodied participants when differentiating between sit, stand, lie, and walk and between mobile and immobile states. When stair-climbing and small movements were added to the classification, algorithm performance decreased.
3	Chang H et al., 2018 China (43)	Feasibility	To assess the accuracy of self-assessment for acute stroke patients via mobile phone application-based scales and determine the value and prospect of clinical use. The aim was also to compare the results of nurse assessment and self-assessment.	50 participants Stroke onset: acute (onset within 12 h before application on smartphone) Stroke severity: not reported	A: Assessment of stroke severity mRS and ADL	Setting: at the hospital, the day before release Duration: 1-time self-assessment. 27 patients self-assessed the scales. Caregivers of other 23 patients completed the assessment	There is a substantial consistency between self-assessment and nurse assessment. Therefore, caregivers can serve as the proper assessor when patients are out of hospital.
4	Chae SH et al., 2020 Korea (74)	Comparative study	To develop and evaluate a home-based rehabilitation system that can recognize and record the type and frequency of upper limb rehabilitation exercises using a smartwatch and smartphone app	23 participants (17 in intervention group and 6 in control group) Stroke onset: chronic stroke Stroke severity: mild-moderate stroke	C: physical therapy	Setting: at-home Duration: Both groups received education on upper limb exercises. Participants were asked to perform the home exercises for 12 weeks. Both groups received weekly phone-calls from a physiotherapist.	Using a commercial smartwatch can facilitate participation in home training and improve the functional score of the Wolf-Motor-Function-Test (WMFT) and shoulder ROM of flexion and internal rotation in the treatment of patients with chronic stroke. This strategy may be a cost-effective tool for the home stroke care treatment in the future.
5	Choi et al., 2015 Korea (27)	Case-control	To develop a valid, reliable mobile aphasia screening test (MAST) for patients in remote locations.	30 patients with aphasia and 30 persons without aphasia Stroke onset: Acute, subacute, chronic stroke (aphasia: 2–8,128 days) Stroke severity: not reported	A: Assessment of aphasia (screening tool)	Setting: not reported Duration: 1-time assessment	The MAST is a valid and reliable tool for detecting aphasia in patients with stroke

(Continued)

Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
6	Ciou et al., 2017 Taiwan (50)	Pilot study	A drop foot rehabilitation training device based on the smart phone is presented. This device is combined with a football APP and feedback controlled functional electrical stimulation (FES).	5 stroke survivors Stroke onset: chronic stroke (5–19 months) Stroke severity: mild stroke (MMSE 24–30)	C: Physical training	Setting: rehabilitation centre Duration: 30 min per session, twice a week for 6 weeks	Significant performance improvement ($p < 0.05$) was found in the patient's ankle dorsiflexion strength, ankle dorsiflexion angle, control timing and Timed Up and Go.
7	Cock DE et al., 2021 Belgium (46)	Feasibility	To investigate the feasibility, usability and acceptability of the Speech Therapy App (STAPP) in the acute phase post-stroke	25 participants with aphasia Stroke onset: acute (2 weeks post-stroke) Stroke severity: mild-moderate (NIHSS 3–15)	C: Aphasia training	Setting: rehabilitation centre Duration: after 2 short training sessions (15–30 min) participants were asked to practice independently with "STAPP' as an add-on to standard care until discharge (median length of hospital stay 9 days)	STAPP is feasible to use as an additional rehabilitation tool along with standard of care in the acute phase post-stroke.
8	Cooray C et al., 2015 Sweeden (40)	Cohort	To investigate whether automatic assessment of the mRS based on a mobile phone questionnaire may serve as an alternative to mRS follow-up assessments at clinical visits after stroke	48 patients Stroke onset: acute stroke Stroke severity: not reported	A: Assessment of mRS (modified Rankin scale (stroke severity) after 3 months (20 questions).	Setting: at-home Duration: 1-time self-assessment:16 made by patient, 6 in collaboration with caregiver, 26 made by caregiver, and 1-time assessment by health professional.	Mobile phone-based questionnaires for automatic assessment of mRS after stroke performed good to excellent compared with clinical visit mRS assessments.
9	Costa et al., 2020 Brazil (47)	Feasibility	To investigate the validity and test-retest reliability og mHealth devices (Google Fit, Health, STEPZ, Pacer, and Fitbit Ultra) to estimate the number of steps and to compare if the number of steps is affected by their location on the body (paretic and non-paretic side)	55 participants Stroke onset: chronic stroke Stroke severity: mild stroke (> 18 on the Mini-Mental State Examination)	A: Assessment of physical activity	Setting: rehabilitation centre Duration: 1-time assessment	mHealth devices ((Google Fit, Health, STEPZ, Pacer, and Fitbit Ultra)) are valid and reliable for step counting in chronic stroke survivors. Body location (paretic or non-paretic side) does not affect validity or reliability of the step count metric.
10	De Bartolo et al., 2018 Italy (75)	Survey	To validate the Post Soft Care-App (PSC), which was administered by physiotherapists to a sample of chronic stroke patients with the aim of highlighting their unmet needs.	53 patients Stroke onset: chronic stroke Stroke severity: not reported	A: Assessment of unmet needs (11-item questionnaire to highlight any changes since discharge or last check-up)	Setting: at-home or rehabilitation centre Duration: 1-time (96% were patient answered, 4% in collaboration with caregiver/staff	The PSC was judged to have helped therapists to improve their communication with patients and to have highlighted at least 1 unmet need. And was fast and easy to administer.
11	Epalte et al., 2020 Latvia (78)	Qualitative interviews	To describe insights about the app "Vigo" usability from a patients' perspective	12 participants Stroke onset: acute, subacute, chronic (9–1,087 days) Stroke severity: mild-moderate (minimum score of 18 on Montreal Cognitive Assessment (MoCA))	C + E Education/ information to promote participation/ adherence to training (music, text, pictures, videos, exercises)	Setting: at-home Duration: each participant tested the application for the duration of a month in their home.	Stroke survivors in general had a positive attitude towards using tablet technologies in their home environment. However, a greater variety of exercises provided in the solution and technical support were wanted.
12	Faria GS et al., 2019 Brazil (70)	Comparative study	To investigate the concurrent validity of the GT3X®ActiGraph accelerometer and Google Fit®smartphone application in estimating energy expenditure of stroke survivors during fast over ground walking.	30 participants Stroke onset: chronic stroke (mean time 98 months Stroke severity: Mild stroke (able to walk independently, no cognitive impairments)	A: Assessment of steps (physical activity)	Setting: rehabilitation centre Duration: 1-time	The GT3X®ActiGraph accelerometer and the Google Fit® smartphone application do not provide valid measures of energy expenditure in chronic stroke individuals during fast overground walking.

(Continued)

Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
13	Fell et al., 2019 USA (30)	Pilot study	To examine correlations between clinician and mobile app scoring of real-time movement data in 4 common clinical tools used to assess stroke recovery at the body function and activity levels of the ICF model.	35 participants Stroke onset: acute/ subacute stroke (stroke onset within the last 3 months). Stroke severity: Mild stroke (able to follow 3-step commands and ambulate 10 m with minimal support, and no aphasia or apraxia).	A: Assessment of movement	Setting: rehabilitation centre Duration: 1-time (physiotherapist assessment and mobile app assessment)	Significant correlation between clinician and mobile app scores for all 4 tests supports the authors' objectives to create a mobile health app that provides clinicians with objective movement data to inform and track recovery.
14	Grau-Pellicer M et al., 2019 Spain (60)	RCT	To investigate the effectiveness of a mobile-health (mHealth) app in improving levels of physical activity.	41 participants Intervention group (IG) $n=24$ control group (CG) $n=17$ Stroke onset: chronic stroke Stroke severity: Mild-moderate (Functional ambulation classification ≥ 3, Barthel Index ≥ 45).	C: Physical activity	Setting: rehabilitation centre Duration: IG: 8-week rehabilitation program (2 days/week, 1 h/ session): aerobic, task-oriented, balance and stretching. CG: conventional program.	Community ambulation increased more in IG than in CG. Sitting time was reduced by 2.96 h/day in the IG and by 0.53 h in the CG. Support and guidance of researchers and careers are required to ensure completeness of clinical assessment data and protocol adherence.
15	Guo et al., 2017 Singapore (69)	Case-control	To determine the reliability of telehealth aphasia assessment based on measures that examine aphasia across the ICF spectrum within the home environment using Access2Aphasia.	30 participants Stroke onset: chronic stroke (stroke onset 6–79 months). Stroke severity: mild to severe aphasia	A: Assessment aphasia	Setting: at-home (online-led group) or rehabilitation centre (face-2-face group) Duration:1-time	A moderate to almost perfect agreement between online and face-to-face speech-pathologist assessment was found.
16	Jang S.H. & Jang W.H., 2016 Korea (19)	RCT	To investigate the effect of a finger training application program using a tablet PC in chronic hemiparetic stroke patients.	21participants Stroke onset: chronic stroke (more than 6 months). Stroke severity: mild-moderate (incomplete weakness of hand and fingers, MMSE ≥ 24, modified Ashworth scale score < 2)	C: Fine motor training	Setting: not reported Duration: application training was conducted 1 session/day, 6 days per week for 4 weeks.	Using application with a tablet PC for 4 weeks, hemiparetic Stroke patients achieved functional recovery of the hand as well as motor recovery of the wrist and hand.
17	Joo S et al., 2019 USA (71)	Comparative study	To (1) quantify the reliability and validity of SGA (smartphone game-based assessment) for pulmonary function and (2) to assess the validity of SGA in comparison to spirometry.	34 participants Stroke onset: chronic stroke (more than 6 months) Stroke severity: mild stroke (Mini-Mental State Examination – Korean version (MMSE-K) score > 24)	A: Assessment of pulmonary function	Setting: rehabilitation centre Duration: 3 spirometer assessments that were compared with the SGA (14 games, to guide in- and expiration)	The SGA data were statistically significant and reliable for pulmonary function assessment in stroke patients.
18	Kang Y-N et al., 2019 Taiwan (22)	RCT	To compare the effectiveness of a stroke health education booklet and a stroke health-education mobile app (SHEMA) with same stroke-related health information, in improving patients' knowledge of stroke risk factors and health-related quality of life compared with stroke health-education booklet.	63 stroke survivors with experience in using apps (30 in intervention and 33 control group) Stroke onset: acute Stroke severity: Mild –moderate stroke (Mini-Mental State Examination ≥ 24, mRS (modified Rankin scale) 1–4	E: Health information education	Setting: at-home Duration: The patients read the booklet or the SHEMA content at home for 7–14 days, and 5 min per day.	No significant effect between groups on improving patients' knowledge of stroke risk factors after a short-term intervention. A larger number of younger patients (aged ≤55 years) tend to improve their stroke-knowledge in SHEMA group than the control group.

(Continued)

Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
19	Kim JH et al., 2012 Korea (25)	RCT	To examine the effects of Rhythmic auditory stimulation (RAS) gait training using a smartphone metronome application on balance and gait abilities of stroke patients	20 patients RAS group, $n=10$ Control group $n=10$ Stroke onset: subacute stroke (stroke onset <6 months) Stroke severity: mild stroke (Mini-Mental State Examination score ≥24)	C: Gait training	Setting: at the hospital Duration: 30-min sessions conventional physical therapy. In addition, RAS group received 30-min gait training 3 times per week for 5 weeks.	Increases in dynamic balance and spatiotemporal gait parameters were observed in both groups. Compared with the control group, the RAS group showed significant improvements in scores on the ABC scale, DGI, TUG, and Up stair and Down stair times.
20	Kizoni et al., 2016 Israel (44)	Feasibility study	To compare performance of app-based hand activities in individuals without a disability from 3-age groups and to assess the feasibility of using tablet apps in individuals with stroke.	20 stroke survivors Stroke onset: subacute (<4 months) and chronic (<12 months) Stroke severity: Mild–moderate upper extremity impairment (Fugl-Meyer assessment)	A: Fine motor assessment ScribbleKid app PegLight app Tap it app Bowling App.	Setting: rehabilitation centre Duration: 1-time assessment	PegLight was the only app that all participants were able to complete. And 15 out of 20 stroke survivors were able to complete the 2 trials of the tapping task. All participants enjoyed using the apps.
21	Ko BW et al., 2016 Korea (51)	Pilot study	To investigate the effects of various rhythmic auditory stimulation (RAS) tempos on stroke gait pattern, when training patients with a smartphone-based rhythmic auditory stimulation application.	15 patients Stroke onset: chronic stroke (>6 months since stroke). Stroke severity: Mild stroke (able to walk >10 m independently, MMSE= 28,4	C: Gait training Each RAS tempo practiced for 10 min. Sensors were attached to ankle joints.	Setting: rehabilitation centre Duration: 1-time assessment and training	Stride length increased significantly after training. Rhythmical tempo variations have a positive impact on the gait of stroke patients.
22	Kondapalli A et al., 2016 USA (52)	Pilot study	To study the use of a phonology-free communication mobile app.	1 participant Stroke onset: not reported Stroke severity: Severe expressive/ Broca's aphasia	C: Aphasia training	Setting: not reported Duration: not reported	The app may be of great benefit to patients with aphasia and other communication disorders. The nurse also found the app helpful for communicating with the patient.
23	Kringle EA et al., 2019 USA (65)	Case study	To describe lessons learned through adaptation of a complex intervention, strategy training, for delivery via mHealth technology (the iADAPTS application).	5 participants who had previously engaged in strategy training Stroke onset: chronic stroke (1–3 years earlier) Stroke severity: Mild–moderate (intact language, Self-Awareness of Deficits Inventory >2, motor impairment 16–36 (Chedoke McMaster Stroke Assessment)	C: Cognition training (strategy training)	Setting: at-home Duration: 5-week intervention period, 3 times per week	Overall high satisfaction with this approach to intervention measured on CSQ-8. It may be feasible to adapt the strategy training protocol for delivery using mobile health technology.
24	Lavoie M et al., 2019 Canada (66)	Case study	To investigate the efficacy of a self-administered treatment using a smart tablet to improve naming of functional words in post-stroke anomia.	4 participants with aphasia Stroke onset: chronic stroke (>1-year post-stroke) Stroke severity: mild to moderate deficits for oral sentence comprehension.	C: Aphasia training	Setting: at-home Duration: 4 times a week for 4 weeks	Significant improvement for both sets of trained words that was maintained at 2 months follow-up. Moreover, in 2 participants, evidence of generalization to conversation was found.

(Continued)

Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
25	Lawson et al., 2017 USA (53)	Pilot study	To investigate the utility of a mobile app to improve motor control for stroke survivors by examining changes in motor ability and participation.	6 participants Stroke onset: chronic stroke Stroke severity: Mild stroke (independently use of app).	C: Upper extremity therapy	Setting: at-home Duration: daily home-training for 6 weeks.	Statistically significant changes were not obtained with this pilot study. However, improvements were found in many assessments posttreatment.
26	Li et al., 2020 China (62)	RCT	To evaluate the feasibility, validity, and reliability of functional assessments administered through the videoconference function of a mobile phone-based app compared with administration through the telephone function in post-stroke patients after rehabilitation hospitalization	120 participants (videoconference follow-up ($n = 60$) or a telephone follow-up ($n = 60$) group Stroke onset: acute stroke Stroke severity: mild stroke (normal cognitive function according to the Montreal Cognitive Assessment with a cut-off score > 26)	A: motor assessment	Setting: at-home Duration: assessment made 2 times (functional status of participants using modified Barthel Index scores were measured in each group at 2-week and 3-month follow-up periods.	The agreements between video-conference follow-up and home visit assessments was higher than that between telephone follow-up and home visit assessments at all follow-up periods.
27	Mallet 2016 Canada (54)	Pilot study	To assess the feasibility of a tablet-based speech-language therapy for patients with communication deficits following acute stroke	30 participants Stroke onset: acute stroke Stroke severity: mild to moderate communication Deficits (AlphaFim 47–90).	C: Aphasia therapy 7 apps tested	Setting: acute care setting (hospital) Duration: 1 h per day (median time with the tablet was 10 days).	97% of patients scored the mobile tablet-based communication therapy as at least moderately convenient 3/5 or better with 5/5 being most convenient.
28	Markle-Reid et al., 2020 Canada (49)	Feasibility	To examine the feasibility of a 6-month integrated transitional care stroke intervention using the "My Stroke Team (MyST)" app and explored its effects on health outcomes, patient and provider experience, and cost. (Team: occupational therapist, physio-therapist, speech language pathologist, nurse, social worker).	30 participants with stroke and multimorbidity (≥ 2 chronic conditions) newly discharged from hospital and referred to an outpatient stroke rehabilitation setting Stroke onset: sub-acute (average of 2 months post-stroke) Stroke severity: not reported	A-B-E MyST app: a secure space for *(i)* patient information; *(ii)* documenting and sharing of visits, conference records, screening tool scores, client goals, and follow-up items; *(iii)* posting "alerts" for individuals or the team; and *(iv)* resource links (stroke guidelines, educational materials, health and social services in the community).	Setting: at-home Duration: Monthly 1-h visits from a member of the team for 6 months (average 4.73 home visits). The team met once per month for 6 months to discuss patient-identified goals and develop a person-centred and evidence-based plan of care for each participant. Only the team were able to add content or communicate through the MyST app	The intervention was feasible and acceptable to both stroke survivors and providers. From baseline to 6 months, there was no statistically significant difference in health outcomes. However, there was a significant reduction in the total per person use and costs of health services.
29	Meeuwis et al., 2020 Netherland (68)	Case study	To present how WhatsApp Messenger may support a modern neurological examination	3 participants (2 with stroke and 1 with TIA) Stroke onset: acute Stroke severity: mild	A: Assessment of deficits	Setting: acute care setting Duration: 1-times assessment	This easy and useful evaluation of the ability to use a text message program should be incorporated in standard neurological history taking and examination
30	Nef et al., 2018 Switzerland (conference abstract) (55)	Pilot study	To develop and test an aphasia tele-rehabilitation application (Bern Aphasia App) to increase training frequency and duration for patients.	The app was tested on 25 healthy participants. Later 134 patients trained with the app. Stroke onset: not reported Stroke severity: not reported	C: Aphasia training	Setting: not reported Duration: not reported	134 aphasia patients trained for 197.2 h. System Usability Scores (SUS) 94.5 for healthy participants and 93.2 for aphasia patients (maximum 100).

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Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
31	Park et al., 2017 Korea (56)	Pilot study	To assess whether MMSE-K (Korean version) can be applied effectively using a smartphone to evaluate cognitive function in stroke patients.	30 participants Stroke onset: acute stroke Stroke severity: mild-moderate aphasia	A: Cognition assessment MMSE (live assessment though the facetime app -30 questions)	Setting: at the hospital Duration: 1-time face-to-face assessment, and 1-time virtual assessment	Good agreement between face-to-face and remote assessments on total MMSE-K score and sub-scores for each domain were found (orientation, memory, attention/calculation, language, and visuospatial function).
32	Paul L et al., 2016 Scotland (28)	Case-control study	To evaluate the potential effectiveness of STARFISH a mobile app- based intervention in stroke survivors	23 participants (15 in intervention group (IG), 8 in control group (CG)) Stroke onset: chronic stroke (4.2±4.0 years) Stroke severity: mild (the ability to walk independently, and comprehend instructions)	C: Physical activity (measuring steps)	Setting: at-home Duration: IG: STARFISH program for 6 weeks. CG: usual care, (no rehabilitation, only appointments with health professionals as required).	A 6-week intervention using the STARFISH app, can increase steps/day (39.3%), walking time, and reduce fatigue in community-dwelling stroke survivors.
33	Polese JC et al., 2019 Brazil (72)	Comparative study	To examine the validity of the GT3X®ActiGraph accelerometer and the Google Fit® smartphone application in estimating stepping activity in people with chronic stroke, compared with the number of steps counted by the examiner.	37 participants Stroke onset: chronic stroke Stroke severity: mild-moderate stroke (no cognitive impairments and the ability to walk independently)	A: Physical activity (measuring stepping activity)	Setting: rehabilitation centre Duration: 1-time assessment	The Google Fit smartphone application showed higher associations with that determined by the examiner than the data estimated by the GT3X® ActiGraph accelerometer.
34	Sarfo FS et al., 2018 Ghana (57)	Pilot study	To assess the feasibility of and satisfaction with a physical therapy tele-rehabilitation intervention (9zest Stroke Rehab App®)	20 participants Stroke onset: chronic stroke Stroke severity: mild-moderate stroke (mRs 1–4)	C: Physical therapy	Setting: at-home Duration: 5-days-a-week exercise program (30–60 min) for 12 weeks.	The intervention was associated with improvements in baseline motor deficits over the 12 weeks of intervention.
35	Segura et al., 2021 Spain (48)	Feasibility	To test the feasibility of the novel app solution; Music-supported Therapy (MST) intervention to support upper limb motor function recovery	5 participants Stroke onset: chronic stroke Stroke severity: mild-moderate (Mini-Mental State Examination > 24) (4 participants with mild strength deficits and 1 patient with moderate strength deficits)	C: Upper-motor therapy	Setting: at-home (3 participants were trained initially at the rehabilitation centre) Duration: 10-week intervention program of 3 sessions per week	Patients clinically improved in upper limb motor function achieving the minimal detectable change or minimal clinically important difference in most of motor tests. The app received high usability ratings post-intervention.
36	Shin DC 2020 Korea (63)	RCT	To investigate the role of smartphone-based visual feedback trunk control training (SPVFTCT) for improvement of trunk control and spatio-temporal gait parameters in stroke patients.	24 participants (12 in each group.) Stroke onset: chronic stroke Stroke severity: mild stroke (sit independently > 30 min.; the ability to walk for 10 min; minimal cognitive deficits (MMSE-K > 24).	C: Physical therapy	Setting: rehabilitation centre Duration: 4 weeks conventional therapy. The SPVFTCT group additionally received SPVFTCT 4 weeks.	The trunk impairment scale in the experimental group was significantly improved compared with the control group ($p<0.05$). The spatio-temporal gait parameters (stride and step length and step width) are significantly more different in the experimental group than in the control group ($p<0.05$).

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Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
37	Shin and Song. 2016 Korea (61)	RCT	To assess the preliminary efficacy and feasibility of smartphone-based visual feedback trunk control training (SPVFTCT) for improving balance and trunk performance in stroke patients.	24 participants (12 in each group.) Stroke onset: chronic stroke Stroke severity: mild stroke (sit independently > 30 min.; the ability to walk for 10 min; minimal cognitive deficits (MMSE-K > 24).	C: Physical therapy	Setting: rehabilitation centre Duration: 4 weeks conventional therapy. The SPVFTCT group additionally received 3 20-min sessions per week of SPVFTCT for 4 weeks.	All measures in the SPVFTCT group improved significantly compared with the control group. In the SPVFTCT group, retention and adherence rates were 100% and 97%, respectively. The SPVFTCT approach is a feasible method to improve balance and trunk performance in stroke patients.
38	Siegel J et al., 2016 USA (67)	Case study	To examine ischemic stroke patients who used the PHA app (personal health assistant). The hypotheses were that the PHA would improve post-discharge satisfaction and decrease rehospitalization for patients recovering from stroke.	2 participants Stroke onset: acute stroke Stroke severity: mild stroke (sufficient dexterity and cognition to utilize the intervention app)	E: Seamless communication intervention and discharge support	Setting: at-home Duration: 30 days of PHA service though the app (to facilitate communication with healthcare after discharge).	Both patients who used the app were very satisfied with the PHA and their post-hospital care coordination. One patient was readmitted for stroke within 30 days.
39	Silveira TM et al., 2018 Australia (24)	Case study	To examine the effect of combining Functional Electric Stimulation (FES), music therapy, and tablet technology for upper limb stroke rehabilitation	1 participant Stroke onset: acute stroke Stroke severity: Moderate stroke (assistance on transfers and ADL, Minimal hand function on paretic side)	C: Motor training (upper limb) Combining a FES protocol with an iPad application.	Setting: rehabilitation setting Duration: during 9-weeks patient received FES 1–2 × per week, and music therapy 1 × per week.	Improvements in all areas of assessment at discharge, which had continued to improve at 7 months post-discharge.
40	Simpson DB et al., 2020 Australia (45)	Feasibility study	1) To investigate the feasibility of delivering a 4-week remotely prescribed functional exercise program using a tablet, app, and sensor system, and 2) provide an estimate of the effect of the intervention on functional outcomes.	10 participants Stroke onset: acute, subacute, and chronic (29–296 days) Stroke severity: mild-moderate (Short performance physical battery test 3–11 points (max. is 12)).	C: Physical activity	Setting: at-home Duration: 4-weeks	It was feasible to prescribe and monitor exercises using an app and sensor-based system. Participants performed 125% and 104% of prescribed sessions and repetitions. Participants rated the system usability (78%), enjoyment (70%) and system benefit (80%).
41	Stark and Warburton, 2016 England (58)	Pilot study	To investigate the effectiveness and feasibility of self-delivered and directed iPad-based speech therapy in patients with chronic aphasia following a left middle cerebral artery-territory stroke.	10 participants Stroke onset: Chronic stroke Stroke severity: Severe aphasia (using the CAT score)	C: Aphasia training Speech therapy app compared with mind-game app	Setting: at-home Duration: Recommended use of 20 min per day, for 4 weeks.	There was significant post-therapy improvement, but no significant improvement after the mind-game intervention and they were maintained at 6-month follow-up.
42	Sureshkumar K et al., 2016 India (76)	Mixed methods	To evaluate the feasibility and acceptability of the intervention "care for stroke app" (information about stroke and the ways to manage post-stroke disabilities (text and videos), home-based exercises, functional skills training, ADL, and assistive devices).	60 participants (stroke survivors and their caregivers) Stroke onset: acute stroke (stroke onset < 6 weeks). Stroke severity: mild and moderate stroke (NIH Stroke Scale 1–15)	C + E: Education/ information and physical activity app	Setting: at-home Duration: Participants were asked to use this intervention at home for 2 weeks during the field-testing phase and for 4 weeks during the pilot-testing.	53% (*n* = 16) of stroke survivors and 67% (*n* = 20) of carers rated "Care for Stroke" as excellent. The remaining participants rated the intervention as very useful

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Table II. (*contd.*)

Study	First author, year, country	Study design	Objective/aim	Participants	Target of app	Context	Study
43	Szalados et al., 2021England (59)	Cohort	To investigate the clinical effectiveness of Eye-Search, a web-based therapy app designed to improve visual search times, in patients with either hemianopia, neglect or both.	426 participants (84% with stroke) Stroke onset: subacute-chronic (44–210 days) Stroke severity: not reported	C. visual training	Setting: at-home Duration: 5–20 days	Eye-search therapy improved search times to the affected visual field of patients with either hemianopia alone or neglect and hemianopia, but not those with neglect alone
44	Verna V et al.,2020(64)	RCT	The aim of this study was to investigate the effectiveness of a negative mismatch-based therapy on the disability and quality of life in patients with stroke in sub-acute phase (using the "Temporal Musical Patterns Organisation (Te.M.P.O)" app.	30 participants randomized to Mismatch group (Mg) or Control group (CTRLg) (receiving Sham) Stroke onset: sub-acute Stroke severity: mild stroke (Mini-Mental State Examination < 24)	C. Cognitive training	Setting: not reported Duration: 20 min/3 times a week for 4 weeks, in addition to the standard cognitive and physical rehabilitation.	The results show a major improvement of the Mg with respect to the CTRLg in all clinical scales score (disability and quality of life)
45	Wall KJ et al.2018 Australia (73)	Comparative study	To develop and explore the feasibility and user acceptance of the Cognitive Assessment for Aphasia App (C3A): a cognitive assessment for stroke survivors, designed to be inclusive of individuals with aphasia	64 participants Stroke onset: acute and chronic stroke (35 with aphasia, 29 without aphasia). Stroke severity: Mild to very severe language deficits.	A: Cognitive assessment	Setting: acute, rehabilitation centre and community settings Duration:1-time assessment	The app seems to be feasible for cognitive assessment for stroke survivors with and without aphasia.
46	Woodhead et al. 2018 England (77)	Crossover design	To test the impact of a novel training app, "iReadMore", and transcranial direct current stimulation (tDCS) of the left inferior frontal gyrus, on word reading ability in central alexia.	21 participants Stroke onset: chronic stroke and with central alexia (more than 1-year post-stroke) Stroke severity: not reported	C: Aphasia (for promoting reading ability)	Setting: rehabilitation centre Duration: 4-week blocks of iReadMore therapy, accompanied with either real or sham tDCS (3 40-min face-to-face sessions/ week). In addition, independently using the app at-home at least 35 h in total.	iReadMore training in post-stroke central alexia resulted in an 8.7% improvement in reading accuracy for trained words, but did not generalize to untrained words. Reading accuracy improved by 2.6% more during anodal tDCS than sham. Reaction times also improved. Reading accuracy gains were still significant (but reduced) 3 months after training cessation.

the most studies were conducted were Korea ($n=8$) and the USA ($n=7$). Pilot studies ($n=10$), feasibility studies ($n=9$) and RCTs ($n=8$) were the most common research designs. The designs of the remaining 19 studies were case ($n=5$), survey ($n=1$), mixed method ($n=1$), cross-over ($n=1$), cohort ($n=2$), case-control ($n=3$), qualitative design ($n=1$), or comparative design ($n=5$).

The target area of the 46 included studies were assessment support ($n=16$), training ($n=25$), discharge ($n=2$), and 2 studies were targeted at supporting both discharge/education/information and training. Only 1 study targeted goal-setting, in addition to assessment and discharge support. No studies were related to the element "participation" using Wade's model of rehabilitation.

The number of participants varied from 1 to 426 stroke survivors, and the app solutions usage was between 1 occasion (assessment support) and 12 weeks (from 1–7 days a week, training support). A total of 23 studies included participants with chronic stroke, 16 studies included participants with acute and/or subacute stroke, while 5 studies included participants with 2 or 3 different onset of stroke. In 2 studies, stroke onset was not reported.

Thirty-three studies included participants with mild-moderate stroke, and only 4 studies included participants with severe stroke (2 studies included participants with severe aphasia, and 2 studies included participants with mild-moderate-severe aphasia). None of the studies included participants with severe motor deficits. In 9 studies the stroke severity was not reported.

The key characteristics of the included studies are shown in Tables I and II.

App solutions to support assessment (n = 16)

Of the 16 studies that investigated apps used in assessment support, 7 apps targeted physical activity (lower limb and mobility (n=5), upper limb (n=1) and pulmonary function (n=1)), 6 stroke severity, dependency, and cognitive function, 2 speech (aphasia) and 1 study addressed identification of unmet needs. Nine apps were used in a hospital or rehabilitation setting, 3 in both a rehabilitation setting and at-home, 3 were used at-home and for 1 app solution the setting was not reported. Five studies included participants with acute stroke, 7 studies included participants with chronic stroke, and 4 studies included participants from 2 or all phases. Participants with mild stroke were included in 7 studies, participants with mild-moderate stroke were included in 3 studies and participants with mild to severe stroke were included in 2 studies. Stroke severity was not reported in 4 studies.

Assessments of physical activity (n = 7). Capela et al. (41) developed a smartphone app to detect physical activity in stroke survivors. They found that the app was able to differentiate between lying, sitting, standing, and walking, but could not detect smaller movements and stair-climbing. Faria et al. (70) showed that neither an Actigraph accelerometer app nor the Google Fit app could provide valid measurements of energy expenditure among chronic stroke survivors during walking. However, Polese et al. (72) compared the same 2 app solutions and found that the Google Fit app could more accurately measure steps taken by chronic stroke survivors. Costa et al. (47), tested different app solutions (Google Fit, Health, STEPZ, Pacer, and Fitbit Ultra) ability to detect steps taken by chronic stroke, and found the solutions were reliable and not influenced by the paretic limb. Fell et al. (30) developed an app solution to support remote assessment of physical function supported by sensors. The authors concluded that the app was feasible and significant correlations were found between clinician and mobile app scores in all 4 tests, i.e. arm function and leg function of the National Institutes of Health Stroke Scale (NIHHS); Functional Reach test; and 10-meter walk test. However, in all the above studies, only participants with mild stroke and the ability to walk were included. Only 1 of the included studies, Kizoni et al. (46), targeted the assessment of upper limb deficits through app solutions supporting hand activity among stroke survivors. One of the included studies showed that an app solution was reliable to support the measurement of pulmonary function among chronic stroke survivors (71).

Assessments of stroke severity and cognitive function (n = 6). Six studies developed app solutions to support assessment of stroke severity, dependency and/or cognitive function. Li et al. (62) found agreement on ADL assessments (using the Modified Barthel Index), between home visit assessment and video-conference assessment though the mobile WeChat app (62). Meeuwis et al. (68) concluded that including the WhatsApp Messenger (a text messaging program) may be a useful contribution in the modern neurological examination to detect cognitive deficits (68). Chang et al. (43) and Cooray et al. (40) developed app solutions for assessment of disability/dependency after stroke, using the modified Ranking Scale (mRS). In both studies there was substantial consistency between the stroke survivors'/caregivers' and health professionals' assessments. In both studies, however, caregivers played an important role in supporting the stroke survivor to perform the assessment, because of cognitive challenges and/or inability to handle a mobile phone. Park et al. (56) found that it was feasible to assess cognitive deficits through the Facetime app, and Wall et al. (73) found that an app solution, used together with a virtual reality device, supported cognitive assessment among stroke survivors with and without aphasia.

Assessment of speech-related deficits (n = 2). Two studies developed app solutions to support the assessment of speech-related deficits. Choi et al. (27) and Guo et al. (69) found that app solutions were valid and reliable for remote assessment of aphasia in stroke survivors.

Assessment of unmet needs (n = 1). De Bartolo et al. (75) developed an app-based questionnaire to support the identification of unmet needs among chronic stroke survivors and to identify changes since discharge or last check-up. They concluded that the app was feasible and that it improved communication between stroke survivors and health professionals after discharge. Most participants were able to use the app by themselves, without support from a health professional or caregiver.

App solutions to support training/intervention (n = 27) Of the 27 studies that included apps aimed at supporting training, 9 targeted lower limb and balance, 5 upper limb or fine motor training, 8 speech training, 1 visual therapy, 2 targeted cognitive therapy, and 2 studies targeted both exercises and health-related information/education. Fourteen interventions took place in the home setting, 8 in a rehabilitation setting, and in 5 studies the setting was not reported. The apps were used for participants with acute stroke (n=4), subacute stroke (n=2), chronic stroke (n=16), subacute-chronic stroke (n=1), and acute-subacute-chronic stroke (n=2). For 2 studies, the stroke onset was not reported. The study participants' stroke severity was mild (n=8), mild-moderate ($n=14$), moderate ($n=1$), and severe ($n=1$). In 3 studies stroke severity was not reported.

App solutions to support lower limb and balance training ($n=11$). Nine studies were targeted at supporting physical training/intervention of lower limb/gait. Ciou et al. (50) found that drop-foot training using an app improved participants' ankle strength and dorsiflexion angle and their Timed up and Go score. Grau-Pellicer et al. (60) showed that an app improved the level of daily activity. The authors pointed out that the support of caregivers or researchers was of significance in achieving adherence to training. Kim et al. (25) showed that a smartphone-based metronome app improved gait, balance and stair climbing. Ko et al. (51) included the same metronome app to support gait training and found positive effects on gait after just 1 training session. In the studies by Shin & Song (61) and Shin (63) an app to support trunk and balance control among chronic stroke survivors was included in addition to conventional therapy, and improvements were found post-treatment in comparison with the control group. Paul et al. (28) found that chronic stroke survivors who used a tablet-based app at home increased their numbers of steps/day and reduced their level of fatigue. Also Sarfo et al. (57) found that physical activity through an app used at home resulted in improvements, although non-significant, in motor and cognitive recovery in chronic stroke survivors. Furthermore, the participants were satisfied with the intervention; however, internet connectivity and stability were a challenge in the Ghanaian context. Simpson et al. (45) found that training at home using a tablet-based app with prescribed exercises was feasible and safe, and participants adhered to both prescribed exercises and repetitions. Finally, 2 studies included app solutions that supported 2 elements of the rehabilitation process; Sureshkumar et al. (76) showed that a smartphone-based app containing both health-related information and prescribed exercises (using both videos and text) was found feasible and useful by acute stroke survivors and caregivers. Epalte et al. (78) also found the app useful in their home environment; however, the participants expressed the need for greater variety of exercises in the app, as well as a need for support in using the app solution.

App solutions to support upper limb training ($n=5$). Three included studies were targeted at supporting upper limb training. Jang & Jang (19) showed that chronic stroke survivors who trained with an app improved their hand and wrist function of the affected upper limb. Also, Lawson et al. (53) showed that chronic stroke survivors who trained at home with an app improved in many assessments post-treatment, though the results were not statistically significant. Chae et al. (74) included 17 participants with chronic stroke and found that a smart watch and a smartphone app can facilitate participation in upper-limb home rehabilitation and improve the functional score of the Wolf-Motor-Function-Test and shoulder ROM of flexion and internal rotation. Segura et al. (48) included 5 participants with chronic stroke and found a minimal clinically important improvement on upper limb motor function recovery when using a music-supported therapy app. Finally, Silveira et al. (24) included 1 stroke survivor who received a combination of functional electric stimulation (FES), music therapy and a tablet-based app. Authors found improvements in all assessments at discharge, which were maintained at 7 months follow-up.

App solutions to support speech training ($n=8$). Eight studies had developed app solutions to support training in relation to speech-related deficits. In a study by Ballard et al. (42) chronic stroke survivors improved their word production accuracy after having trained their speech using an app in addition to face-to-face visits. Participants expressed that they enjoyed the app training, but that regular contact with a speech pathologist was also important. Kondapalli et al. (52) included only 1 participant with severe aphasia in their study. Authors found improvements in communication speed and the app supported staff-patient communication. However, the setting and duration of training was not reported. Four chronic participants with aphasia also trained using an app at home in the study by Lavoie et al. (66). Significant improvements were found in naming of functional words, which were maintained 2 months post-training. In a study by Stark & Warburton (58) chronic stroke survivors with severe aphasia improved significantly after training with a tablet-based language therapy app. Woodhead et al. (77) showed that chronic stroke survivors who trained with an app at home improved reading accuracy of trained words, although not generalization to other words. Mallet et al. (54) included acute stroke survivors who used several tablet-based apps to train their speech. Most participants found the tablet-based therapy convenient. Cock et al. (46) also found a speech therapy app feasible to be used independently alongside conventional therapy by acute stroke survivors. Nef et al. (55) found high usability scores for an app with the aim to increase frequency and duration in training of stroke-related aphasia. However, the stroke severity, onset, and the setting were not reported.

App solutions to support cognitive therapy ($n=2$). Only 2 studies were targeted at supporting training of cognitive function. Kringle et al. (65) and Verna et al. (64) concluded that an app to support cognitive training was feasible. The setting was home training in the study of Kringle et al. (65), but not reported in Verna et al. (64).

App solutions to support discharge, knowledge of stroke and goal-setting (n = 5)

Five studies developed an app specifically aimed at supporting discharge and knowledge of stroke (22, 49, 67, 76, 78). In a study by Sureshkumar et al. (76) approximately half of the stroke survivors and caregivers found that the app provided very useful information about their problems, causes of the stroke, and ways to manage their recovery independently. Also, Epalte (78) concluded that the Vigo app was handy, provided understandable information, and supported participation in therapeutic activities. However, Kang et al. (22) found no significant difference between knowledge provided through an app or conventional stroke health education through a booklet. Siegel et al. (67) and Makle-Reid et al. (49) explored how an app could support a seamless communication between healthcare professionals and stroke survivors after discharge. In the study of Siegel et al. (67) only 2 patients were included, of which 1 was readmitted to hospital within 30 days after discharge. Nonetheless, both participants found the app solution useful in improving the coordination of healthcare after discharge from hospital. Markle-Reid et al. (49) included 30 participants with stroke and other comorbidities, and found the app solution to be feasible for both stroke survivors and the healthcare team that delivered outpatient rehabilitation, but found no statistically significant difference in patient health outcomes after 6 months' intervention. However, there was a significant reduction in the total per person use and costs of health services, especially a great reduction in hospital readmissions. Furthermore, this study used the app solution for several purposes; assessment, goalsetting, documentation, and communication within the health professional team as well as for providing health-related and educational material for both the health professional team and the stroke survivors/caregivers.

DISCUSSION

The aim of this scoping review was to describe and review the evidence regarding mobile/tablet and web-based apps used to support rehabilitation after stroke. A further aim was to describe participants' stroke severity and the use of apps in relation to setting and phase of the rehabilitation process. Of the 46 included studies, 16 included apps that would support assessment (stroke severity, language, motor deficits, etc.), and 25 studies supported training (lower limb and balance, upper limb, visual, cognitive and speech) among stroke survivors; however, none of these studies focused on compensatory strategies. Five studies included an app that supported health-related information/education and discharge (22, 49, 67, 76, 78). None of the 46 studies focused on supporting activities related to participation (e.g. social participation) and only 1 study focused on setting goals and continuously evaluating these (49). However, Lawson et al. (53) had a secondary goal focused on increasing participation through upper motor recovery. Likewise, optimizing the patients' language and motor abilities may have a positive effect on quality of life and social participation (28, 66). Even though app solutions supporting stroke rehabilitation are emerging, there is still a lack of research on the clinical effects of apps within post-stroke rehabilitation, which is reflected in the small number of studies, small sample sizes and study designs that involve mainly preliminary and feasibility results. In a review by Zhou et al. (31), 12 studies that integrated apps in post-stroke rehabilitation were included, with 5–48 participants. Only 2 of the 12 studies used a RCT design, and 9 studies showed positive effects regarding physical, cognitive and language function. However, neither the stroke onset or severity, nor the phase or setting in which the app was used was reported. In our scoping review, 23 studies included participants with chronic stroke, 16 studies involved participants with acute and/or subacute stroke, and 5 studies included participants with acute and/or subacute and/or chronic stroke. Two studies did not report stroke onset.

Of the 46 included studies, 21 took place in a rehabilitation setting, 17 in the participants' homes, and 3 in both settings. In 5 studies the setting was not reported. Of the 27 studies focusing on training, 14 studies were carried out in the home setting. With a shorter time on inpatient rehabilitation and reduced support from the health professionals, rehabilitation in the home setting has increased (79). Solutions that have shown positive effects on compliance and adherence to home training after discharge (45, 53) would be highly relevant and contribute to person-centred stroke rehabilitation. The use of apps can thus support stroke rehabilitation, promote self-management and empowerment in the later stages of the rehabilitation process (80). However, in the majority of apps targeting training in a home-setting, a health professional continuously supported/facilitated/adjusted/evaluated the home-training intervention using either face-to-face visits (66), and/or phone/Skype (42, 45, 48, 53, 57, 65, 74). In 2 studies support was supplied by significant others (58, 76) and in 1 study there was a lack of information regarding support (59). Since lack of continuous personalization of content and exercises may negatively affect adherence and motivation (78), it seems to be important that stroke survivors receive some kind of continuously customized support to maintain motivation, self-management and empowerment (45, 78) when interventions are delivered through an app.

Stroke rehabilitation based on mobile apps has the advantage of availability, convenience, and low cost (31). Several studies point out that apps are accepted among stroke survivors and significant others, even older patients without previous experience of using a tablet could utilize app-supported therapy (27, 44, 58). However, patients unable to use technologies due to motor or cognitive deficits are often excluded from studies (67) as shown in our scoping review. Given that 25% of stroke survivors are at risk of a new stroke or in life-long need of support (81), technologies supporting activity and participation should be taken into account (6, 7, 82). Stroke survivors who are cognitively challenged may require more training (69) and/or assistance from a significant other (54) to use the app independently. It is important to develop user-friendly apps with large text size, minimum user options, and step-by-step voice-guided directions (27). Furthermore, it should be considered how patients with limited hand function can make use of the app solutions, since double-clicking and zooming may be difficult (5, 44), although using touch screen-compatible gloves might assist.

Currently available apps have limited usability and focus, providing only one aspect of support in the rehabilitation process, such as clinical assessment or a narrow focus on exercise (30). Only three studies included in this scoping review aimed to support several components of the rehabilitation process (not only information regarding how to manage stroke-related deficits (video/text/pictures), but also discharge support, in addition to providing exercise programmes (videos and text) (76) and goal-setting (49). Stroke survivors, their significant others, and health professionals, have expressed a need for more timely information, a more coordinated cross-sectional transition from inpatient to outpatient rehabilitation, a better overview of the entire rehabilitation process, and improved follow-up and contact with health professionals after discharge (6, 7, 42, 82). An app solution aimed at supporting people with chronic diseases and accommodating patients' needs for a more comprehensive solution and a greater overview of the rehabilitation process has been tested in patients newly diagnosed with osteoporosis in Denmark (83). The app was shown to empower the patients by increasing adherence to medicine and training, and self-management of the disease (84). However, the app has not yet been tested within stroke rehabilitation and across different phases of the rehabilitation process. Future apps should accommodate stroke survivors' and significant others' needs for solutions, regardless of stroke severity and throughout the entire rehabilitation process (82).

Strengths and limitations

One strength of this scoping review was the broad literature search that resulted in a final total of 46 studies. The literature search was systematically conducted using selected databases based on relevant search terms. Although the database search was done with assistance from a librarian expert in the field, it is possible that some studies might have been missed due to lack of search terms. For example, 10 apps to support speech-related deficits (aphasia) was identified in the search. Knowing that a great research focus exists on this specific deficit, relevant studies may have been missed. However, searching all different stroke-related deficits was not the intention of this study. To get the latest published studies, a search alert was created for PubMed and CINAHL, which yielded only one further study. An updated search was therefore performed before submission, which resulted in an additional 11 studies to this scoping review. However, studies written in other languages than English, as well as studies that could not be retrieved, constitute a selection bias. A further strength was that 2 authors and a research assistant determined which studies to include, and 2 authors extracted chosen variables on the data-charting form, while bearing in mind that the extracted data was to be presented in a structured way. Disagreements on inclusion or exclusion of an abstract or full text were resolved by discussion and reaching a consensus (33). These steps increased the reliability of the study. Another strength was that transparency of the literature search and selection process throughout the study was ensured, rendering it replicable (32). The studies included had a large variation in study designs. Therefore, it was not possible to give a more specific summary of the results. However, this was not the intention; the aim was broad: we wanted to find numerous studies to present the state-of the art regarding the current use of apps in stroke rehabilitation. A further limitation, often mentioned when doing scoping reviews, is that studies with few participants are included. Three studies in this scoping review concluded that the app solution was feasible, based on only 1 or 2 participants (24, 52, 67). However, due to the heterogeneity of included studies in a scoping review, assessment of the quality of included studies was not the aim. Also, in some of the included studies stroke severity (mild, moderate, severe) was either not mentioned, or lacked detail on how it was defined or measured. A final limitation of this scoping review was the lack of a prespecified study protocol.

Conclusion

This scoping review provides an overview of studies that include mobile/tablet and web-based app solutions to support stroke rehabilitation. In all but one study, the app targeted only one element of the rehabilitation process: usually assessment or intervention/training. Future app solutions to support stroke rehabilitation should also include participants with severe cognitive and motor deficits and should support stroke survivors and their significant others throughout the entire rehabilitation process.

Knowledge from this scoping review may have important implications for researchers and policymakers in their consideration of how and which app solutions may support stroke rehabilitation. In future studies, stroke survivors and significant others should be involved in the development of person-centred app solutions.

Rehabilitation implications

- Stroke rehabilitation can be supported by using mobile/tablet and web-based applications.
- Most developed applications focus on either assessments, supporting training or discharge from hospital.
- Applications to support the stroke survivors and the significant others throughout the entire rehabilitation process are needed.
- Most of the applications supporting stroke rehabilitation are addressed to people with mild to moderate stroke.
- People with severe stroke should be included in future research on the use of applications to support stroke rehabilitation.

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