A systematic review and meta-analysis of outcome measures to assess postural control in older adults who undertake exergaming

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Abstract

Exergaming has shown to be an effective tool to improve postural control (PC) in older community dwelling individuals. Outcome measures (OMs) used are varied and individually could hold limitations to the effectiveness of the intervention. This systematic review and meta-analysis aims to explore the OMs currently used to assess PC in exergaming interventions, for healthy elderly individuals > 60 years. The literature search was conducted across five databases (CINAHL, EMBASE, PubMed, ISI, SPORTdiscus and Science Direct) using a range of search terms and combinations relating to exergaming, balance, exercise, falls and elderly. Quality assessment was conducted using the PEDro Scale and a custom-made quality assessment tool. Eleven trials were included in the meta-analysis with a mean (SD) PEDro score of 5.36 (1.57). Primary and secondary OMs showed small effects in favour of alternative training modes, though insignificant for all primary OMs. Tertiary OMs could not be included in the meta-analysis due to varying output parameters from different instrumentation. Heterogeneity remained high across trials and no studies performed long term follow up of exergaming on PC. Exergaming is a potential alternative for PC training, although still in its infancy. Strong and well-designed RCTs are needed targeting specific populations > 60 years. Variability in instrumented OMs prevent generalising aspects of quantified PC. Improvements in technologies may provide data not currently available from clinical and laboratory based methods with means to measure PC more realistically and specifically to a population’s ADLs, though this remains a new area of research.

Key words: Exergaming; Postural Control; Elderly; Outcome Measures; Meta-analysis; Community-dwelling; Balance; Falls

1.0 Introduction

1.1 Background

Falls are associated with ageing and disease, with one third of people aged 65 years and older falling at least once per year [1, 2]. In older individuals, a strong predictor of falls is impaired postural control (PC) among other factors [3, 4]. Postural control is the ability to maintain, achieve, or restore a state of balance during any posture or activity [5]. Correct PC requires accurately timed vestibular, visual, proprioceptive and somatosensory inputs for adaptive strategies for orientation and balance [6]. Participation in balance-based training is low due to the tedious and monotonous nature of the training [7]. These therapies are repetitive which reduce attention span and impair the effectiveness of the exercises, particularly the large volume of practice associated with chronic neurological and musculoskeletal conditions [7].

A more recent method of PC training is exergaming [7, 8]. Exergames are computer games driven by the user’s gross physical movements. Due to portability, they facilitate community deployment whereby older individuals have experienced exergaming as a form of PC training [9]. The Nintendo Wii Fit™ had been the most popular exergaming instrument and results have shown beneficial effects on PC [9]. Other exergaming models include X-Box Kinect™, PlayStation Eyetoy™ and Dance Dance Revolution™. The X-Box Kinect™ is revolutionary in its development due to being the first commercial gaming system that does not require a hand held controller or external device, more so it requires the use of infra-red technology to track an individual’s movements.

Outcome measures (OMs) used in exergaming interventions, employed for balance evaluation, have been previously categorised as functional assessment (documents balance status and change after intervention), systems assessment (determines the underlying reason for impaired balance control), static posturography (quantify postural sway while a subject remains as still as possible) and dynamic posturography (use of external balance perturbations, changing surface and visual conditions) [10]. The Berg Balance Scale (BBS) [11] and the Tinetti Performance Oriented Mobility Assessment (POMA) [12] quantify functional balance in an ordinal pattern as the participant performs balance and mobility tasks that represent activities of daily living (ADLs). The Functional Reach Test (FRT) [13] uses distance to quantify limits of stability of the centre of mass. The Single Leg Stance (SLS) [14] or the Timed Up and Go (TUG) [15] use the time domain to measure the task being performed via a stop watch. These measures provide information about postural control, likelihood of falling and functional capabilities. Inter-rater reliability has been previously reported excellent for BBS, TUG and FRT as has good intra-rater reliability [16]. Unobtrusive self-report questionnaires such as the Tinetti Falls Efficacy Scale (FES) [17] and the Activities-specific Balance Confidence Scale (ABC) [18] measure perception of balance confidence and fear of falling of an individual in performing ADLs.

Force platforms quantify the centre of pressure (COP) excursion in mediolateral (ML) and anteroposterior (AP) direction during quiet stance in varying conditions [7]. The COP has previously characterised postural control by evaluating the relative sensitivity of COP based measures to changes in postural steadiness [19] and has been correlated with poor balance and risk of falls [20]. Older adults have previously demonstrated larger areas of COP excursion on a force platform with eyes open, eyes closed or with visual feedback. They displayed longer movement times, longer path lengths of the participant's centre-of-gravity (COG) to different points within their limits-of-stability, and shorter distances of functional reach when compared with younger adults [21]. Miniaturised electronic-based wearables with inertial sensors (e.g. accelerometers and gyroscopes) have objectively and reliably measured postural sway during quiet stance [22-24]. Wearables have been introduced in clinics as an alternative to evaluating PC in the hope to eliminate clinician bias, increase sensitivity to mild impairments (ceiling effects) and improve reliability of measures [25, 26]. They have been tested in clinical populations whereby a subset of sensitive, reliable and valid instrumented postural sway characteristics had been formed [27].

It appears necessary to systematically explore OMs used in exergaming interventions in the hope to establish if an influence on intervention effect exists and any individual limitations that OMs may hold.

1.2 Objective

The aim of this systematic review and meta-analysis is to explore the outcome measures currently used to assess PC in exergaming interventions for healthy elderly individuals > 60 years.

2.0 Methods

2.1 Search strategy

This systematic review was reported according to the PRISMA guidelines [28]. The systematic review was beyond the stage of data collection and therefore could not be registered with PROSPERO, however, it did receive an official statement pertaining to its satisfaction of the inclusion criteria. This is available upon request. Electronic databases (CINAHL, EMBASE, PubMed, Web of Science, SPORTdiscus and Science Direct) were searched for publications from January 2000 to April 2016 for interventions performed in clinical and community based settings. The key search terms were merged with Boolean conjunction (OR/AND) and applied on three search levels. Key Search terms used were: (exergam* OR exer-gam* OR videogam* OR video-gam* OR video-based OR Wii OR Nintendo OR X-box OR Kinect OR play-station OR playstation OR virtua* realit* OR dance dance revolution) AND (sport* OR train* OR exercis* OR intervent* OR balanc* OR strength OR coordina* OR motor control OR postur* OR power OR physical* OR activit* OR health* OR fall* risk OR prevent*) AND (old* OR elder* OR senior*). Three levels of screening were carried out: (1) title, (2) abstract, and (3) full-text. The reference lists of the included articles were also searched. Inclusion/exclusion criteria were agreed upon by the two reviewers (RT & GB).

2.2 Selection Criteria (PICOS)

Table 1: Inclusion and exclusion criteria

	Inclusion	Exclusion
Population	Older Individuals between the age of 60 and 85 years old, no neurologic or orthopaedic condition, community dwelling or independently in retirement centres, without cognitive impairment, able to ambulate independently without assistive devices were included.	Individuals who were outside the age range of 60 - 85 years old. Populations with specific neurological (i.e. stroke, Parkinson’s disease, and multiple sclerosis), metabolic (i.e. diabetes), or musculoskeletal (i.e. rheumatoid arthritis) deficits that might impair PC were excluded.
Intervention	Intervention group treated with exergaming as balance training only or combined with other forms of training such as strength training were included.	Studies where the intervention group was not treated with exergaming as balance training (i.e. virtual reality treadmill training, biofeedback) was excluded.
Comparison	A comparison group treated with traditional balance training or with no intervention or both were included.	Studies not utilising any comparison groups were excluded.
Outcomes	Outcome measures designed to objectively and subjectively assess PC (functional assessment, laboratory based assessment, self-report assessment).	Balance as a tertiary measure was excluded.

Studies	Randomised controlled trials (RCT), controlled trials (CT), two group pre and post comparison studies, whereby primary outcome measures were used to assess balance or PC either/or before, during and after a bout of exergaming were included.	Studies with fewer than six participants in each intervention group were excluded. Studies in which no inferential statistics were reported were excluded. Studies that did not meet the inclusion criteria (e.g. all (non-human) animal research)

2.3 Data Extraction

Quantitative data were extracted by one reviewer (RT) and checked by another (GB). Specific details about the interventions, populations and study methods were extracted. Primary methods to assess PC were categorised based on traditional standing and functional mobility tests categorised into rating scales, distance based measures and timed tasks. Secondary methods were based on self-report measures of balance and fear of falling (self-report questionnaires). Tertiary methods were categorised as any instrumentation that quantified PC (force platforms, perturbation platforms and accelerometers).

2.4 Quality Assessment

Evidence level of included studies were assessed using the Oxford 2011 Centre for Evidence-Based Medicine Levels of Evidence [29]. Of the five levels of evidence, level 1 is deemed to be the highest quality of evidence (supplementary file 1, A). To eliminate unintended bias while assessing the studies, both reviewers collaborated and eliminated any conflicting opinions. Eligibility and quality of studies was assessed using the Physiotherapy Evidence Database Scale (PEDro) and were independently assessed by both reviewers (supplementary file 1, B). Methodological quality was also assessed using a custom-made tool derived from a previous systematic review (supplementary file 1, C) [30].

2.5 Data analysis

Intervention effects were assessed by grouping studies for meta-analysis by the method of assessing PC (Primary, secondary and tertiary). The difference of the target outcome between the intervention and the control group including the pooled standard deviations, were calculated for different categories of outcome measure. Random effects models (Review Manager (Revman), version 5.3, Copenhagen, Denmark) were used and between-group standardized mean differences (SMD) were calculated based on continuous measurement scale (mean ±SD). Hedge's g was used to quantify effect sizes for SMD to account for small sample sizes (n<20). For trials utilising multiple intervention arms and compared an exergaming group with an alternative balance training group (group fitness, standardised balance training program, Tai Chi etc.) and a control group (no exercise), the alternative balance training control group were compared to the exergaming group. Where a secondary active control group was included in the study, the control group most representative of traditional balance training was compared to the exergaming group. If the heterogeneity test revealed a value of $p < 0.1$ or $I^2 > 25\%$, then heterogeneity was considered likely. Heterogeneity was deemed moderate at <50% and considerable at >50% [31, 32].

3.0 Results

3.1 Search Strategy

The database search yielded 809 publications (Figure 1). After removing all duplicates (346), 463 publications were abstract screened whereby 435 were excluded leaving 28 publications. After searching reference lists of the 28 included publications, an additional 26 were obtained leaving 54. Of the 54 publications, 42 were excluded with reasons to give the final number of included publications for qualitative synthesis in the review (n=12). The publications remaining for qualitative review can be found here (supplementary file 1, D). Of the 12 publications, one was excluded from the meta-analysis where insufficient data were reported. Data was acquired from one author [33] and another failed to respond [34]. Additionally, the Cochrane Central Register of Controlled Trials revealed no further publications for inclusion is this review.

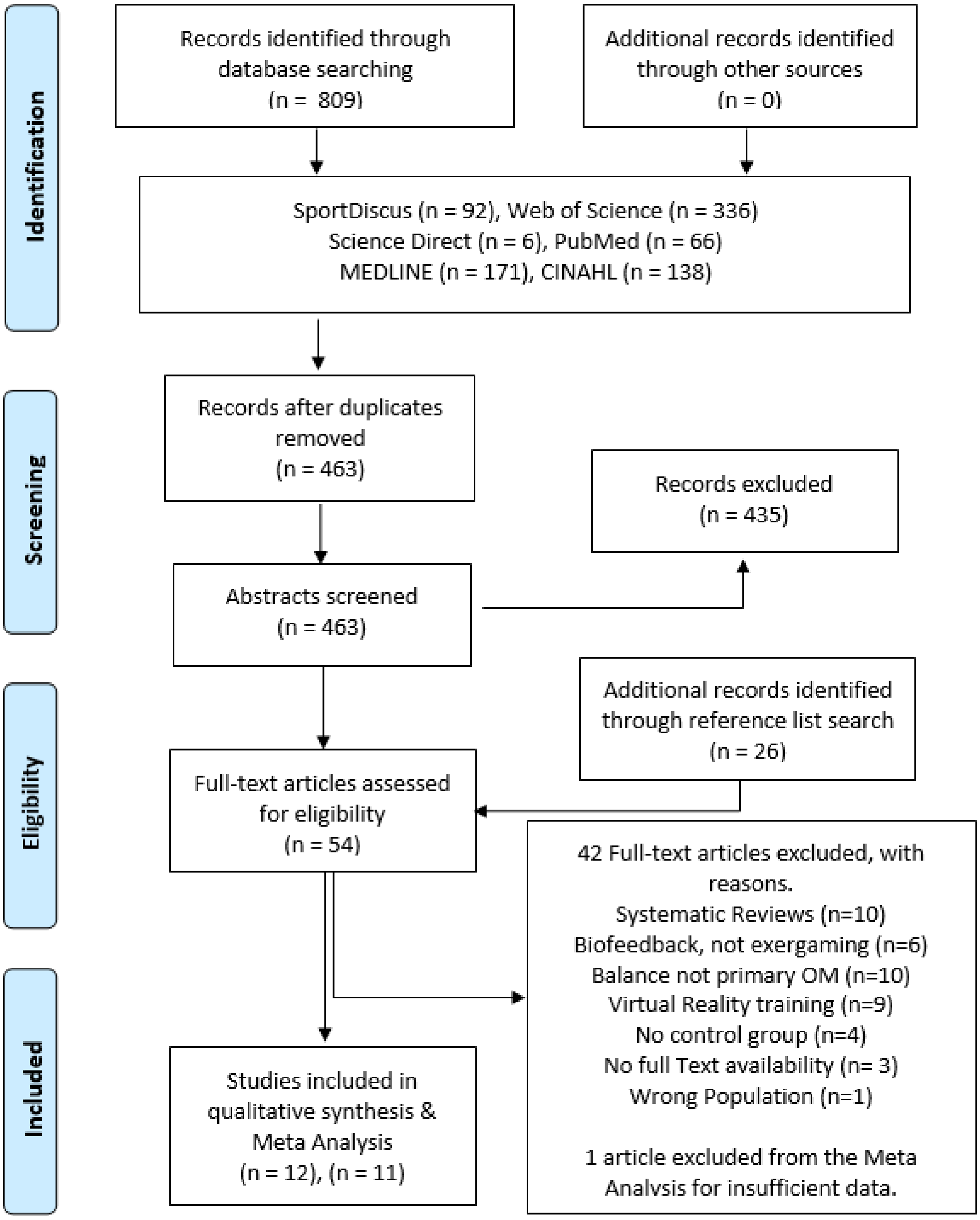

Figure 1. Flow of study screening and selection

3.2 Quality Assessment

Nine of the included publications were considered level 2 evidence (RCT's) and 3 non-RCT's were considered level 3 evidence base (supplementary file 1, E). The mean (SD) methodological quality score of the 12 trials included in the review was 5.17 (1.64). This increased to 5.36 (1.57) for the eleven trials included in the meta-analysis. When excluding the level 3 evidence trials (non-RCT) from the quality assessment the score increased to 5.44 (1.74). A third of the trials reviewed were rated below the mean score which can be attributed to a lack of blinding of the participants, therapists and assessors and a lack of allocation concealment (Table 3). There was a seeming lack of explanation for randomisation across trials with only two studies adequately explaining the method for randomising participants. Six trials failed to describe location and no intervention follow up was conducted for any of the trials (supplementary file 1, F).

Table 2. Overview of the study design, sample characteristics, groups, intervention type and location for included studies

Author and Date	Study Design	Sample: Population; Sample Size (n); age, years (mean ± SD), M/F	Groups	Intervention & Follow up (Y/N)	Location/ Settings
Pluchino et al., 2012	RCT 3 arms (PS)	Community-dwelling older adults, n=40; 72.5 ± 8.4 years, 15/25	IG1 : Standard Balance Exercise ; (n=14), IG2 :Tai Chi (n=14), IG3 : WF (n=12)	60 minutes, 2 x per week, 8 weeks. (N)	Research laboratory/training facility, Wii group unsupervised.
Ray et al., 2012	RCT 3 arms	Community-dwelling older adults, n=87, 75 years (no SD given), 29/58	GF: (n=40), WF + weighted vest: (n=29), CG: (n=18)	GF & WF: 3 x week 45 mins duration, 15 weeks. (N)	Laboratory
Toulotte et al., 2012	RCT 4 arms	Community-dwelling older adults., n=36, 14/22. See adjacent column for mean age (SD) per group	G1: APA, (n=9, 84.2 ± 8.1 years, 3/6). G2: Wii Fit, (n=9, 72.2 ± 8.6 years 4/5). G3: APA + WF, (n=9, 76.4 ± 4.7 years, 3/6). G4: CG (n=9, 71.8 ± 8.0, 4/5).	60 minutes per week x 20 weeks. (N)	Gymnasium at retirement centre
Merriman et al., 2015	RCT 2 arms	Community-dwelling n=59 & Retired Persons n=17, subgroups: healthy n=42, fall prone n=34, 16/60. See adjacent column for mean age (SD) per group	IG: Balance Training (n=38, 17 his of falls, 74.06 (6.66) years, 21 healthy, 74.90 (8.97) years, 1/37). CG: (n=38, 17 his of falls 73.41 (7.00) years, 21 healthy 74.33 (11.09) years, 15/23)	IG: 5 weeks, 2 x 30 min BT/week CG: diary of light, med, heavy Physical Activity. (N)	Sheltered accommodation / community centre / testing laboratory
Sato et al., 2015	RCT 2 arms	Community-dwelling older adults, n=54, 69.25 ± 5.4 years, 11/43	IG: (n=29) CG: (n=28)	65.34 (9.63) days, 40 mins - 1 hour per session, 2-3 times per week, total 24 times. (N)	N/A
Whyatt et al., 2015	RCT 2 arms	Sheltered accommodation and local activity groups, n=84, 25/57. See adjacent column for mean age (SD) per group	IG: Balance Game Training, n=40, 77.18– 6.59 years, 5/35. CG: n=42, 76.62– 7.28 years 20/22. Subgroups. High Risk Falls: IG: (n=15, 77.73 – 8.01 years, 2/13). CG: (n=12, 79.00 – 7.03 years, 6/6). Low Risk Falls: IG: (n=25, 76.83– 5.64 years 3/22). CG: (n=30, 75.67 – 7.28 years, 14/16).	IG: 30 minutes per session, 10 x sessions; over 5 weeks. CG: 5 weeks of recording levels of physical activity. (N)	N/A
Lai et al., 2013	RCT 2 arms	Community-living persons n=30, 72.1 [4.8] years, 13/17	Group A: (n=15, 70.6 (3.5) years 7/8). Group B:(n=15, 74.8 (4.7) years, 6/9). Both Groups performed an intervention phase and a control phase.	12 weeks' trial. IG: 30 min, 3 times/ week x 6 weeks then 6 weeks no exercise. CG: no exercise x 6 weeks then IG 6weeks. (N)	N/A
Singh et al., 2013	RCT 2 arms	Community-dwelling older women, n=38, 36 completed intervention.	IG: balance-focused virtual-reality games 61.12 (3.72) years, CG: therapeutic balance exercises: 64.00 (5.88) years,	30 minutes, 2 x / week for 6 weeks. (N)	N/A
Chow and Mann, 2015	RCPS 2 arms	Community-dwelling, n=20, 69 (range 65 - 78), 7/13	IG: Daily Cyber Golfing n=10, 70.4 (5.4) years, 3/7 CG: regular table games n=10, 68.0 (3.0) years, 4/6.	Daily, 30-45 minutes for 2 weeks. (N)	N/A
Nicholson et al., 2015	Non-RCT	Local retirement villages and educational settings, n=41, 74.5 (5.4) years, 14/27	IG: Wii group (n = 19, 75.11 (5.85) years, 7/12, 2 fallers). CG:(n = 22, 73.91 (5.12 years, 7/15, 3 fallers)	IG: 3 × 30 min Wii Fit sessions per week for six weeks. CG: usual everyday activities and exercise routines. (N)	Unsupervised, in pairs in community hall of a retirement village
Park et al., 2015	Non-RCT	Community Dwelling Individuals, n=30	VRG: (n=15, 66.5±8.1 years, 9/3) and a BEG: (n=15, 65.2±7.9 years, 10/2)	30 min 3 times a week for 8 weeks. (N)	N/A
Tange et al., 2012	Non-RCT (PS)	Elderly individuals, n=39,	WSG: n=20 77 (68-82) years, WF: n=19, 84 (80-89) years	2 x / week during 6 weeks in one-hour sessions. (N)	N/A

RCT = randomised control trial; (PS) = Pilot Study; SD = Standard Deviation; M/F = Male/ Female; (n) = number; (Y/N) = Yes/No; G1 = Group 1; G2 = Group 2; G3 = Group 3; G4 = Group 4; APA = Adapted Physical Activities; WF = Wii Fit; CG = Control Group; IG = Intervention Group; GF = Group Fitness; VRG = virtual reality group; BEG = Ball Exercise Group; WSG = Wii Sports Group; N/A = Not Applicable; mins = minutes.

Table 3. Outcomes from PEDro scale quality assessment

Author and Date	Eligibility Criteria	Random Allocation	Concealed allocation	Baseline Comparable	Blind Subject	Blind Therapist	Blind Assessor	Adequate Follow up	Intention to treat	Between group comparison	Point Estimates and Variability	Total
RCT												
Pluchino et al., 2012 *	Y	Y	Y	Y	N	N	N	N	N	Y	Y	5
Ray et al., 2012 *	Y	Y	N	N	N	N	N	N	N	Y	Y	3
Toulotte et al., 2012 *	Y	Y	Y	Y	N	N	N	Y	N	N	Y	5
Merriman et al., 2015 *	N	N	N	N	N	N	N	N	Y	Y	Y	3
Sato et al., 2015 *	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	8
Whyatt et al., 2015 *	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Lai et al., 2013 *	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Singh et al., 2013 *	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Chow and Mann., 2015 *	N	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Non-RCT												
Nicholson et al., 2015 *	N	N	N	Y	N	N	N	Y	Y	Y	Y	5
Park et al., 2015 *	Y	N	N	Y	N	N	N	N	Y	Y	Y	4
Tange et al., 2012	Y	N	N	N	N	N	N	Y	N	Y	Y	3
Total	9	8	4	9	1	1	3	8	5	10	12	

RCT = Randomised Control Trial; Non-RCT = Non Randomised Control Trial; Y = Yes; N = No; * = Included in Meta-Analysis.

3.3 Data Extraction

Intervention characteristics are available in Table 2. Intervention duration ranged from 5 to 20 weeks, individual sessions ranged from 30 to 60 minutes and session frequency ranged from 1 to 3 times per week. The majority of interventions were conducted in a research facility or a dedicated testing room in a community centre. None of the interventions took place in the home environment and two trials performed exergaming unsupervised [35, 36] (Table 3). Trials were conducted in the USA [35-37], the UK [38, 39], The Netherlands [34], France [40], Malaysia [41], Hong Kong [33], Japan [42], Taiwan [43] and South Korea [44].

3.4 Intervention Effect

3.4.1 Primary and Secondary OMs

Of the 11 trials included in the meta-analysis, six reported PC outcomes from rating scales [35, 38-40, 42, 43], three reported stand and reach tasks, one reported a sit and reach task [33, 35-37] and seven trials included timed tasks consisting of standing balance and mobility assessment [33, 35-37, 41, 43, 44]. Data for included studies can be viewed in supplementary file 1, G. Five trials used self-report methods to quantify balance confidence and fear of falling [35, 36, 38, 39, 43]. Four trials used various versions of the falls efficacy scale [35, 36, 38, 43]. Two trials administered the ABC scale [38, 39], one trial administered fall risk for older individuals living in the community [35] and one trial administered a questionnaire to measure fear of falling [38].

Exergaming had less of an effect on PC than alternative balance training modes when measured using rating scales (SMD: -0.27, 95% CI = -0.23 to 0.78; I^2 = 80%) (Figure 2) and distance-based reaching tasks (SMD: -0.28, 95% CI -0.70 to 0.15, I^2 = 57%) (Figure 3) but no effect was seen in favour of either intervention method through timed tasks (SMD: -0.03, 95% CI -0.30 to 0.24; I^2 = 50%) (Figure 4). Exergaming had less of an effect on balance confidence and fear of falling than active controls when measured using questionnaires (SMD: -0.23, 95% CI 0.03 to 0.44; I^2 = 0%).

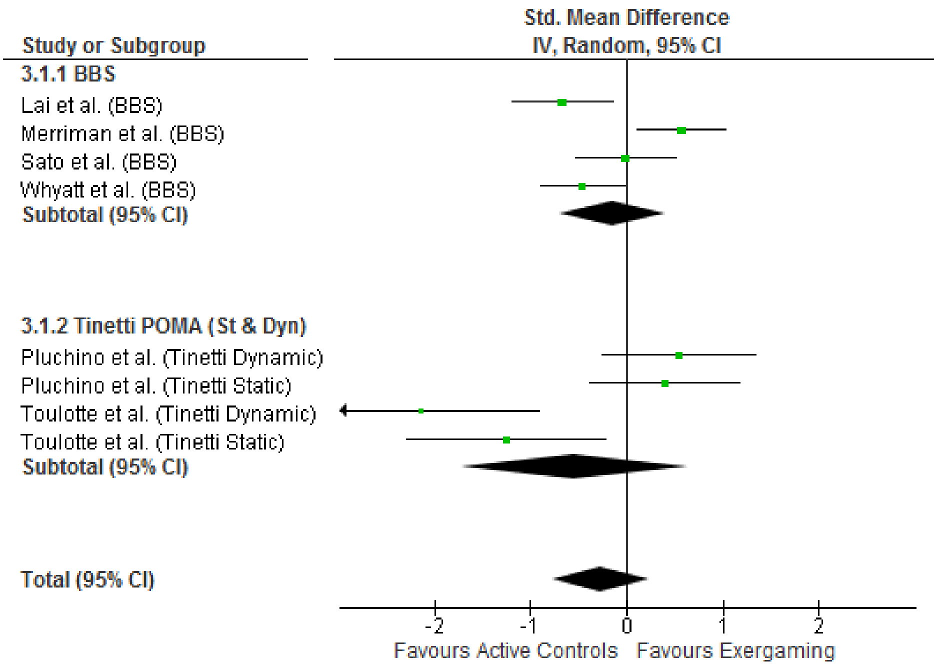

Figure 2. Outcome measures using rating scales for PC assessment in Exergaming vs. active controls. BBS = Berg balance scale; POMA = Performance Oriented Mobility Assessment; Std. = standardised; IV = inverse variance; CI = confidence interval.

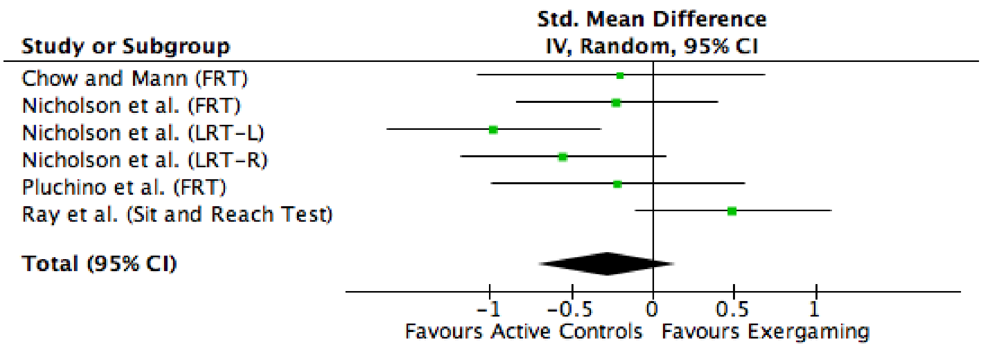

Figure 3. Outcome measures using reaching tasks for Exergaming vs. active controls. FRT = Functional Reach Test; LRT – L = Lateral Reach Test Left; LRT-R = Lateral Reach Test Right; Std. = standardised; IV = inverse variance; CI = confidence interval.

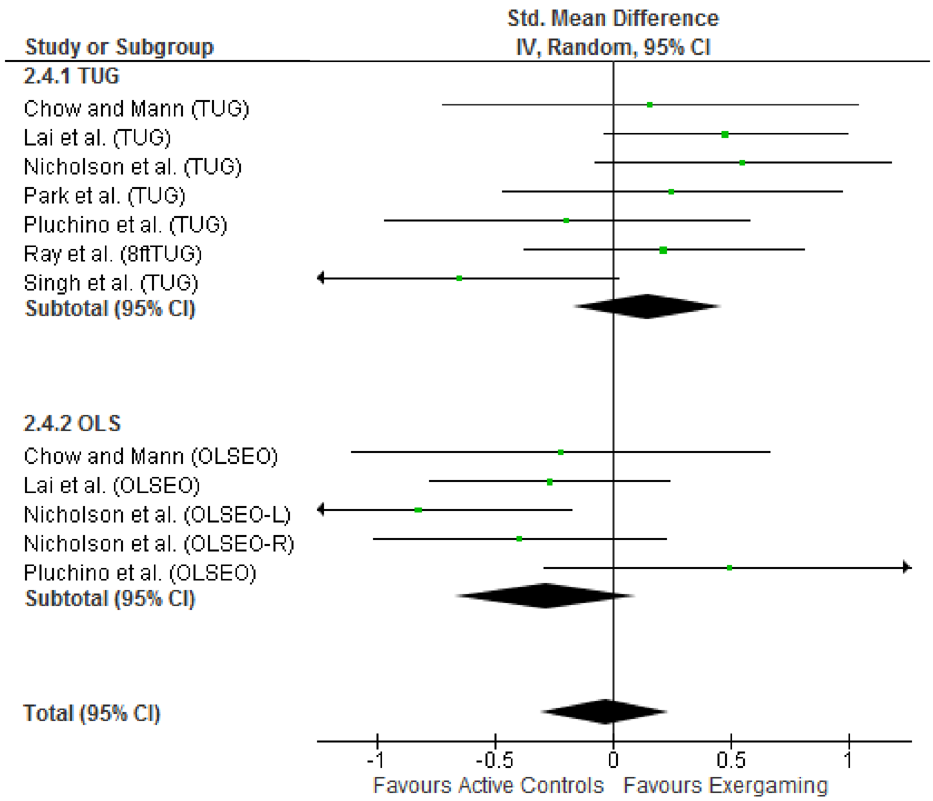

Figure 4. Outcome measures using timed tasks for exergaming vs. active controls. TUG = Timed Up and Go; OLSEO = One Leg Stance Eyes Open; Std. = standardised; IV = inverse variance; CI = confidence interval.

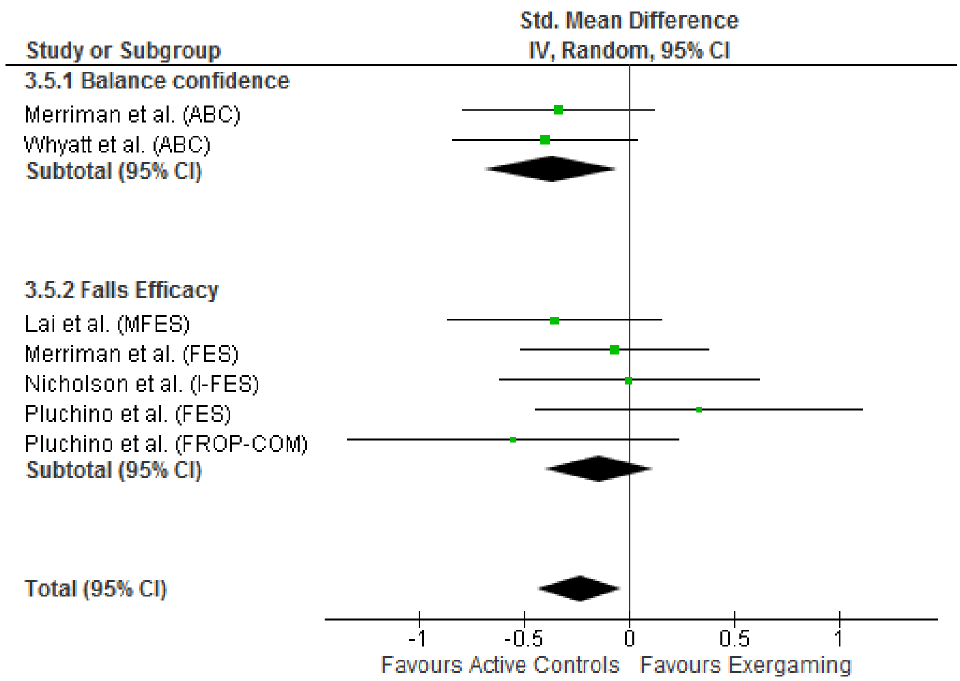

Figure 5. Self-Report Measures of balance confidence and fear of falling for exergaming vs. active controls. FES = Falls Efficacy Scale; ABC = Activities-specific Balance Confidence Scale; FROP-COM = Falls Risk for Older People living in the Community; I = Iconographical and M = Modified; Std. = standardised; IV = inverse variance; CI = confidence interval.

After excluding non-RCT's to observe for any differences in the direction of the effect, the effect made a positive transition towards exergaming for distance-based reaching tasks (SMD: 0.10, 95% CI -0.39 to 0.59, I^2 = 26%) and marginally for timed tasks (SMD: 0.01, 95% CI -0.28 to 0.30, I^2 = 34%), though remained statistically insignificant. A noticeable reduction in heterogeneity across studies was observed for sub-categories of primary OM (supplementary file 1, H). Findings from primary and secondary OMs with insufficient data to pool into meta-analysis can be viewed in supplementary file 1, I.

3.4.2 Tertiary OMs

The instrumentation used to quantify PC had many variations of measurement output which meant inclusion in the meta-analysis was not feasible. Individual results pertaining to intervention effect can be found in supplementary file 1, J.

Table 4. Overview of primary, secondary and tertiary outcome measures used to assess balance

Author and Date	Systems and apparatus	Primary OMs	Secondary OMs	Tertiary OMs	Details
Pluchino et al., 2012	AccuSway Force Platform, Proprio 5000 Dynamic Posturography platform	One-Leg Stance (s), Functional Reach Test (cm), Timed Up & Go Test (s), Tinetti Performance Oriented Mobility Assessment	Falls Efficacy Scale (FES), Falls Risk for Older People– Community Setting (FROP-COM).	The Postural Sway Test (COP + Time to boundary), Dynamic Posturography Test (perturbation platform)	Postural Sway Test Parameters: COP characteristics in AP and ML direction
Ray et al., 2012	NeuroCom SOT	8ft Timed Up and Go Test (s), Chair stand x 15-25 reps weighted, 6-minute walk test, Sit and Reach Test.	N/A	Sensory Organisation Test: 6 conditions, 3 trials/ condition. 18 trials total. 20 s/ trial.	Composite Equilibrium Score of weighted value of 6 conditions: Strategy Analysis score: Scores between 0 and 100 represent a combination of the two strategies; ankle and hip.
Toulotte et al., 2012	Nintendo Wii Fit + WBB	Unipedal Test Eyes Open, Eyes Closed, Tinetti Balance Assessment tool.	N/A	Wii Fit Test - Position of Centre Of Gravity (COG)	The videogame console gives two percentages (right and left) for the position of the centre of gravity. We calculated the percentage difference between right and left and concluded as to the overall position of the centre of gravity.
Merriman et al., 2015	Wii Balance Board (embedded with safety frame surrounding)+ Custom Designed Game	Berg Balance Scale	Balance Confidence (ABC) Scale, Fear of Falling (FOF) Falls Efficacy Scale (FES)	Static and Dynamic Balance Test.	Static: No. of secs within target area (max 10) converted to a percentage. 3 trials per target zone and average score across trials was collected. Dynamic: No of time to reach targets at fixed locations in 60s.
Sato et al., 2015	N/A	Berg Balance Scale, Functional Reach Test (cm), Chair Stand-30s	N/A	N/A	N/A
Whyatt et al., 2015	Nintendo Wii Fit, Wii Balance Board, Zimmer frame for safety, The NeuroCom Balance Master	Berg Balance Scale	ABC Scale	Custom made Static Balance Test (COP Displacement), Dynamic Balance Test - Limits of stability (COP)	Static: percentage of time spent in the target area. Dynamic: No. of targets hit COP displacement. Scores represent levels of COP spatial accuracy and data for all balance tests were converted to percentage change between Session 1 and Session 2.
Lai et al., 2013	The Catsys 2000 system measures postural sway, Xavix Measured Step System (XMSS)	Berg Balance Scale, Timed Up and Go Test (s), Unipedal Stance Test, XMSS stepping test	Modified Falls Efficacy Scale (MFES)	Stepping Test, Sway Area (SA), postural sway (Sway Velocity (SV) of COP in bipedal stance with eyes open and closed)	Sway Area (SA) and Sway Velocity (SV) COP in a bipedal stance with eyes open and closed. Postural sway was measured for 75 s (standard test procedure: 10 s start-up period, 60 s recording period, and 5 s run-out period), while standing directly on the platform
Singh et al., 2013	Probalance System	Timed up and Go Test (s), Ten Step Test		Postural Sway	Anterior –posterior and medial – lateral sway scores were converted to an overall performance index (OPI) by the Probalance software program. Lower OPI scores reflect better ability to regulate postural sway.

Chow and Mann, 2015	N/A	Timed up and go test (s), Single leg stance test, Functional Reach test (cm).	N/A	N/A
Nicholson et al., 2015	N/A	Timed Up and Go Test (s) Functional reach (cm) Lateral reach left (cm) Lateral reach right (cm) Single Leg Stance left (s) Single Leg Stance right (s) 30-s chair stand, Gait speed (m/s)	N/A	N/A
Park et al., 2015	BioRescue	Timed Up and Go Test (s)	Static Balance	30 sec sway length (mm) & average sway speed (mm^2) EO (COP) + biofeedback
Tange et al., 2012	N/A	Berg Balance Scale at 0, 3, and 6 weeks	N/A	N/A

OMs = Outcome measures; N/A = Not Applicable; COP = Centre of Pressure; SOT = Sensory Organisation Test; (s) = seconds; (cm) = centimetres; (m/s) = metres per second; mm2 = millimetres squared; EO = Eyes Open

4.0 Discussion

This systematic review and meta-analysis aimed to explore OMs used to assess PC in exergaming interventions in individuals aged 60 years or more. The evidence from the meta-analyses suggest that, overall, the use of primary and secondary OMs do not impact the outcome of the intervention although after dividing the meta-analyses by individual measure type, some measures favoured exergaming more so than others and heterogeneity was moderate to high for primary OMs. After removing the non-randomised studies from the meta-analyses, the overall effect swayed toward exergaming.

4.1 Limitations with the measures

The primary measures used in this systematic review consist of clinical balance assessments which were originally created to identify balance problems or the underlying cause of a problem to predict risk of falls and determine effectiveness of intervention [10]. Healthy community dwelling older adults tend to have higher functioning capabilities and the 8 points of clinically significant change [45] required in the BBS questions the validity of this assessment for already high functioning individuals and has shown ceiling effects in this regard [46]. The gait section of the Tinetti POMA is seldom used and has also shown ceiling effects [45]. The FRT, despite its purpose, has not been well correlated with centre of mass displacement due to availability of compensatory strategies to reach not accounted for in the test [47]. The TUG also suffers the inability to detect early onset of impairment and the inability to understand if it is the gait or balance component of the scale that is affected may limit this form of measure. The use of rating scales, distance-based measures and timed tasks is practical and inexpensive for PC assessment however, the ceiling effects observed in this population hinder the ability to predict any future concerns of healthy individuals, which is valuable information in order to understand changes in PC. The use of questionnaires to evaluate self-perceived balance confidence and fear of falling are useful as they are nonintrusive and support the targeted direction of an intervention [10]. The ABC scale was developed on elderly outpatients and the confidence they perceived was based on a perceived need for a walking aid and personal assistance to ambulate outdoors [18]. Balance evaluation measures have been previously rated in terms of the ability to measure different aspects of PC and only one measure assessed all 6 aspects of postural control [48]. Adapted measures could discriminate higher functional balance ability in this specific population, which could result in a greater understanding of the effect of the intervention on PC.The needs of higher functioning older adults are less dependent and more focused on higher levels of activities of daily living [18].

The range of equipment and output parameters relating to the COP characteristics of PC requires consistency in order for instrumented outcome measures to be generalizable in the future. For example, comparing COP parameters using a force platform in Pluchino et al.'s [35] trial with the percentage change of the COG measured on a Wii Balance Board in a trial by Toulotte et al. [40]. Several studies did report that participants tended to enjoy exergaming and increased motivation was observed but not measured in several trials. This concurs with several previous systematic reviews [49-51]. A limitation to force plate PC assessment is the inability to measure stepping action of dynamic balance, or indeed the dynamic balance accounted for during gait [52]. Individuals perform reactive and proactive PC adjustments on a force platform [20], but with the individual rooted to the platform, whether it is embedded or raised, not all components of the PC system are challenged as the base of support remains in a static state. Recent research has shown the importance of stepping action for prevention of falls and improving PC [53]. Postural control demands may be influenced by the complexity of the task and the environment in which the task is performed [54]. The use of a body worn accelerometer (BWA) to track PC and gait in any environment has previously been demonstrated as part of the development of an instrumented physical capability assessment (ICAP) [26], yet was not used to quantify PC in any of the trials in this review. The ability of BWA to track PC over a period of time with standardised protocols [25] could enable accurate assessment of PC in community environments for both healthy and fall prone individuals, with varying complexity of task and environmental demands. The potential for BWAs to be able to track higher functioning older individuals may eliminate the psychometric limitations seen in more traditional methods.

4.2 Overall effect

The meta-analyses did show that exergaming interventions are less effective when compared to alternative balance training modes. After adjusting the meta-analyses to include only RCT's there was a shift in effect which could be attributed to the removal of non-RCTs. This is an assumption and must be considered lightly. None of the trials included in the current review performed follow-up measurements leaving a gap in the knowledge of long-term effects of exergaming on PC. Previous systematic reviews have also reported similar findings [9, 55] although reported on *p* values alone. The use of meta-analyses to report effect sizes are arguably more appropriate for intervention evaluation [50].

4.3 Strengths and Limitations

This systematic review was conducted in line with the PRISMA statement. The effects of the current meta-analysis must be taken with caution due to the small number of trials included in the review. The high heterogeneity and a lack of intention-to-treat analysis may not give a comprehensive picture of the effects of exergaming on PC. Furthermore, this review reported on healthy community dwelling individuals only and not those with pathological conditions and at higher risks of falls. The non-RCT's used in the meta-analyses sway potential biases and although we attempted to account for the differences, results should be interpreted carefully, particularly concerning selection bias and reporting bias.

5.0 Conclusion

Exergaming is still in its infancy and heterogeneity in intervention design may affect the overall intervention effect. High quality RCTs with long periods of follow up are needed in order to inform recommendations for exergaming interventions focusing on improving PC. OMs used to assess PC in this population hold psychometric limitations and balance measures do not assess all aspect of PC. OMs that can differentiate balance problems within this population may help direct exergaming interventions. Improvements in technologies may provide further insight with means to measure PC more specifically to a population's ADLs.

Conflict of Interest statement

The authors declare that there are no conflicts of interests.

Additional File 1. Supplementary data and Figures

Supplementary data to this article can be found in additional file 1.

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