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Exergame for the functional rehabilitation of adults over 55 with neurological diseases

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ABSTRACT. Rehabilitation based on Exergame is showing a rapid evolution, with interesting applications for the recovery of mobility, balance, postural control, coordination and fine motor skills, and including home-based training. At present, there are no precise indications for Exergame-based rehabilitation of people over 55 affected by stroke, Parkinson's disease, or multiple sclerosis. This review examines the proposed modalities and the effectiveness of Exergame-based rehabilitation interventions for adults over 55 with stroke, Parkinson's disease or multiple sclerosis, highlighting the limitations, advantages, controversies and impact of this approach. We examined randomized controlled trials published between 2016-2020, with search in the databases of PubMed, Scopus, Cochrane Library, RehabData, selecting 24 studies. The study of patients with chronic or subacute stroke in outpatient treatment, and with small sample sizes, prevails. Wide variability characterizes the rehabilitation methods, the technological platforms used, the type and dose of exercise administered, the outcome measures. The adequacy and efficacy of Exergames remains uncertain in the neurological elderly, and the functional improvement in the neurological adult patient is not yet attested using this type of approach.

Key words: *Exergame, functional rehabilitation, virtual reality, neurological diseases, outcome measures.*

RIASSUNTO. Exergame per la riabilitazione funzionale di adulti over 55 con malattie neurologiche. La riabilitazione basata su Exergame sta mostrando una rapida evoluzione, con interessanti applicazioni per il recupero della mobilità, dell'equilibrio, del controllo posturale, della coordinazione e della motricità fine, comprendendo il contesto dell'allenamento domiciliare. Al momento, non esistono indicazioni precise per la riabilitazione basata su Exergame di soggetti over 55 colpiti da ictus, malattia di Parkinson, o sclerosi multipla. Questa revisione esamina le modalità proposte e l'efficacia degli interventi riabilitativi basati su Exergame per adulti over 55 con ictus, morbo di Parkinson o sclerosi multipla, evidenziando i limiti, i vantaggi, le controversie e l'impatto di questo approccio. Sono stati esaminati studi randomizzati controllati pubblicati tra il 2016-2020, con ricerca nei database di PubMed, Scopus, Cochrane Library, RehabData, selezionando 24 studi. Prevale lo studio su pazienti con ictus cronico o subacuto in trattamento ambulatoriale, e con dimensioni piccole dei campioni. Ampia variabilità caratterizza le modalità riabilitative, le piattaforme tecnologiche utilizzate, il tipo e la dose di esercizio somministrato, le misure di esito.

Introduction

The use of technology, including exergaming (EG), is rapidly increasing in functional rehabilitation, also of the older adult. Recent studies have highlighted positive aspects regarding the rehabilitation use of this type of technology, diversified and potentially very broad.

EG are video games that combine real-time motion detection and feedback about performance, to promote physical condition and practice of simulated functional tasks. The participant's movements, detected by special sensors or through an external controller, animate an avatar on the screen/monitor representing the player involved in different type of games. Several options of changing the virtual environment and objects, task difficulty level, and adapt the specific task to the user requirements are provided. Minimum risk and ludic aspects of gaming may augment motivation toward motion and fulfilment of objectives. This technology can deliver multisensory, task-oriented exercises that are promising in the rehabilitation process of neurologic disorders. The multisensory feedback boosts motor learning and facilitates cortical reorganisation, thereby facilitating the recovery of functions and activities.

EGs have emerged as therapeutic approaches in clinical settings, providing improvements in the functions of the upper limbs, in daily activities (1,2) and in gait (3) in post-stroke patients and in motor symptoms (4) and balance (5) in patients with Parkinson's disease (PD). EG treatment also allows for long-term exercise planning, which is useful for reducing the impact of multiple sclerosis (MS) related disorders in adults. Commercial interactive gaming system such as Wii (Nintendo, 2006) and Kinect (Microsoft, 2010), designed for an entertaining purpose of a 'typical' healthy user, found to be effective when used in rehabilitation programs to assist in patients' recovery of motor function (6).

The Wii, with variety of games enabled through its peripheral devices (Wii Remote and Wii Balance Board), has been used with the Wii Fit for physical activity conditioning (7) and balance rehabilitation (8) in people with MS (9), stroke (1,10-12) and subacute stroke (13).

The Kinect system, inclusive of hands-free interface device (Kinect sensor) compatible with the Xbox 360 and

L'adeguatezza e l'efficacia degli Exergames rimane incerta negli anziani neurologici, ed il miglioramento funzionale nel paziente neurologico adulto non è ancora attestato utilizzando questo tipo di approccio.

Parole chiave: Exergame, riabilitazione funzionale, realtà virtuale, malattie neurologiche, misure di esito.

Xbox One console, and leveraging the creation or adaptation of new games by open source software, proved reliable for assessment of postural control and training of muscle tone and power in post-stroke patients (14).

EG rehabilitation leads to improvement of gross body (15) and upper body mobility (16), with benefits transferred also to daily activity (17-20), and rehabilitation learning sustained up to 3 (15) and 6 months (21). Effects are particularly evident for EG training applied in addition to conventional therapy, while limited generalizability of results prevents to reach conclusions on mobility outcomes when EG administered alone (19).

Few EG systems have been developed specifically for rehabilitation purposes. Among these, Serious Games are systems involving cognitive and motor tasks, developed to support rehabilitation. Robotic systems, ranging from simpler end effector to more complex exoskeleton, are particularly promising in sensorimotor rehabilitation.

In the practice of occupational rehabilitation, most therapeutic interventions aim at the recovery of function by the adult suffering from diseases such as stroke, PD or MS. The use of rehabilitation technologies based on EG can represent an advantage for the use of resources and for the different possibilities of administering the exercise. Although technological rehabilitation can be generally considered a safe treatment, there is no complete overview of the functional rehabilitation approach with EG for the older adult. Many issues, such as best dose of therapy, timing, and types of programs, individual adaptation of treatment, long-term sustainability of effects, remote administration, safety related concerns, and others, are yet to define clearly.

In this review, we consider the adequacy and efficacy aspects of Exergame treatments for the functional rehabilitation of the adult with stroke, PD, or MS.

Methods

A literature search was undertaken between August and October 2020 in the international online bibliographic databases PubMed, Scopus, Cochrane Library, RehabData, using the keywords: *(exergame OR active video game) AND (elderly OR older adults) AND (rehabilitation OR occupational therapy)*. The identification, screening, eligibility and inclusion of studies were performed following the 2009 Prisma flowchart. Two reviewers (a physician and a research assistant) conducted the search independently. Articles that met the following criteria were included in the review: published since 2016, randomized controlled trial, focusing on the use of exergames or active video games/virtual reality rehabilitation of older adults (mean age ≥ 55 years old) affected by neurological disease (stroke, Parkinson's disease, multiple sclerosis), written in English and with full text available online.

Articles were excluded if they were review, if focused at improving cognitive tasks, considered other pathologies, healthy or frail subjects, or did not describe any rehabilitative intervention.

The title and/or abstracts of the studies were scanned for the study objective, study population, exergame platform, training procedure, measurement. Borderline cases (such as studies with participants' age not fully corresponding to that supposed), were evaluated according to their contribution to knowledge.

A scoring sheet was developed on a Microsoft Excel for the full-text review. Data were sorted in categories, including participants (population, main selection criteria, number of subjects, and participants age), study (methodology, location, and focus), game technologies and exercises (gaming system, games, exercise, playtime, frequency and duration), and measure of evaluation (outcomes and results).

The methodological quality of the included studies was evaluated by a classification system, the Jadad Scale (Oxford quality scoring system) (22) commonly used by the health care community, according to randomization, blinding, and drop out. In this scoping review the methodological quality of the studies did not determine their inclusion or exclusion.

Results

A total of respectively 83 and 50 articles were found in the databases by the two reviewers (searching phase, Aug-Oct 2020), reduced to 30 potential eligible studies after exclusion based on title and abstract (screening phase, November 2020). Disagreements over inclusion was resolved by consensus after referring to criteria and relevant theoretical and empirical issues. Eventually twenty-four studies were eligible by both reviewers, and included in the review (Table I).

All studies, except one with "virtual reality" in the title (24), included keywords such as *exergame, videogame, virtual reality, virtual rehabilitation, rehabilitation games, Nintendo Wii, Kinect, biofeedback, proprioception, balance training-rehabilitation.*

Although our main focus was on EG, we included 18 articles (75%) with "Virtual Reality" in the text and / or in the title. In this review indeed, we use the term virtual reality (VR) referring to EG features.

The studies were published in 2016 (three), 2017 (seven), 2018 (six), 2019 (seven), and 2020 (one), from America (eight), Europe (six), East (seven) and Middle East (three). All studies were RTC, randomized controlled trial, (with five pilot study). The methodological quality of RCTs assessed by the Jadad scale was high in 70% of cases. Majority of studies (fifteen) focused on chronic or subacute stroke (including haemiplegia), eight focused on Parkinson's disease (PD), and one study on multiple sclerosis (MS).

Table I. *Summary of the studies: details of experimental (ExpG) and control (CtrlG) groups, type of intervention and duration, primary and secondary outcome measures, key results, unattained goals, and hints for future investigations* (see common legend)

Study	Participants	Intervention	Outcome measures **Primary** / Secondary	Key results ExpG	Unattained goals / Drawbacks *Hints for future investigations*
Henrique et al (2019) Brazil	• Total n. = 31 • Age ExpG (yr) = 74.10 (SD 10.09) • Gender ExpG = 7M, 9F • Pathology = Stroke	**Individual, supervised, outpatient** • ExpG = Protocol based on Passarelli et al. (RE?): exercise simulated 6 activities where user must move hands, upper limb, lower limb and torso during standing, with different difficulty level (30 min PT, 2/wk x 12 wk). • CtrlG = Similar protocol of conventional rehabilitation (30 min PT, 2/wk x 12 wk).	• Balance = **BBS** • Upper limb motor function = **FMA**	• BBS and FMA improved significantly in both groups after rehabilitation. • ExpG showed better (non significant) balance results than CtrlG, with the same intervention time. • Significant differences between the two groups, in changes from pre-intervention to post-intervention values (shoulder, elbow, forearm, and total variables), same treatment time.	No improvement in the rehabilitation of the hemiparetic hand. *Evaluate lower limb motor function;* *Evaluate patient's engagement;* *Include other pathologies;* *Intervention group combining the 2 therapies;* *Interest for multicentric study.*
Sheehan et al (2019) Canada	• Total n. = 18 • Age ExpG (yr) = 42.2 (SD 9.5) • Gender ExpG = 5 M, 4 F • Pathology = Stroke	**Individual, supervised, outpatient** • ExpG = Unilateral and bilateral UE training in all planes to perform five UE activities against gravity 2(-) min PT, 2 or 3/wk x 4 wk) + Usual rehabilitation (occupational and physical therapy). • CtrlG = Traditional therapy session (occupational and physical therapy) 2 or 3/wk x 4 wk).	• Upper limb motor function = **FMA-UE, BBT** • Self-reported health status = **SIS** • Self-reported measure of UE use = **MAL (MAL-AOU, MAL-QOM)** • Feasibility and safety= session time and adverse event.	• MAL-QOM: significant difference between groups in T1 (post intervention) compared to the CtrlG, but not in T2 (4w follow-up) • Significant MAL-QOM score from baseline in ExpG. • Significant difference in mobility domain of the SIS and SIS-Physical between the two groups. • SIS-Total significant changes in ExpG from baseline to post-treatment and were still present at T2.	No recorded finger movements. *Need more patients;* *Stratify patients with different clinical characteristics;* *Evaluate patients' perception and satisfaction;* *Understand the relationship between patient characteristics and how gains are maintained over time;* *Long-term follow-up;* *Identify the ideal treatment intensity and duration.*
Hung et al (2019) Taiwan	• Total n. = 33 • Age ExpG (yr) = 56.58 (45.88-AA.25) • Gender ExpG = 12M, 5F • Pathology = Stroke	**Individual, supervised, outpatient** • ExpG = Shoulder and elbow movement training to perform 8 games both bimanual and unimanual (30 min PT, 2 or 3/wk x 12 wk) + ADL training (15 min) and conventional hand function training (30 min) • CtrlG = Therapist-based training with variety of bilateral or unilateral UE movement training (30 min PT, 2 or 3/wk x 12 wk).	• Upper limb motor function = **FMA-UE** (PROXIMAL and DISTAL), WMFT-TIME, WMFT-FAS, MAL-AOU, MAL-QOM. • Participation = PRPS, accelerometry.	• No between-groups differences for any scores, either post-intervention or at the 3m follow-up point. • The ExpG showed significant improvements in FMA-UE, FMA -PROX, and FMA-DIS, in WMFT-TIME and MAL (AOU and QOM). • The CtrlG only showed significant improvements in FMA-UE and FMA-PRO and WMFT-TIME. • At 3m follow-up both groups shows significant improvement in FMA-UE (P=0.015), FMAPROX (P=0.01) and WMFT-TIME, and CtrlG also WMFT-FAS.	Functional gain in MAL not maintained at the 3-month follow-up. *Analyze the low retention effect in the participation domain for ExpG.*
Ferraz et al (2018) Brazil	• Total n. = 62 • Age ExpG (yr) = 67 (SD 1) • Gender ExpG = 10M, 10F • Pathology = PD	**Individual, supervised, outpatient** • ExpG = Strength and muscular endurance, cardiorespiratory fitness, postural balance, and executive function exercise to perform 1 or 2 mini-games repeated in different levels of intensity, each lasts about 3 min. (30 min PT, 3/wk x 8 wk). • CtrlG = functional training or aerobic training on a stationary bicycle with progressively increasing of maximum heart rate (40 min PT, 3/wk x 8 wk).	• Walking capacity = **6MWT** • Gait speed = 10MWT • Lower limb strength and power = SRT • Body fat composition = BMI and abdominal circumference • Perception of functional capacity = WHODAS 2.0 • Quality of life = PDQ-39 and EuroQol-5D • Perception of functional capacity = GDS	• All groups showed significant improvements in 6MWT, SRT, and WHODAS 2.0. • Only ExpG demonstrated significant improvement on gait speed performed in 10MWT. • Functional trainingG and ExpG improved the perception of quality of life and no groups decreased body mass index significantly. • Only BicycleG and ExpG obtained a significant difference in reducing abdominal circumference. • No significant differences were found among the 3 groups in any outcomes.	Non-significant result between groups on 6MWT. *Functional outcome and MFT measures;* *Need a control of cardiac performance during all proposed interventions;* *Needs to study the effects of different modalities of exercise program;* *Need more patients.*
Cikajlo et al (2019) Slovenia	• Total n. = 20 • Age ExpG (yr) = 67.6 (SD 7.6) • Gender ExpG = 5M, 5F • Pathology = PD	**Individual, supervised, outpatient** • ExpG = 3D visualization hand movement training with a pick and place task in the virtual world requiring manipulate virtual cubes (30 min PT, 10 session within 3 wk). • CtrlG = 2D visualization (on LCD) hand movement training with a pick and place task in the virtual world requiring manipulate virtual cubes (30 min PT, 10 session within 3 wk).	• Kinematics hand temporal and spatial parameters= **TRTIE, ATuM, TNoT, IB, ATI. BBT, UPDRS** • Motivation = **IMI** • Upper limb motor function = UPDRS, BBT	• Substantial differences between the first and the last session for each group. The differences were statistically significant for ATUM, IB and ATI. • Significant differences between the first and the last session for the "perceived competences" measure scale (IMI). The ExpG increase in effort/importance and the CtrlG improved in pressure/tension in the last session.	BBT and UPDRS not statistically significant between the groups before and after. The immersive 3D equipment (glasses) may not be appropriate for every person with PD. *Need more patients and need to increase compliance.*
Shih et al (2016) Taiwan	• Total n. = 20 • Age ExpG (yr) = 67.3 (SD 9.94) • Gender ExpG = 9M, 1F • Pathology = PD	**Individual, supervised, outpatient** • ExpG = balance-based exergaming intervention including reaching activities, weight-shifting activities and marching activities, with progressively increasing level of difficulty (30 min PT, 2/wk x 8 wk). • CtrlG = conventional balance training session including reaching activities, weight-shifting activities and marching activities, with progressively increasing level of difficulty (30 min PT, 2/wk x 8 wk).	• Postural stability = **LOS, OLS (CoP)** • Functional balance = **BBS, TUG**	• Functional balance (BBS and TUG) improved significantly in both groups post training compared with pre-training. • ExpG significantly improved LOS performance and OLS on the less affected leg in the eyes-closed condition. • ExpG compared with CtrlG exhibited better performance in directional control of LOS post-training.	Conventional balance training did not reach the minimal detectable change in patients with PD. Results not generalizable. *Need more patients;* *Reduce possible error in data normalization due to calibration variability during session preparation;* *Revise patient selection (include others who have a more marked level of deficit, or a non-high baseline level of performance).*

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Tabella I. *(segue)*

Study	Participants	Intervention	Outcome measures **Primary** / Secondary	Key results ExpG	**Unattained goals / Drawbacks** ***Hints for future investigations***
Gandolfi et al (2017) Italy	• Total n. = 76 • Age ExpG (yr) = 67.45 (SD 7.18) • Gender ExpG = 23M, 15F • Pathology = PD	**Individual, supervised, home with skype telerehabilitation** • ExpG = in-home VR-based graded balance training with the Nintendo Wii Fit system (TeleWii) (50 min PT, 3/wk x 7 wk) • CtrlG = in-clinic sensory integration balance training (SIBT) (50 min PT, 3/wk x 7 wk)	• Postural control = **BBS** • Perceived level of balance confidence in ADL = ABC • Gait = 10MWT, DGI • QoL = PDQ-8	• Significant between-group differences found only for BBS scores. • Both groups showed an overall significant improvement at the end of treatment and at 1m f-up, as measured on the ABC, 10-MWT, DGI, and PDQ-8. • No statistical significant difference in satisfaction rates.	No measures of muscle strength and body mass; Results not generalizable if pts with cognitive deficits. *Consider the effects of training regarding biomechanical constraints that can affect balance such as muscle strength and lean body mass.*
Mugler et al. (2019) USA	• Total n. = 32 • Age ExpG (yr) = 58.5 (SD 19.4) = 60 (SD 7.2) • Gender ExpG = 10M, 13F • Pathology = Stroke	**Individual, outpatient** • ExpG = 3-muscle pairs isometric MyoCI training session (60 or 90 min PT, 1/wk x 6 wk) • CtrlG = 3-muscle pairs movement-based MyoCI training without arm restraint (90 min PT, 1/wk x 6 wk)	• Upper limb motor function = **FMA-UE at 6w**, WMFT • Spasticity = MAS • Elbow range-of-motion at weeks 6 and 10 = ROM • Amount and quality of home-based function = MAL-30	• MyoCI training of 3 muscle pairs significantly reduced impairment (FMA-UE) from baseline to week 6 in each group, and gains persisted at 1 month after training stopped. • No significant differences between groups. • Participants' lab-based and home-based function also improved at weeks 6. • Spasticity also decreased over all subjects and elbow range-of-motion improved. Both moderately and severely impaired patients showed significant improvement.	No effects of stroke type and mixed effects of stroke location on outcomes because of limited lesion localisation; No differences between groups. *Need more patients;* *Consider the patient's active control over the game mode;* *Consider the use of wearable device.*
Lee et al (2018) South Korea	• Total n. = 30 • Age ExpG (yr) = 61.80 (SD 6.85) • Gender ExpG = 9M, 6F • Pathology = Stroke	**Individual, supervised, outpatient** • ExpG = three sessions of game-based virtual reality canoe paddling training (30 min PT, 3/wk x 5 wk) + conventional physical and occupational rehabilitation program aimed at improving balance, lower limb strength and ADL (30 min PT, 10/wk x 5 wk) • CtrlG = conventional physical and occupational rehabilitation program aimed at improving balance, lower limb strength and ADL (30 min PT, 10/wk x 5 wk)	• Postural balance = **mFRT** and **postural sway test** (CoP, PL, SV) • Upper limb motor function = **MFT**	• Postural balance and upper extremity function showed significant improvements in both groups when compared with the baseline (only mFRT and SV in CtrlG). • The experimental group showed significantly more improvement than the control group in mFRT, SV and MFT.	No control over the intensity of conventional rehabilitation training; No placebo in CtrlG. *Ameliorate blinding study design;* *Quantify the intensity of traditional rehab program;* *Include a comparison between task-oriented training and VR training;* *Include long term F-up.*
Rowe et al (2017) California	• Total n. = 30 • Age ExpG (yr) = 56 (SD 11) • Gender ExpG = 9M, 6F • Pathology = Stroke	**Individual, robot assistance, outpatient** • ExpG = high assistance finger training while controlling the number, amplitude, and exerted effort of training movements (60 min PT, 3/wk x 3 wk) • CtrlG = low assistance finger training while controlling the number, amplitude, and exerted effort of training movements (60 min PT, 3/wk x 3 wk)	• Motor function = **BBT at 1m**, FMA, Lateral Pinch Strength, 9HPT, WMSS • Motivation, self-efficacy, and depression = IMI, BDI, GDS • Finger proprioception	• BBT and FMA improved significantly over time. • There was no effect of group for any outcome measure. • Group effects became significant when examined as a function of time for the FMA and the Lateral Pinch Strength Test. • Motivation was significantly higher for participants in the high-assistance group.	Finger proprioception did not vary significantly; Higher level of robotic assistance could reduce patient's attention; High percentage of haemorrhagic stroke survivors among participants; Small benefits of assisted grip; No task-specific training associated; Patient's attention not considered; Evidence of only small differences, and only in FMA, pinch, and in secondary endpoints. *Promote the spontaneous use of the impaired limb with the robot;* *Analyse the effects of attention.*
Tollár et al (2018) Hungary	• Total n. = 74 • Age ExpG (yr) = 70.0 (SD 4.69) • Gender ExpG = 12M, 13F • Pathology = PD	**Small group (4-6), supervised, outpatient** • ExpG = agility exergaming (EXE) (60 min PT, 5/wk x 5 wk) • CtrlG1 = stationary cycling (CYC) exercise training in a "spinning class." (60 min PT, 5/wk x 5 wk) • CtrlG2 = habitual activity	• Patients' mobility and clinical symptoms = **UPDRS-II** • Life domains, QoL = SE-ADL, EQ-5D, PDQ-39, BDI • Gait and balance = TAT • Balance control = BESTest • Fall risk = BBS test • Gait adaptability = DGI • Walking capacity = 6MWT • Postural stability = standing posturography (CoP)	• After treatment, UPDRS-II scores improved but changes did not differ between ExpG and CtrlG1 but differ respect CtrlG2. • BESTtest, TAT, the Dynamic Gait Index, EQ5D sum, 6MWT PDQ mobility and 8 out of 8 posturography measures improved in ExpG and CtrlG1 similarly with no change between ExpG and CtrlG1. • depression was reduce similarly in ExpG and CtrlG1. • ExpG resulted better than CtrlG1 in improved SE-ADL, BBS and 2 measures of posturography. • BESTtest, TAT, the Dynamic Gait Index, and 4 out of 6 posturography measures did not change.	Motor and non-motor symptoms improved regardless of the exercise stimulus; Short duration, hospital setting only. *Promote longer duration of trias;* *Introduce home-based exercises;* *Consider the executive function as a moderator of mobility improvement;* *Consider neural, biomechanical, or behavioural markers to determine whether EXE and CYC affect mobility and clinical effects through different mechanisms.*
Givon et al (2016) Israel	• Total n. = 47 • Age ExpG (yr) = 56.7 (SD 9.9) • Gender ExpG = 11M, 12F • Pathology = Stroke	**Small group (6-8), supervised, outpatient** • ExpG = five video-game consoles alternatively: Microsoft Xbox Kinect, Sony Play-Station 2 Eyetoy, Sony PlayStation 3 MOVE, Nintendo Wii Fit and the SeeMe VR system (60 min PT, 2/wk x 12 wk) • CtrlG = Fitness and Mobility Exercise Program, the Graded Repetitive Arm Supplementary Program and the task-oriented intervention (upper and lower extremity movements, stretching, marching and arm swings, walking, functional activities such as picking up and transferring objects) (60 min PT, 2/wk x 12 wk)	• Feasibility = **compliance** (session attendance - percentage attended out of 25 sessions), satisfaction level (questionnaire) and **adverse effects** (monitoring) • Efficacy: **Gait speed, Grip strength = 10MWT, Jamar Dynamometer** (hands, kg) • Physical activity = steps/day • Functional ability of the upper extremity = MAT	• High treatment compliance for both interventions, but satisfaction rated higher for the ExpG. • Significant within-subject effects found for gait speed, demonstrating an improvement for both groups between pre to post evaluations, not maintained at 3m follow-up. • Significant improvement for both groups in grip strength of the weaker and stronger hand between pre to post and pre to 3m follow-up measurements. • There was no significant change in secondary outcome measures (Daily steps and functional ability of the weaker hand did not increase in either group).	Heterogeneous control group. *Include more walking in the training;* *Intensity information, such as perceived exertion, should be added;* *Consider the role of the caregiver for group video exergaming.*

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Tabella I. *(segue)*

Study	Participants	Intervention	Outcome measures **Primary** / Secondary	Key results ExpG	Unattained goals / Drawbacks *Hints for future investigations*
Lupo et al. (2018) Italy	• Total n. = 15. • Age ExpG (yr) = 52.56 (SD 13.02) • Gender ExpG = 6M, 3F. • Pathology = Stroke.	**Individual, supervised, outpatient** • ExpG = Balance training with biofeedback and simulate ADL (30 min PT, 3/wk, 10 sessions). • CtrlG = Conventional balance rehabilitation training for the recovery of independence in ADL based on the use of stable sur-faces (i.e. steps) and unstable ones (i.e. oscillating tables and balls of different sizes.) (30 min PT, 3/wk, 10 sessions).	• Balance = **BBS, Stabilometric parameters** (CoP OE, CE) • Mobility = **RMI**. • Global disability = BI • Severity of the stroke = **NIHSS, CNS** • Compliance = PRPS.	• The ExpG group showed a significant improvement in balance skills compared with the CtrlG group (BBS) even after 30 days from EI. • Significant regression of signs and symptoms (NIHSS) was observed in ExpG versus the CtrlG. • Stabilometric tests showed a significant reduction of COP trajectory in both the OE (COP-OE) and CE (COP-CE). • Level of participation in the rehabilitation program was greater in the ExpG group.	Small group; No multidimensional assessment with gait and dynamic balance evaluation. *Evaluate efficacy in patients affected by moderate stroke or other pathologies in which balance is impaired, such as cerebellar ataxia and/or PD.*
Kannan et al. (2019) USA	• Total n. = 25. • Age ExpG (yr) = 57.5 (SD 8.04). • Gender ExpG = 7M, 6F. • Pathology = Stroke.	**Individual, supervised, outpatient** • ExpG = balance cognitive motor (Dual Task, DT) exergame training (CMT) with Wii-Fit games in conjunction with cognitive tasks (11 min PT, 20 sessions over 6 wk). • CtrlG = Conventional customized, progressive balance, endurance and strengthening training (60 min PT, 20 sessions over 6 wk).	• Balance control = **LOS-MVL** for volitional balance, **COM position and velocity, COM state stability** for reactive balance during perturbation • Cognitive = **LNS for WM**, attention + processing speed • Dual-task condition = **SPT** and **LOS with LNS** • Clinical balance = BBS, 6MWT, TUG, 10MWT, cogTUG, Chair stand test, 4step square test, ABC. • Cognitive-motor exergaming scores = games scores	• Post intervention, under DT reactive conditions, ExpG improved both motor (MVL, LNS) and cognition, while the CtrlG improved motor alone. • Under DT volitional conditions, motor performance improved only in ExpG. • Significant increase in COM state stability from pre to post training demonstrated for both groups, without groups differences. • Significant improvement in all clinical balance measures score in pre-post training for both groups. • Significant increase in scores Bubble Balance, TableTilt, Basic Step, and Light Run ExpG only.	Results from the Category Fluency task were not considered during analysis due to the lack of data for some participants; Small group, with light deficit. *Involve individuals in acute and subacute stages of stroke.* *Involve individuals with mild cognitive deficits to examine any effects of the paradigm for cognitive-motor interference.*
Jonsdottir et al. (2018) Italy	• Total n. = 16. • Age ExpG (yr) = 55.4 (SD 7.7). • Gender ExpG = 3M, 7F. • Pathology = MS.	**Individual, inpatient and outpatient** • ExpG = Serious Games based upper extremity therapy with Virtual reality, to improve movement coordination, reaction speed and timing, hand-eye coordination and spatial awareness (40 min PT, 4-5/wk, 12 sessions over 4 wk) + usual rehabilitation services. • CtrlG = Exergames training to improve timing, dexterity, hand-eye coordination, perceptual skills and spatial awareness (40 min PT, 4-5/wk, 12 session over 4 wk).	• Activity level fine and gross arm and shoulder movements = **9HPT, BBT**. • User experience indicators = EQ-VAS, SF-12.	• ExpG had a clinically and statistically significant increase in velocity of fine pinch, grasping and releasing movements of the treated hand as measured by the 9HPT but there was no significant between groups treatment effect for either test. • Only CtrlG had a significant increase in perception of health (EQ-VAS) and significant improvement in the physical domain of the SF-12: mental domain. • Significant between groups treatment effect only in perception of health (EQ-VAS).	Small group; No significant difference between groups; No motivational effect of the serious games. *Test serious games in the home-based setting.*
Thielbar et al. (2020) USA	• Total n. = 20. • Age ExpG (yr) = 59.7 (SD 10.5). • Gender ExpG = 17M, 3F. • Pathology = Stroke.	**Multiple or Individual, home-based** • ExpG = First SU: home-based single-user (SU) VR upper extremity therapy (60 min PT, 4/wk x 2 wk) + MU mode (60 min PT, 4/wk x 2 subsequent wk) → 16 session over 4 wk. • CtrlG = First MU: home-based multiuser virtual reality (VR) upper extremity therapy (MU) (60 min PT, 4/wk x 2 wk) + SU mode (60 min PT, 4/wk x 2 subsequent wk) → 16 session over 4 wk.	• Calculated **Total Arm displacement** • **Session duration**. • Upper limb function= FMA-UE • Time spent using each MU and SU • Compliance = IMI	• Arm displacement during a session was significantly affected the mode of therapy. • While arm displacement was seen in both groups, the First MU group tended to produce more than the First SU group. • Compliance was very high (99% compliance for MU mode and 89% for SU mode). • Participants spent significantly more time training in the MU mode than in the SU mode. • Participants in the First MU group generally had longer sessions, no significant. • FMA-UE score improved significantly in both groups. • Scores for the IMI rated higher for the MU mode than the SU mode, but no statistically significant differences were present between groups.	Participants' use of a standard screen may have adversely affected the results; No long term FU; Finger movement not monitored. *Add finger exercises and hand grasping activities;* *Use 3D monitors/televisions to enhance interaction;* *Evaluate effects of e-motivation (BREQ-2 scale).*
Song et al. (2018) Australia	• Total n. = 60. • Age ExpG (yr) = 68 (SD 7) • Gender ExpG = 15M, 16F • Pathology = PD	**Individual, initially supervised than alone, home-based** • ExpG = step, balance, cognitive load VR open-source Dance Revolution "Stepmania" game (15 min, 3/wk x 12 wk) + usual healthcare. • CtrlG = no intervention, usual healthcare.	• Stepping performance= **choice stepping reaction time Test** • Gait= **FGA** • Phys, neuropsych measures, n falls, self-report mobility and balance: Hip abductor muscle power, TUG, MCA, TMT A-B, NFGQ, FESq.	• No differences between ExpG and CtrlG in primary or secondary outcomes except for the Timed Up and Go test, (more in the control group). • ExpG perceived improved mobility, decrement in TUG. • Interaction effects seemingly positive effects for the low severity group. • minimally supervised ExpG in mild-mod PD is feasible (high compliance 86%), has differential impact by severity of disease.	Small group (high functioning people); No overall short-term positive effects on physical and cognitive function; No FU; Insufficient amount of practice; EG adequate to the severity of disease? *Investigate the influence of training dose and disease severity;* *Determine if greater supervision and personalization of the intervention would be more effective than minimal supervision;* *Assess long-term effect.*
Park et al. (2017) South Korea	• Total n. = 20. • Age ExpG (yr) = 62.80 ± 17.16 • Gender ExpG = 5M, 5F. • Pathology = Stroke.	**Individual, supervised (+safety harness), inpatient** • ExpG = Xbox Kinect (30 min, 7/wk, 6 wk) + 30 min of conventional PRT. • CtrlG = Conventional strengthening, functional, balance and gait training PRT (30 min, 7/wk x 6 wk).	• Lower limb motor recovery= **FMA** • Balance= BBS • Gait= TUG, 10mWT	• Scores on FMA-LE, BBS, TUG, and 10mWT improved significantly in both groups. • The pre-to-post difference scores on BBS, TUG, and 10mWT for the ExpG were significantly more improved compared with CtrlG. • VR training improves motor function.	Different training dose in the two groups; Participants were patients at first stroke and w/o cognitive deficit; Possible error in feedback of Kinect due to the limitations of the sensor to differentiate the participant from the therapist providing assistance. *Correct the above limitations.*

(segue)

Tabella I. *(segue)*

Study	Participants	Intervention	Outcome measures **Primary** / Secondary	Key results ExpG	Unattained goals / Drawbacks *Hints for future investigations*
Ribas et al. (2017) Brazil	• Total n. = 20. • Age ExpG (yr) = 61.70 ± 6.83 • Gender ExpG = 4M 6F • Pathology = PD.	**Individual, supervised, outpatient** • ExpG = Nintendo Wii Balance Board (30 min, 2/wk x 12 wk). • CtrlG = conventional exercise program (30 min, 2/wk x 12 wk: 10 min warming, stretching and active exercises; 10 min resistance exercises for the limbs; 10 min diagonal exercises for the trunk, neck and limbs).	• Balance= **BBS** • Fatigue= FSS-BR • Exercise capacity= 6MWT • QoL= PDQ39	• ExpG showed significant balance and fatigue improvement at 12w, not sustained at 60-day follow-up.	Small group; No recording of the number of falls before and after intervention; No measures regarding safety and playing ability. *Find ways to reduce the risk of falling for patients who conduct training at home or who need direct supervision from a qualified professional.*
Nijenhuis et al. (2017) Netherlands	• Total n. = 19. • Age ExpG (yr) = 58 (48-65) • Gender ExpG = 7M, 2F. • Pathology = stroke.	**Individual, self-administrated (1/w control), home-based** • ExpG = Arm and hand exergame program with a technology-supported system: SCRIPT dynamic wrist and hand orthosis (30 min, 6/wk x 6 wk). • CtrlG = conventional home exercise programme with arm and hand training (30 min, 6/wk x 6 wk).	• User acceptance= **training duration** • Arm and hand function= **FMA, Grip strenght, IMI, ARAT, BBT** • QoL= SIS	• Averaged weekly training duration higher in CtrlG. • Perceived motivation positive and equal in both groups. • Both groups showed moderate improvements on most clinical outcomes with no differences between groups. • Changes in Box and Block Test correlated positively with training duration. • Training duration strongly and positively correlated with training-induced changes in the Box and Block Test.	Small group; Different MJF distribution between groups; Different number of available exercise between groups; Neither the assessor nor the patients were blinded; Errors or overestimation by patients in recall of exercise time. *Find ways to improve adherence, optimization of technology, and regular contact between patients and a professional.*
Allen et al. (2017) Australia	• Total n. = 38. • Age ExpG (yr) = 67.5 ± 7.3 • Gender ExpG = 12 M, 7F. • Pathology = PD.	**Individual, initially supervised, home-based** • ExpG = Arm and hand coordination exergame under single and dual cognitive task conditions with Unity game development software (3/wk x 12 wk). Approximately 15 minutes of actual training duration. • CtrlG = no intervention but usual care and activities.	• Upper limb performance= **9HPT** • Upper limb speed and accuracy= tapping test and error • Upper limb dexterity= coin rotation task, BBT, hand PT • UE perception ability= MAM and global perceived effect scale • Cognition= MCA, TMT-A, -B • QoL= PDQ39	• No between group differences primary or in any secondary outcome measures except for the tapping test (speed score under single task conditions). • ExpG increase speed but also error in tapping test (deteriorated in accuracy under both single and dual cognitive task conditions). • ExpG did not perceive any overall improvement. • ExpG showed a significant trend towards improvement in TMT-A	Cognitively intact patients, mild to moderate PD severity; Short-term study; No variety of games. *Consider the specificity effect of task practice, long-term adherence, and greater variety in games;* *Explore the interaction between cognitive aspects and motor recovery of the upper limb.*
Şimşek et al. (2016) Turkey	• Total n. = 42. • Age ExpG (yr) = 54.15 ± 20.29 • Gender ExpG = 11 M, 5F. • Pathology = stroke.	• Individual, supervised, inpatient. • ExpG = Nintendo Wii-based balance and upper extremity training (45-60 min, 3/wk x 10 wk). • CtrlG = Bobath neurodevelopmental treatment (NDT) with upper extremity activities, strength, balance gait and functional training (45-60 min, 3/wk x 10 wk).	• ADL= **FIM** • QoL= **NHP**	• Both group improved significantly in FIM and NHP with no between group differences. • ExpG was more satisfied.	No without treatment control group, no FU; Limited number of games; No BMI measurement; The choice with respect to outcome measures was inadequate; There was a continuing need for the therapist's guidance to correct the patient's compensatory mechanisms and movements. *Consider a combined treatment group, double blind controlled study;* *Increase the variety of games and study their influences on patients.*
Lee et al. (2017) Taiwan	• Total n. = 47. • Age ExpG (yr) = 59.35 ± 8.95 • Gender ExpG = 13 M, 10F • Pathology = stroke.	**Individual, supervised, outpatient** • ExpG = Microsoft Kinect function for Xbox training with interactive VR balance-related games (45 min, 2/wk x 6 wk) + 45 min standard treatment rehabilitation protocol. • CtrlG = ST rehabilitation protocol (90 min: 45 min strengthening, endurance, ambulation, and ADL training + 15 min of warm-up exercises + 30 min of functional balance exercises, 2/wk x 6 wk).	• Balance= **BBS**, FIT, logTUG • ADL= MBI • Balance confidence= ABC • QoL= SIS	• Both groups shows significant improvement in BBS and logTUG from pre to post and at [illegible] (EXP has improved the most). • No significant difference in other outcome measures within or between groups.	Traditional treatment was constant; No strict control over the specific tasks performed during routine therapy. *Higher rehabilitation doses and frequencies to be use.*
Utkan Karasu et al. (2018) Turkey	• Total n. = 23. • Age ExpG (yr) = 62.3 ± 11.75 • Gender ExpG = 5 M, 7F • Pathology = stroke.	**Individual, inpatient** • ExpG = Nintendo Wii-based balance rehabilitation (20 min, 5/wk x 4 wk) + conventional balance rehabilitation exercises with PT, OT and cognitive therapy. • CtrlG = conventional balance rehabilitation exercises (2-3 h a day, 5 days a week x 4 wk).	• Balance= **BBS, TUG, FIT, PASS, SBI** • Postural sway (COP) • FIM and FAM	• Both groups improve significantly in all the measures except COP; ExpG showed greater improvement than CtrlG. • Significant improvements in BBS and FRT; TUG test scores was not significant. • PASS significant improve in both groups, no difference between groups. • Wii Fit-based balance rehabilitation plus traditional treatment improves static and dynamic balance, functional motor ability, and independence.	Short follow-up period; Small groups; Both subacute and chronic stroke patients included. *Study the effect of the Wii Balance Board in improving dynamic balance.*

Mean size of the experimental group (ExpGr) was overall sixteen subjects, with 4% females. As for age, in two studies (7,27), the age range in ExpGr was very broad (27-78 years), while it was just below the age limit of 55 in another study (28). We kept these last studies in the review due to important contribution to knowledge.

In the studies considered, the criteria for inclusion of patients in the study samples were based on disease type, severity and duration, motor or cognitive potential, and sometimes age. Exclusion was determined by the presence of cognitive / sensory deficits, aphasia, low vision, motor problems or syndromes incompatible with training. In some cases, the patient's need of use of assistive devices or previous experience with EG determined retrospective exclusion as a participant.

EG and VR

In fifteen articles the concepts of VR and EG were used interchangeably, since VR was meant as stylistic component of EG (i.e. exercise by gaming through virtual environments, virtual objects or players). Instead in three articles (9,11,30), the authors specifically differentiated between EG (commercial games, more convenient and easy to use), and VR (specific for rehabilitation). In six articles (25%) the term "virtual reality" does not appear.

Type of treatment and duration

The training was provided on an outpatient (50%) or inpatient (16%) basis, or at home (33%) (Table I). EG-VR training was delivered as a stand alone treatment (71%), or it was in addition to traditional treatment (29%). The experimental treatment lasted on average 630 minutes over 6 weeks, with a follow-up (in 10 studies only) at 2.7 months after treatment. Primary outcomes included balance and gait (54%), upper limb functionality (41%), and physical activity (4%).

Type of platforms and sensor devices

The technological platform observed in the included studies were:

– (29%): Nintendo Wii Fit with balance board (23,29-31), Nintendo with Wiimote (32) and Nintendo Wii Sports with a paddle integrated sensor (3);
– (41%): Kinect (28,34-36), Xbox Kinect (6,7,26,37), and Kinect2Sctratch (11);
– (30%): Other platforms: Stepmania used with a special mat (8), and Script with special dynamic orthosis for UE (39).

Rehabilitation specific designed platforms were:

– Unity Game Development software (40), Rehab@home (9), and Riablo (24);
– myoelectric computer interface Phython used with a cursor (27);
– MotionRehab AVE (41);
– 3D Oculus with head mounted device (42);
– a finger robotic exoskeleton in the form of a special glove (25).

As a theoretical reference, Hebbian's theory of plasticity (25) and Gentile's theory of motor learning (37) were mentioned in two studies, while neurobiological theory was implicitly assumed in a study related to balance training (24).

Safety and feasibility of exergaming

In some studies, patient's safety aspects were considered by verifying a posteriori the absence of adverse events occurring during training with EG (28,30), or by recording the number of accidental falls during the same period (23) or during the following six months (38) (Table II).

In some cases, the patients' subjective perceptions of pain, fatigue or discomfort arising during exercise were considered as a safety criterion to immediately end the training session (32).

Some studies observed specific risks associated with carrying out the exercises: risk of repetitive injury, with patients complaining of upper extremity soreness after a 30-minute Kinect2Scratch games intervention (11), and shoulder pain due to the use of hemiparetic side (33).

Increased pressure/tension score and corresponding higher level of average tremor was observed in PD patients engaged in 3D vs. 2D VR manipulation tasks (42).

One study adopted preventive measures (a harness safety belt) to minimize risk for stroke patients performing standing activities (6).

Home based training has been shown to be feasible (9,26,38-40) even in innovative ways (e.g. Myoelectric computer interface training) (27), though safety in the home setting could be a problem for patients with cognitive decline (23). Direct supervision by a physical or occupational therapist was almost always required to set and regulate the type and progression of exercises, to assist or encourage the patient, and ultimately to administer assessment tests. Otherwise, there were regular home visits by the researcher (25,36,38,39) or contact via skype during the sessions (23).

Patient perceptions

Patient motivation and compliance were generally high (6,7,24,25,26,30,36,38), with an explicit greater appreciation of technological training than traditional rehabilitation (36,40). Satisfaction and motivation were assessed by questionnaires at follow-up or at each training session, often using the Intrinsic Motivation Inventory (25,36,39,42), or including quality of life assessment (23,26,31,32,34,37,39,40). In case of non-evaluation of users' perceptions, this has been addressed as a specific limit of the study (9,28). Patients reported that adherence to the program was strengthened by a wide variety of exercises available and regular contact with the referral therapist (39,40).

Problems detected with patients using technological equipment

The possibility of a Kinect sensor error in distinguishing the assistant from the participant during some phases of the assisted movement has been reported (6). Space problems with equipment have been reported in relation to the home setting (40). The participants' lack of experience with technology did not reduce participation in training (36). Eye fatigue could arise in PD patients who

Table II. *Main conclusions of articles based on: the used platform, significant intra/inter group effects, participants' experience, and adverse events encountered* (see common legend)

EG platform	Brief description /name of game	Use of external device	Significant effects (intra/inter group) analysed and identified							Participants' experience	Adverse Events (AE)	[illegible]
			Upper Limb	Lower Limb	Balance	Physical Activity	Cognition/executive functions/ADL, mobility	Gait	Spasticity			
Kinect	Motion Rehab AVE	RGB video detection camera; a depth-range sensor; an infrared sensor	√ intra and inter group (not wrist and hand)	-	√ intra group	-	-	-	-	Not assessed	Not assessed	Henrique et al. (2019) Brazil
Kinect Jintronix system	Choice of five UE activities performed against gravity	Camera and desktop computer, clinical website	X No	-	-	-	√ intra and inter group	-	-	Four patients withdrew (3 in ExpG) for lack of time, general fatigue, and loss of motivation. Choice of EG based on patient's abilities, interests, motivation, and fatigue. High adherence rate.	No serious AE reported in ExpG. One case of dizziness	Gheidari et al. (2019) Canada
Kinect2Scratch	Scratch 2.0, TIDieR checklist, ActiLife 6 software	Triaxial ActiGraph GT3X+ accelerometers	√ intra group	-	-	-	-	-	-	Participation measured by PRPS and accelerometry resulted higher in the ExpG than in the CtrG	Not serious AE reported. Most participants in the CtrG complained of UE soreness after training, subsided spontaneously.	Hung et al. (2019) Taiwan
Xbox Kinect 360	Kinect Adventures games	-	-	-	-	-	-	√ intra group	-	ExpG improved QoL (PDQ-39 and EQ-5D). All groups improved in activity and participation (WHODAS 2.0), 6DS.	Not assessed	Ferraz et al. (2018) Brazil
Unity3D software, Oculus Rift CV1, or laptop	3DCubes exergaming system	Small size gloves; 4D camera (Leap Motion Controller), 2D or 3D feedback displays	√ intra group	-	-	-	-	-	-	ExpG was more motivated (increased enjoyment/interest at IMI)	Not reported but patients could experience visual discomfort, fatigue or even transient myopia	[illegible] et al. (2020) Slovenia
Microsoft Kinect	Reaching task 1, Reaching task 2, Obstacle avoidance, Marching	Kinect sensor	-	-	√ intra group	-	-	-	-	Not assessed	Not reported	Shih et al. (2016) Taiwan
Nintendo Wii	Wii Fit gaming system	Balance board	-	-	√ inter group	-	√ intra group	√ intra group	-	Satisfaction questionnaire at (mFS) showed no differences between groups. Logbook to record feelings, difficulties or AE	Not reported	Gandolfi et al. (2017) Italy
Myoelectric computer interface (MyoCI)	Target game for arm	Wireless, active EMG electrodes. Padded wrist and hand splint fixed to the armrest of a chair. Cursor.	√ intra group	-	-	-	√ intra group	-	√ intra group	Use of technology was well tolerated	Not reported. 1 patient excluded for nausea.	Mugler et al. (2019) USA
Nintendo Wii	Nintendo Wii Sports Canoe Paddling Training	Safety belt on their waist during the training, motion controller, canoe paddle accessory, Grip-assist gloves, springboard Balance Board	√ intra and inter group	-	√ intra and inter group	-	-	-	-	Not assessed	Shoulder pain due to increase use of the upper extremity	Lee et al. (2018) South Korea

(segue)

Tabella II. *(segue)*

EG platform	Brief description /name of game	Use of external device	Significant effects (intra/inter group) analysed and identified: Upper Limb	Lower Limb	Balance	Physical Activity	Cognition/executive functions/ADL, mobility	Gait	Spasticity	Participants' experience	Adverse Events (AE)	Reference study
FINGER robotic exoskeleton	Guitar Hero	FINGER robot	**√ intra and inter group**	–	–	–	–	–	–	Both groups improved in motivation (IM, better in ExpG), self-efficacy, and depression	Not assessed	Rowe et al. (2017) California
X box Kinect 360	Kinect Adventures video game	Polar watches strapped to the chest	–	–	**√ intra group**	**√ intra group**	**√ inter group**	**√ intra group**	–	100% adherence, 0% dropout rate	Not reported	Tollár et al. (2019) Switzerland
3 of 5 following alternately: Xbox Kinect, Sony PS-3, Eyetoy, Sony PS-3, MOVE, Nintendo Wii Fit, SeeMe VR system	Wii Fit, walking/jogging game, other games played in pairs	Consoles equipment	**√ intra group (grip strength)**	–	–	**X No**	–	**√ intra group**	–	High treatment compliance for both ExpG (78%) and CtrlG (66%), but satisfaction was rated higher for the ExpG (93%) than the CtrlG (71%)	Not reported	Givon et al. (2016) Israel
The RIABLO™	Exercise to simulate ADL	Inertial motion sensors, elastic bands placed on the chest and leg, force platform and EG based feedback	–	–	**√ inter group**	**X No**	–	–	–	Level of participation in the rehabilitation program was greater in the ExpG group	Not assessed	Lupo et al. (2018) Italy
Nintendo Wii	Four Wii-fit games (Bubble Balance, Table Tilt, Tight Rope Walking, Soccer Head, Basic Run or basic step)	Eight-camera motion capture, 29 reflective markers placed on the body joints; balance board; TheraBands in CtrlG	–	–	**√ intra group**	–	**√ inter group**	–	–	Not assessed	Not assessed	Kannan et al. (2019) USA
Kinect / (CtrlG: Nintendo Wii Console)	Rehab@Home: six arm rehab games in virtual space w purposeful movements in home and garden environments/ (CtrlG: commercial EG requiring arm movements)	Camera and a depth sensor/ (CtrlG: controller)	**√ intra group**	–	–	–	–	–	–	Serious games were perceived positively in terms of user experience, satisfaction and motivation	Not reported	Lenzolotte et al. (2018) Italy
Kinect	VERGE system (MU virtual reality system), 2 different virtual environments: Ball Bump, Trajectory Trace, and Food Fight exercises	Wireless mouse	**√ intra group**	–	–	–	–	–	–	Patients spent significantly more time training in the MU mode than in the SU mode. IMI scores rated higher for the MU mode than the SU mode, but no significant differences between groups.	Not assessed	Thielbar et al. (2020) USA
VR open-source Dance Revolution	Dance Revolution "Stepmania" game, modified version	Custom-made step Mat, six arrows as well and two central stance panels, small computer	–	**X No**	**X no**	**X no (except in TUG better in CtrlG)**	**√ inter group**	**X no**	–	Reported perception of mobility &balance, high adherence, not effective in improving the outcomes	One participant reported a non-injurious fall. Monitored by self-report log book	Song et al. (2018) Australia
Xbox Kinect	Kinect Sports Pack and the Kinect Sports Pack 2	Kinect sensor and console sensor infrared camera, harness mounted to the ceiling for safety	–	**√ intra group only**	**√ inter and intra group**	–	–	**√ inter and intra group**	–	High level of compliance, more in ExpG	Not reported	Park et al. (2017) South Korea

(segue)

Tabella II. *(segue)*

EG platform	Brief description /name of game	Use of external device	Significant effects (intra/inter group) analysed and identified							Participants' experience	Adverse Events (AE)	Reference study
			Upper Limb	Lower Limb	Balance	Physical Activity	Cognition/executive functions/ADL, mobility	Gait	Spasticity			
Nintendo Wii	Seven Wii Fit games	Balance Board	-	-	**√ intra group, not at FU**	-	-	-	-	No significant improvement in the QoL domains was reported	Not reported.	Ribas et al. (2017) Brazil
SCRIPT exercises	Gaming exercises, controlled by arm and hand movements	SCRIPT dynamic wrist and hand orthosis with sensors, the SaeboMAS and a computer with touchscreen	**√ intra group**	-	-	-	-	-	-	Self-reported frequency and duration of training in a diary; motivation (IMI). Weekly home visits were highly appreciated by both groups.	Not assessed	Nijenhuis et al. (2017) Netherlands
Unity game development software (specifically developed)	Two coordination EG (Marshmallow game and Chicken game) under six different conditions	Table-top mat, keyboard and tablet	**√ intra group only in one outcome (tapping speed)**	-	-	-	**√ intra group**	-	-	97% of adherence monitored through participant log books. At 12w questionnaire: 68.8% enjoyed the games; 68.8% found the system easy to use; 43.8% would continue. All participants improved in their ability to play the games. Patients would have preferred more variety in the games provided.	Not reported. Monitored through participant log books. One participant reported an exacerbation of a previously existing chronic pain condition and withdrew (unclear if this was related to trial participation)	Allen et al. (2017) Australia
Nintendo Wii	Five games selected from the Wii sports and Wii Fit packages for upper limbs (tennis and punch out) and balance training (tightrope tension, tilt table and heading), respectively	Balance board, Wii remote control and "nunchucks" equipment	-	-	-	-	**√ intra group**	-	-	Treatment satisfaction assessed using VAS. ExpG was better satisfied from the therapy.	Not reported	Şimşek et al. (2016) Turkey
Microsoft Kinect Xbox	Nine games selected from the Kinect Sports, Kinect Adventures, and Your Shape Fitness Evolved packages	Television, handrail placed in front of the participant if required for safety	-	-	**√ intra group**	-	**X No**	-	-	The pleasure scale and AE were recorded after each training session. Experience was more pleasurable in ExpG (Feasibility: 4M-PAES).	ExpG reported 19 AE (soreness of the upper limbs in 6, muscle hypertonicity in 5, dizziness in 6, and leg pain in 2). CtrlG reported 30 AE (soreness of the lower limbs in 10 and upper limbs in 5, muscle hypertonicity in 7, dizziness in 2, shoulder pain in 4, and lower back pain in 2). No serious AE reported.	Lee et al. (2017) Taiwan
Nintendo Wii	Wii Fit	Balance Board; (KAT 3000 balance platform)	-	-	**√ intra and inter group**	-	-	-	-	ExpG enjoying the sessions.	Not assessed	Utkan Karasu et al. (2018) Turkey

wear glasses while using immersive 3D equipment (42), and frustration could occur in older adults with cognitive problems (37).

Balance training

Balance training was based on WiiFit games (23,30,31) or dual-task training technique (29), or a combination of upper limb exercises (32) and postural and locomotor skills (34,35), or focusing on physical conditioning and muscle-strengthening (26,33). The Kinect (33), the Riablo (24) and Stepmania (38) were also used.

The patient mostly maintained an upright position, or sometimes alternating sitting-upright (26), or always sitting (33).

Upper limbs training

Upper limb training was based on gross limb movements (11,27,28,33,40,41) or finger and hand movements (25,33,39,42), including trunk movements (41). The patient maintained the sitting or alternated the sitting / standing position. Biofeedback technique (27) and robotic therapy (39) have also been used. Beside Wii remote (32), particular devices such as gripping assist gloves (33), special force-sensing gloves (25), hand-wrist splint (27), hand orthosis (39), or head-mounted device (42) were sometimes used with particular systems.

Particular techniques

Multi-user therapy (36) and robotic (25) were used for upper limb training, while Dual Task was used for balance training (29). Biofeedback with myoelectric interface was used to reduce spasticity in upper limb muscles (27), and biofeedback associated with IMU sensors and static force platform was used to improve postural and balance skills (24).

Feedback and difficulty level

Almost all EGs included visual-auditory feedback provided to the patient in real time, as a form of encouragement, for correction, or as scoring information. The therapist established the initial difficulty level of exercise, based on the patient's skills and motivation, and adapted it gradually, even at a distance, based on the attained score (39).

In some cases the patient himself decided independently the intensity of the exercise, on the basis of subjective perception (26,41). Rest intervals between activities were sometimes indicated in the protocols (27,32). In one study, patients also had the opportunity to play the video clip of the training sessions, to understand errors and correct performance (32). Wide variability characterized the number of sessions, from a minimum of 6 (27) to over 30 (6,32,38,39,40), as well as the session duration, from a minimum of 15 (29,38,40) to 60-90 minutes (27), with a maximum cumulative training duration of 25-30 hours (43).

Outcome measures

Each study used heterogeneous sets of outcome measures to evaluate rehabilitation. Overall, 54 types of measurement tools appear in the analyzed studies (Table III). The most used were the Berg Balance Scale, together with instrumental measurements of balance and gait, the Timed Up & Go, and other tests for the upper limbs function (Fugl-Meyer Assessment, Box & Block Test, and Motor Activity Log). Most of outcome measures are generic and performance-based (except Fugl-Meyer, which is stroke-specific, and Motor Activity Log which is self-reporting).

Additional tests, questionnaires, clinician-rated instruments or patient-reported results appear with low frequencies of use (we counted 27 different tools used only once by a single study) to assess general health, quality of life, emotions, fatigue, pain, falls, spasticity, manual and fine dexterity, disability and independence, cognitive aspects, strength, and transfer ability. Pathology-specific measures were addressed to stroke (14 tools), to PD (6 tools) and MS (2 tools). 44% of the outcome measures included indications about MCD (Minimal Detectable Change) or MCID (Minimal Clinically Important Difference) as statistical properties. 66% of the studies provided outcome results that were comparable to the available MCD and MCID reference values.

Instrumental quantification of outcomes

Some studies have used additional instrumental methods to quantify the results: "leap motion controller" for hand movements and tremor (42), kinematic analysis for range of motion during reaching tasks (27), automatic calculation of the finger motions (25), electronic platforms for static and dynamic balance (24,30), the Wii Balance Board integrated system (33), accelerometer and force dynamometer (7).

Other physiological (heart rate), psychophysical (Borg scale) and subjective measures (VAS), or neuropsychological measures were used through the studies.

Effectiveness of EG-VR training

Despite significant improvements in balance achieved through EG-VR, those were not sufficient for patients to achieve independence in activities of daily living (6,37), either this result occurred only in a small sample (30). In other cases, the improvements in balance did not attained the threshold of MDC (35) or MCID (23). Upper limb function (27), fine hand movements (9), and perception of general health (26) improved significantly after training. A greater volume of upper limb activity was achieved compared to traditional therapy (36), however this was not associated with evident functional relapse (39). The benefits obtained from EG-VR training were not maintained at follow-up (6,7,11,27,28), or were maintained but at a short follow-up (30,37). In some cases, patients reported subjectively perceived improvements in ADL performance (36,38), which however did not rule out general aerobic training as a concomitant cause (26).

Discussion

As already highlighted in the literature (19), the studies on the use of EG in rehabilitation don't provide

Table III. *Outcome measures in the studies examined* (see common legend)

Outcome measure/ measurement mode	Target	Neurological population to which it refers	Type of measure	Domains	Inclusion in core-set	MCD	MCID	Reference to reviewed papers
BBS (1989)	Balance (static and dynamic)	Neurologic conditions	Performance-based	**Activity.** 14-item clinician-rated scale that assesses sitting and standing, static and dynamic balance (only one item on sitting balance).	CPG APTA (Moore et al. 2018)	4.66-6.7 (chronic stroke) 7 acute stroke 5 PD (Moore et al. 2018)	12.5 in acute stroke	-(Čikajlo and Peterlin Potisk 2019; Shih et al. 2016) -(Gandolfi et al. 2017) -(Henrique et al. 2019) -(Kannan et al. 2019) -(Karasu, Batur and Karataş 2018) -(Lee et al. 2017) -(Lupo et al. 2018) -(Ribas et al. 2017) -(Tollár, Nagy and Horváth 2019)
Electronic platform/ walkway	Balance, gait	Neurologic conditions	Performance-based	**Activity.** Assessment of quality of gait and postural stability.	–	–	–	-(Lee et al. 2017) -(Lupo et al. 2018) -(Kannan et al. 2019) -(Karasu et al. 2018) -(Shih et al. 2016) -(Song et al. 2019) -(Tollár et al. 2019)
FMA (1975)	UE-LE	Stroke specific. Acute and chronic patients post-stroke.	Performance-based impairment index	**Body function/structure.** (5 domains with 155 items): • Motor function (Upper and Lower limbs) • Sensation (touch sensitivity, and joint position sense) • Balance (seated and standing) • Joint range of motion • Joint pain	CPG APTA (Moore et al. 2018)	FMA-LE score in patients with chronic stroke is 4.17, or a 19% change from baseline	Established for LE (6 points), not for UE. For chronic stroke: 3 for severely impaired patients, and 4 to 7 for mildly to moderately impaired patients.	-(Henrique, Colucci and De Marchi 2019) -Norouzi-Gheidari et al. 2019) -(Hung et al. 2019) -(Mugler et al. 2019) -(Rowe et al. 2017) -(Nijenhuis et al. 2017)
TUG, TUGcog (1991)	Balance	Neurologic conditions	Performance-based	**Activity.** It is a test of mobility, balance, and locomotor performance.	StrokEDGE Taskforce, Parkinson Taskforce, Multiple Sclerosis Taskforce	2.84	Time < 20 secs typically indicates independence in most ADL's and outdoor mobility while 20-29 secs indicates probable need for a gait aid and supervision for outdoor mobility.	-(Čikajlo and Peterlin Potisk 2019; Shih et al. 2016) -(Lee et al. 2017) -(Kannan et al. 2019) -(Karasu et al. 2018) -(Song et al. 2018)
BBT (1985)	UE	Neurologic conditions	Performance-based	**Activity.** Assesses manual dexterity in terms of number of blocks grasped, transported and released in one minute.	–	5.5 cubes / min (most affected side) and 7.8 cubes/min (least affected side)	–	-(Norouzi-Gheidari et al. 2019) -(Rowe et al. 2017) -(Sondsdottir et al. 2018) -(Allen et al. 2017)
MAL (2006)	UE	Stroke	Self-report, semi-structured interview to assess arm function	**Activity/Participation.** Amount of the affected hand usage (MAL-AOU) and the quality of movement (MAL-QOM) during 30 daily functional tasks.	No. This tool captures the important element of the patient's perception of arm function. Its inclusion would complement data gathered in a clinically administered, performance-based test.	16.8% (MAL-AOU), 13.4% (MAL-QOM)	1.0-1.1	-(Hung et al. 2019) -(Nijenhuis et al. 2017) -(Norouzi-Gheidari et al. 2019) -(Mugler et al. 2019)
6MWT (1968)	Walking	Neurologic conditions	Performance-based	**Activity.** Measure of gait velocity and endurance	StrokEDGE consensus panel recommendations (Bushnell et al. 2011)	29 meters for people with acute stroke; 50 meters in neurological patients (Bohannon 2016)	Not reported for stroke. Estimated to be 54-80 meters for patients with COPD.	-(Ferraz et al. 2018) -(Kannan et al. 2019) -(Ribas et al. 2017) -(Tollár et al. 2019)
10 MWT (2006)	Walking	Neurologic conditions	Performance-based	**Activity.** Measure of walking speed (instructions for to walk at a comfortable pace or to walk as quickly as possible)	StrokEDGE consensus panel recommendations (Bushnell et al. 2011)	0.1 m/s in subjects with stroke	For geriatric population: 0.05m/sec (small meaningful change) and 0.13m/sec (substantial meaningful change). For comfortable gait speed, 0.16 m/s in patients post stroke. For fastest gait speed, 0.25m/sec in PD patients.	-(Ferraz et al. 2018) -(Gandolfi et al. 2017) -(Gimm et al. 2016) -(Kannan et al. 2019)
PDQ39 (2016)	Health related Quality of Life	PD	Patient reported outcome	**Functioning.** Impact of PD on specific dimensions of functioning and well-being.	StrokEDGE Taskforce, Parkinson Taskforce, Multiple Sclerosis Taskforce	Defined	A decrease of at least 5.39 points in the PDQ39	-(Allen et al. 2017) -(Ferraz et al. 2018) -(Ribas et al. 2017) -(Tollár et al. 2019)

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Tabella III. *(segue)*

Outcome measure/ measurement mode	Target	Neurological population to which it refers	Type of measure	Domains	Inclusion in core-set	MCD	MCID	Reference to reviewed papers
FRT/ mFRT (1990)	Balance	Neurologic conditions	Performance based	**Body Structure, Function. Activity.**	StrokEDGE TaskForce, Parkinson TaskForce, Multiple Sclerosis TaskForce	Acute stroke: 2.3-2.6 cm (paretic-non paretic side) Subacute stroke 6.7 cm PD 7.3 cm	-	-(Givon et al. 2016) -(Lee et al. 2017) -(Várzea et al. 2018)
Reporting of adverse events	Fatigue, soreness, Hypertonicity, dizziness, localized pain, falls	Neurologic conditions	Self-report	**Activity.** Assessment of subjective perception while performing tasks/activities	-	-	-	-(Allen et al. 2017) -(Hung et al. 2019) -(Lee et al. 2017) -(Song et al. 2019)
Patient's reported outcomes	Amelioration in movement, QoL, satisfaction, user experience	Neurologic conditions	Self-report	**Participation.** Opinion on the degree of participation in social and family activities and roles.	-	-	-	-(Givon et al. 2016) -(Ijmuiden et al. 2018) -(Nijenhuis et al. 2017) -(Song et al. 2018)
GDS (1983)	Emotion	Neurologic conditions	Patient reported outcome	**Body Function.** Assess depression and suicide ideation in elderly subjects.	-	-	-	-(Ferraz et al. 2018) -(Givon et al. 2016) -(Rowe et al. 2017)
IMI (1982)	Emotion	Neurologic conditions	Patient reported outcome	**Participation.** Multidimensional measurement assessing the subjective experiences of participants when developing an activity	-	-	-	-(Colomer and Pinedo-Pernik 2019) -(Nijenhuis et al. 2017) -(Rowe et al. 2017)
ABC (1995)	Balance, self-efficiency after stroke	Stroke	Performance based	**Activity.** perceived level of balance confidence in activities of daily living	-	-	-	-(Gamboa et al. 2017) -(Ramos et al. 2019) -(Lee et al. 2017)
ARAT (1981)	UE	Stroke	Performance based	**Body Structure, Function. Activity.** Evaluative measure of UE motor ability and disability.	StrokEDGE consensus panel recommendations (Bushnell et al. 2015)	-	For chronic stroke: use a 10% change on the total scale	-(Givon et al. 2016) -(Nijenhuis et al. 2017) -(Rowe et al. 2017)
9HPT (1985)	Finger dexterity	Neurologic conditions	Performance based	**Activity.** The test uses a wooden or plastic board with 9 ½" pegs.	StrokEDGE TaskForce Responsive measure of change in people with PD	"normal" is a completion in 18 s or less (0-5pegs/s)	-	-(Allen et al. 2017) -(Ijmuiden et al. 2018) -(Rowe et al. 2017)
FIM (1983)	Disability	Neurologic conditions	Performance based	**Activity.** Measurement of disability, according to the ICF. Contains 18 items (13 motor and 5 cognitive tests). FIM subscales could be of interest (e.g. transfer and locomotion).	StrokEDGE TaskForce, Parkinson TaskForce, Multiple Sclerosis TaskForce	-	22 points	-(Givon et al. 2016) -(Kanbur et al. 2018) -(Şenyüz and Çakmak 2016)
Subjective perception (VAS, Borg) (1921-1965)	Pain, discomfort, difficulty	Neurologic conditions	Self-report	**Body Function, Structure.** Assessment of subjective perception while performing tasks/activities.	-	-	-	-(Ferraz et al. 2018) -(Norouzi-Gheidari et al. 2019) -(Şenyüz and Çakmak 2016)
SIS (1999)	Health status and QoL, self-efficiency after stroke	Stroke	Self-report questionnaire	**Activity/Participation.** 8 domains with 59 items) • Strength • Hand function • ADL/IADL • Mobility • Communication • Emotion • Memory and thinking • Participation/Role function. A final item is on stroke recovery perceived (0 = no recovery, 100 = full recovery)	StrokEDGE consensus panel recommendations (Bushnell et al. 2015)	24.0, 17.8, 15.3, and 25.9 respectively for strength, ADL/IADL, mobility, and hand function subscales	9.2, 5.9, 4.5, and 17.8 respectively for strength, ADL/IADL, mobility, and hand function subscales	-(Lee et al. 2017) -(Nijenhuis et al. 2017) -(Norouzi-Gheidari et al. 2019)
EuroQol-5D (2001)	Health	Neurologic conditions	Patient reported outcome	**Body Structure, Function, Participation.** Assess problems in 5 dimensions: mobility, self-care, usual activities, pain/discomfort, anxiety/depression	StrokEDGE TaskForce, Parkinson TaskForce, Multiple Sclerosis TaskForce	-	-	-(Ferraz et al. 2018) -(Tollár et al. 2019)

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Tabella III. *(segue)*

Outcome measure/ measurement mode	Target	Neurological population to which it refers	Type of measure	Domains	Inclusion to core-set	MCD	MCID	Reference to reviewed papers
UPDRS- UPDRS-II (1980)	Health	PD	Patient reported outcome	**Body Function, Activity, Participation.** Comprehensive assessment designed to monitor the burden and extension of PD across the longitudinal course of disease.	StrokEDGE TaskForce, Parkinson TaskForce, Multiple Sclerosis TaskForce	-	3.1 points	-(Cikajlo and Peterlin Potisk 2019) -(Tollár et al. 2018)
MAS (1987)	Spasticity	MS, stroke	Performance based	**Body Structure, Function.** Spasticity	StrokEDGE TaskForce	-	1 point decrease (also as response to Botox)	-(Mugler et al. 2019) -(Şenyılk and Çakılr 2016)
BDI (1961)	Emotion	Neurologic conditions	Patient reported outcome	**Body Function.** Quantifies severity of depression	-	Score>10 indicates depression	-	-(Rowe et al. 2017) -(Tollár et al. 2019)
NIHSS (1997)	Deficits	Stroke	Performance based	**Body Structure, Function.** Quantitative measure of neurological deficit post stroke (LOC, ability to respond to questions and obey simple commands, papillary response, deviation of gaze, hemianopsia, facial palsy, resistance to gravity in front limb, plantar reflexes, limb ataxia, sensory loss, visual neglect, dysarthria, and aphasia).	StrokEDGE TaskForce	-	-	-(Lupo et al. 2018) -(Rowe et al. 2017)
TMT (1958)	Cognitive abilities	Neurologic conditions	Performance based	**Activity.** Processing speed and executive function.	-	-	-	-(Allen et al. 2017) -(Song et al. 2018)
dynamometry	Force	Neurologic conditions	Performance based	**Body Structure.** Assessment of grip/pinch force.	StrokEDGE TaskForce	-	-	-(Simon et al. 2016) -(Nijenhuis et al. 2017)
WMFT (1989)	UE	Stroke	Performance based	**Activity.** 15 timed movement tasks and 2 strength-based tasks	StrokEDGE consensus panel recommendations (Bushnell et al. 2015)	-	1.5 seconds	-(Hung et al. 2019) -(Mugler et al. 2019)
5-STS (2010)	Transfer skill	Neurologic conditions	Performance based	**Activity.** Multi-dimensional task that relies on LE strength and balance	StrokEDGE TaskForce, Parkinson TaskForce, Multiple Sclerosis TaskForce; (Best practice evidence)	Cut-off score of 15 sec. was predictive of fallers in elderly	Cut-off score of 12 secs is discriminatory between healthy elderly and subjects with chronic stroke	(Porras et al. 2018)
PDQ8 (1998)	Quality of life and overall status	PD	Patient reported outcome	**Activities, Participation.** Eight domains: mobility, ADL, emotional well-being, stigma, social support, cognition, communication, and bodily discomfort.	-	-	5.7-7.4 points	(Gandolfi et al. 2017)
WHODAS 2.0 (1980)	Health and Disability	Neurologic conditions	Patient reported outcome	**Activities, Participation.** Assess individual difficulties in different domains: cognition, mobility, self-care, getting along with others, life activities, participation. Score on 5 points ordinal scale (0=none, 4 = extreme).	-	-	-	(Porras et al. 2018)
DGI (2012)	Balance while walking	Neurologic conditions	Performance based	**Activities.** Ability to modify gait in response to task demands.	-	-	1.90 for older adults with a DGI score < 22/24	(Gandolfi et al. 2017)
MFT (1983)	Hand functions	Stroke	Performance based	**Activities.** Evaluates unilateral manual performance in hemiparetic patients after stroke.	-	-	-	(Lee et al. 2018)
TAT (1986)	Balance and gait	Neurologic conditions	Performance based	**Activity.** Balance and gait subscale.	-	Elderly individuals scoring <19 on the balance test have a high risk of falling	-	(Tollár et al. 2018)
BESTest (2009)	Balance	Neurologic conditions	Performance based	**Body Structure, Function, Activity.** 27 tasks with a total of 36 item grouped into 6 systems.	-	-	-	(Tollár et al. 2019)
SE-ADL (1968)	Independence	PD and neurologic conditions	Performance based	**Activity.** Assessment of functioning in ADL.	-	12.33	-	(Tollár et al. 2019)
Katz bADL (1963)	Independence	Neurologic conditions	Performance based	**Activity.** 6 basic ADL observed	-	-	-	(Glasor et al. 2016)
RMI (1991)	Gait, balance and transfers	Stroke	Performance based	**Body Structure, Function.** 14 self-reported items and 1 direct observation item	StrokEDGE TaskForce	-	-	(Lupo et al. 2018)

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Tabella III. *(segue)*

Outcome measure/ measurement mode	Target	Neurological population to which it refers	Type of measure	Domains	Inclusion in core-set	MCID	MCID	Reference to reviewed papers
Barthel Index (1965)	Self-care, independence	Stroke	Performance based	**Activity.** Assesses the ability of an individual to care for him/herself.	-	-	15 points	(Lupo et al. 2018)
CNS (1986)	Motor and cognitive functions	Stroke	Clinician rated instrument	**Body Function. Activity.** Neurological assessment of cognitive and motor functions.	-	-	-	(Lupo et al. 2018)
PRPS (2004)	Motivation	Stroke, Spinal Cord Injury	Clinician rated instrument	**Body Function. Participation.** Assesses a patient's participation in therapy.	-	-	-	(Lupo et al. 2018)
SF-12 (1996)	Health	Neurologic conditions	Patient reported outcome	**Participation.** Physical and mental health	StrokEDGE Taskforce	-	-	(Imoudotti et al. 2018)
PASS (1999)	Balance, transfer	Stroke	Performance based	**Activity.** Assesses the ability to maintain or change a given lying, sitting or standing as well as move between these postures.	StrokEDGE Taskforce	-	-	(Karaso et al. 2018)
CSRT (2001)	Balance	Neurologic conditions	Performance based	**Body Function. Activity.** Strong predictor of falls in older adults.	-	-	-	(Song et al. 2018)
FGA (developed as a modification of the DGI) (2004)	Balance while walking	Stroke	Performance based	**Body Function. Activity.** Strong predictor of falls in community-dwelling older adults.	CPG APTA (Moore et al. 2018)	4.2-6	-	(Song et al. 2018)
NFGq (2009)	Gait	PD	Self-report	**Body Function. Activity.**	-	-	-	(Song et al. 2018)
FESIq (2005)	Concerns about falling	Neurologic conditions	Self-report	**Activity.** 16 item questionnaire that assesses confidence in performing daily activities without falling.	StrokEDGE Taskforce			(Song et al. 2018)
M-PAES (2011)	Emotion	Neurologic conditions	Self-report	**Activity. Participation.** Assesses enjoyment in physical activity.	-	-	-	(Lee et al. 2017)
FSS (1989)	Fatigue	MS and neurologic conditions	Self-report	**Body Function.** Measures the severity of fatigue and its effect on ADL and lifestyle.	-	A score ≥4 indicates fatigue	-	(Ribas et al. 2017)
MAM q (1999)	Hand dexterity	Neurologic conditions	Patient reported outcome	**Activity.** Assessment of hand function based on the patient's responses to functional questions.	-	-	-	(Allen et al. 2017)
NHP (1970)	General health	Neurologic conditions	Patient reported outcome	**Participation.** Assesses perceived health (encompassing the social and personal effects of illness).	-	-	-	(Şimşek and Çekok 2016)
BRAIN TEST (2009)	Finger dexterity	PD	Performance based	**Activity.** Movement speed and accuracy.	-	-	-	(Allen et al. 2017)
CRT (2009)	Hand dexterity	Neurologic conditions	Performance based	**Activity.** Movement speed and accuracy.	-	-	-	(Allen et al. 2017)
Accelerometry	Walking	Neurologic conditions	Performance based	**Activity.** Assessment of number of daily steps.	-	-	-	(Simon et al. 2016)

Legend (alphabetical order) for Tables I, II, and III.

ABC - Activities-Specific Balance Confidence scale
ARAT - Action Research Arm Test
ATI - Average tremor indicator
ATotM - the average time of manipulation
BBS - Berg Balance Scale
BBT - Box and Block Test
BDI - Beck Depression Inventory
BEST - Balance Evaluation Systems Test
BHS - Beck Hopelessness Scale
BI - Barthel Index
BRAIN TEST - BRadykinesia Akinesia INcoordination Test
CNS - Canadian Neurological Scale
cog TUG - cognitive Timed Up and Go
CoP - Center of pressure), the path length (PL) and sway velocity (SV)
CRT - Coin Rotation Task
CSRT - Choice Stepping Reaction Time Test
DGI - Dynamic Gait Index
EQ-5D - Euro-Qol-5 Dimensions Questionnaire
EQ-VAS - EQ-5D visual analogue scale
FESIq - Fall Efficacy Scale-International questionnaire
FGA - Functional Gait Assessment
FIM - Functional Independence Measure, transfer (FIMt) and locomotion (FIMl)
FMA - Fugl-Meyer Assessment
FRT - Functional Reach Test
FSS - Fatigue Severity Scale (BR: Brazilian version)
GDS - Geriatric Depression Scale
Katz IADL - Katz Index of IADL
IB - the number of inserted cubes
IMI - Intrinsic Motivation Inventory
LNS - letter-number sequencing task
LOS - the limits of stability test
MAL - Motor Activity Log, Amount of Use (MAL-AOU), Quality of Movement (MAL-QOM)
MAMq - Manual Ability Measure questionnaire
MAS - Modified Ashworth Scale
mBI - modified Barthel Index
MCA - Montreal Cognitive Assessment
mFRT - modified Functional Reach Test
MFT - Manual Function test
m-PAES - mod Physical Activity Enjoyment scale
MVs - movement velocity
NFGq - New Freezing of Gait questionnaire
NHP - Nottingham Health Profile
NIHSS - National Institutes of Health Stroke Scale
OLS - one-leg stance test
PASS - Postural Assessment Scale for Stroke Patients
PDQ8 - Parkinson's Disease Quality of Life questionnaire
PDQ39 - Parkinson Disease Questionnaire-39
PRPS - Pittsburgh Rehabilitation Participation Scale
PL - path length
RMI - Rivermead Mobility Index
SBI - Static Balance Index (measured by Kinesthetic Ability Trainer, KAT)
SE-ADL - Schwab and England Activities of Daily Living scale
SF12 - 12-Item Short Form Survey
SIS - Stroke Impact Scale
SPT - Slip Perturbation test
SRT - Sitting-rising Test
SW - sway velocity
TAT - Tinetti Assessment Tool
TFFTtE - Time from first touch to end
TMT - Trail Making Test (part A and B)
TNoT - the total number of trials
TUG - Timed Up and Go
UPDRS - Shortened Unified Parkinson's disease rating scale
UPDRS-III - Movement Disorders Society Unified Parkinson's Disease Rating Scale
WMFT - Wolf Motor Function Test
WHODAS 2.0 - World Health Organization Disability Assessment Schedule 2.0
5 STS - 5 times Sit-to-Rise Test
6MWT - 6 min Walking Test
9HPT - 9 Hole Peg Test
10 MWT - 10-mt Walking Test

generalizable data, due to the smallness of the samples, the variability of the training methods and dosage, as well as the poor control of the results at follow-up. In our opinion, a certain fragility of the conclusions also derives from the heterogeneity of the outcome measures used among the studies. In many respects, EG based rehabilitation meets the indications of the rehabilitation guidelines (43): high repetition and task-oriented training; combined exercises; fall prevention; hand dexterity and fine motor skills; home rehabilitation; prevention of secondary disabilities. The studies we have analyzed, randomized controlled trials published in the last 5 years on the use of EG in the rehabilitation of the older adult, suggest interesting developments especially in relation to the training of mobility, balance and postural control, as well as of coordination and hand dexterity. All these motor skills affect independence and quality of life of neurological patients. The EG based rehabilitation allows for large volumes of exercise by customizing tasks training and stimulating patient motivation. In particular, remote monitoring of physical activity throgh EG based rehabilitation represents a significant opportunity for the management of patients at home and in continuity of care.

Although our main focus was on the use of EGs, regardless if associated with immersive or non-immersive VR, we found that 18 of the 24 included articles (75%) used "virtual reality" in association with "exergame", and without a clear distinction between the two terms. Only in three articles, EG (easy-to-use and cost-effective commercial games) and VR (specific tools for rehabilitation) were treated as distinct techniques, but without reporting an obvious advantage of one over the other.

Training based both on EG and VR leads to savings in terms of staff employed and convenience. Excellent adherence to therapy and a greater total amount of exercise accumulated by patients are a strength, which can also contribute to improvements in quality of life, regardless of the type of exercise (26).

In the future, a more functional and task oriented EG design could increase the efficiency of motor learning in patients (41) and encourage the acquisition of more efficient automatic behaviours (44). Mitigation of some critical issues relating to home-based training may occur in the future also thanks to the refinement of innovative techniques, such as robotics and exoskeletons. However, directly available care and supervision of patients with high disease severity remains a key aspect of home rehabilitation. Training at home using platforms that involve multiple users in the game could be a valid modality for the remote rehabilitation of patients with mild illness; however the effects of this methodology have not been explored in the literature so far (only the study by Thielbar et al. employs part of the experimental group in multi-user mode). The high involvement of patients in VR and EG could induce some disadvantages, typically due to the perception of time pressure, and consequently low precision in exercise execution, compensatory movements or tremors, as well as greater postural instability and even risk of falling. A key point still to be clarified are the recommendations on the type and dosage of training based on the severity of the disease and the patient's cognitive abilities. The duration and intensity of rehabilitation, generally short in the studies analyzed, could be decisive for a greater relevance of the outcomes.

Since neurological patients have a high potential for motor improvement even after discharge from the hospital, training based on VR and EG could represent a valid alternative to traditional rehabilitation in the perspective of continuity of patient care. The studies analyzed, although within the limits highlighted, show that VR and EG can be included in a training program for patients who have suffered from stroke, PD or MS. The rehabilitative effects obtained with EG-VR are generally comparable to those obtained through traditional rehabilitation and appear to benefit mainly patients with mild to moderate disease severity.

Several questions emerge from the analyzed studies, which will have to be answered in the future:

- find out which factors influence the patient's acceptability, motivation and adherence to therapy (28,37,39,40,41,42);
- verify to what extent the patient's physical characteristics such as muscle strength, lean mass (23) or obesity (32) affect motor recovery, and how the benefits obtained can be maintained over time (26,28,38);
- which variables to monitor during exercise, to more precisely control intensity and tolerability (34);
- better define the conditions for tele-rehabilitation (9,11,28,39) also considering new modalities (eg wearable exoskeletons) (27);
- study of the rehabilitation of the lower limb (41);
- verify the effects associated with different exercise programs on important outcome measures such as fitness and mobility, quality of life, daily activities, cost-benefit ratio, fall risk and muscle strength (34), and verify functional relapses (40);
- performing studies on much larger sample sizes, including other pathologies, to confirm the clinical efficacy of the approaches (24,39,42) and to investigate the superiority of EG and VR over conventional programs (30,32);
- explore the interaction between cognitive aspects and motor therapy interventions (40).

In rehabilitation, appropriate selection of outcome measures is essential to obtain informative data on the efficacy of treatments and to assess the change over time of motor and functional aspects, as recommended by clinical practice guidelines (45) and by the StrokEDGE consent group (46). A fundamental set of recommended outcome measures for the neuro-rehabilitation of the older patient is still missing. Recent stroke guidelines (47,48) recommend the use of primary and secondary outcome measures, which include measures of impairment, activity limitation, and quality of life, and with established psychometric properties. Self-assessment measures should complement objective measures to assess functional gain and motivational aspects.

Many of the scales used in the studies analysed (Berg Balance Scale, Fugl-Meyer, Balance Confidence Scale, Functional Gait Assessment, 10-meter Walk Test and 6-

minute Walk Test) are recommended as primary outcome measures for neurological conditions in adults. Other, such as the Wolf Motor Function Test, the Action Research Arm Test, the ten-meter and six-minute Walk Tests, and the Stroke Impact Scale, are recommended as secondary outcomes. Subjective patient experience has often been evaluated in studies through the Intrinsic Motivation Inventory (49).

Our review was thorough in examining the RCTs found in databases and offering an integrated view on the technical, individual and rehabilitative aspects of the problem. It is possible however, that some interesting works including "grey literature" have not been addressed.

Regarding the limitations of our study, it was not possible to compare the long-term benefit obtained from a specific platforms used in patients with the same pathology, or with the same characteristics in terms of age, sex and severity of motor disorders. Limited duration of the trial in the studies and variety of platforms, training methodologies and outcome measures helped to blur homogeneous conclusions. Furthermore, in the samples studied, already numerically scarce, the female gender was very little represented (4%), which could also generate an imprecise knowledge of the motivational and functional aspects related to exercise, generally different between male and female (50,51). The lack of standardization between studies with respect to the rehabilitation protocol is an aspect that should be improved in future in this research area.

Conclusions

The EG rehabilitation of the older adult with stroke, PD or MS seems to offer multiple advantages. However, to date it is not possible to draw precise indications on the effectiveness and optimal treatment methods for the various pathologies, especially in relation to functional recovery.

Further efforts are needed to collect data on larger samples and analyze them according to an agreed research direction, also by better defining the significant parameters to be evaluated through more homogeneous and standardized outcome measures.

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