Movements of older adults during exergaming interventions that are associated with the Systems Framework for Postural Control: a systematic review

Robin Tahmosybayat[a], BSc, Katherine Baker[a], PhD, Alan Godfrey[b], PhD, Nick Caplan[a], PhD, Gill Barry[a], PhD.

[a] Department of Sport, Exercise and Rehabilitation, Faculty of Health and Life Science, University of Northumbria, Newcastle Upon Tyne, UK.
[b] Department of Computing and Information Science, Faculty of Engineering and Environment, University of Northumbria, Newcastle Upon Tyne, UK.

Corresponding Author

Gill Barry PhD, FHEA, MSc, BSc (Hons)
Senior Lecturer in Biomechanics
Department of Sport, Exercise and Rehabilitation
Faculty of Health and Life Sciences
Northumbria University
Newcastle upon Tyne
NE1 8ST

Highlights

- The totality of postural control is not currently trained in exergaming interventions.
- The choice of exergame console and choice of game influence the areas of postural control trained.
- Sensory integration and perturbation-based reactive postural control are not currently trained in exergaming interventions.
- Exergames eliciting stepping movements and whole-body movements outside the base of support better meet the requirements for training postural control.

Abstract

One in three older adults fall annually, in part due to impairments in the physiological systems that make up the postural control (PC) system. Exercise, particularly balance training, helps to prevent deterioration and even to improve outcomes in the PC system. Exergaming (exercise-gaming) is interactive computer gaming whereby an individual moves the body in response to onscreen cues in a playful format. Exergaming is an alternative method to standard practice for improving PC outcomes, which has been shown to reduce the risk of falling. Exergaming has received research attention, yet the intervention is still in its infancy. There could be benefit in exploring the movements trained with respect to a framework known for identifying underlying deficits in the PC system, the Systems Framework for Postural Control (SFPC). This may help target areas for improvement in balance training using exergames and shed light on the impact for fall prevention. A literature search was therefore conducted across six 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. Movements were rated by two reviewers based on the 9 operational definitions of the SFPC. Eighteen publications were included in the analysis, with

a mean PEDro score of 5.6 (1.5). Overall, 4.99 (1.27) of the 9 operational definitions of the SFPC are trained in exergaming interventions. Exergaming does encourage individuals to stand up (3), lean while standing (4), move upper limbs and turn heads (6) and dual-task while standing (9), to some extent move the body forwards, backwards and sideways (1), and coordinate movements (2) but hardly at all to kick, hop, jump or walk (7), or to force a postural reaction from a physical force to the individual (5) and it does not mimic actual changes in sensory context (8). This is the first review, to our knowledge, that synthesises the literature on movements trained in exergaming interventions with respect to an established theoretical framework for PC. This review could provide useful information for designing exergames with PC outcomes in mind, which could help target specific exergames for multi-factorial training to overcome balance deficits. Some elements of PC are too unsafe to be trained using exergames, such as restricting sensory inputs or applying physical perturbations to an individual to elicit postural responses.

Keywords: Exergaming, Postural Control, Elderly, Movement Characteristics, Systems Framework for Postural Control

1.0 Introduction

1.1 Background

Falling is a consequential aspect of aging, neurological or musculoskeletal disease [1-4]. Exercise is a well-established means to reduce the risk of falling in older adults by significantly improving the systems that constitute balance, muscle strength, flexibility and endurance [5, 6]. To maintain balance, the visual, vestibular and somatosensory systems cooperate to create postural and kinetic reactions to the immediate environment and over time these systems inevitably begin to decline [7]. Balance based training has shown to improve the multitude of systems that constitutes the postural control (PC) system, which when impaired can be a strong predictor of falls for older adults [8-10].

Exergaming (exercise-gaming) is showing to be as effective as alternative methods at improving PC outcomes in community dwelling individuals [11, 12]. Current methods employed include group-based classes based on fall prevention training programmes such as the Otago exercise program [13] and the Falls Management Exercise programme (FaME) [14], which include key components such as balance, muscle-strengthening, flexibility and endurance [15] and well as Tai Chi and functional floor activities that train coping skills for confidence. The plethora of outcome measures used in exergaming interventions each hold individual limitations in higher functioning older adults, improvement retention has not been assessed longitudinally and the heterogeneity of intervention characteristics make generalising outcomes problematic [16].

Movement characteristics of exergames have been previously explored and have focused on stepping exergames due to their natural occurrence during gait and their importance in the prevention of falls [17]. The system setup used for exergames heavily influences the movements performed and therefore the movements

trained during a given intervention. Although previous research has explored the importance of movement quality for designing future exergames for fall prevention, there is a need to utilise a framework based on postural control to fully understand the gaps in training for the underlying mechanisms. Outcome measures have been previously explored in a scoping review which identified components of PC included in standardised balance measures based on the Systems Framework for Postural Control (SFPC) [18]. The SFPC was designed to detect underlying balance problems from a balance assessment tool "BESTest" developed and validated by Horak and colleagues [19].

The ability to maintain equilibrium and postural orientation is reportedly context specific and the underlying physiological risk factors for balance are multifactorial, similarly to risk factors for falls [20]. In any of the six components of the SFPC (Table 1), a constraint can come about from neurological, musculoskeletal or medicinal factors and subsequently increase the risk of falls and injuries from falls. Biomechanical limitations in the feet and the base of support (BoS) can affect the limits of stability due to reductions in size, strength, range and control of the feet or increases in pain. Inaccurate representation of the stability limits from the central nervous system (CNS) may result in postural instability in basal ganglia disorders such as Parkinson's disease [20]. A tilted or inaccurate internal representation of visual or postural verticality can result in an incorrect automated alignment with respect to gravity, which in turn increases instability, such as in individuals with unilateral vestibular loss (tilted) or individuals with hemi-neglect due to stroke (inaccurate) [21]. Older adults at risk of falls have shown to use movement strategies to maintain postural stability more at the hip than at the ankle and have used stepping actions due to the lack of ability to exert angle torque at the ankle as a preliminary strategy [22]. There is also a lack of control of dynamics in older fallers in the form of larger than normal lateral excursions of the centre of mass (CoM) and more irregular foot placements. These limitations during gait or during postural transitions can lead to a trip, slip or fall depending on the context of the immediate external environment. Limitations in the ability to communicate sensory information in complex internal sensory environments can also put individuals at risk of falling in specific sensory contexts (stood in a well lit room with a solid floor versus stood in a field at night) [23]. Individuals with Alzheimer's disease may prohibit the re-weighting of sensory dependence from the CNS even with a reliable peripheral sensory system [20]. Cognitive processing is required for simple PC strategies and increase with the complexity of the task with the addition of a secondary task [24]. Neurological impairments can influence the ability to control posture and perform a secondary task and can lead

to falls due to the lack of cognitive processing capabilities [20]. The use of the SFPC to rate exergames may help target areas that are or are not being trained in exergaming interventions and may provide recommended games for specific components of the framework to subsequently tailor future training.

Using the SFPC, this review will explore movement characteristics that train the PC system during exergaming interventions. We hope to systematically address which movements are being trained and which system set-up best meets the components of the SFPC. This approach may inform design of exergames in the future by addressing the underlying mechanisms of PC. The movements elicited during exergaming interventions may be dependent on the exergaming apparatus used, games played and movements required to drive the exergame.

1.2 Objective

Therefore, this systematic review aims to evaluate the movements trained with the consoles used in exergaming interventions associated with the components of the SFPC.

2.0 Method

2.1 Study selection criteria, search strategy and quality assessment

The reporting of this systematic review was performed according to the PRISMA guidelines [25]. Full details of the inclusion and exclusion criteria and the search strategy are provided in an earlier paper reporting interventions effects according to primary, secondary and tertiary PC outcomes in exergaming interventions [16]. Succinctly, randomized control trials (RCTs) and non-randomized control trials (non-RCTs) that assessed and reported PC outcomes were included. Interventions were compared with traditional balance training modes and/or no exercise controls and included trials studied healthy community-dwelling older adults over 60 years who may or may not have fallen. Publications were all written in the English language from the UK, USA, the Netherlands, France, Malaysia, Hong Kong, Japan, Taiwan and South Korea. No publications were translated. Trials that studied individuals with balance impairments that prevented unassisted ambulation were excluded. Six electronic databases were searched for articles published between January 2000 and April 2016 using search terms related to exergaming, balance, exercise, falls and older adults for interventions based in clinical and community based settings. A further search was conducted to identify any additional publications from April 2016 to December 2017 as this review follows on from a previous systematic review. Additional publications were written in the English language from the USA, Singapore, Greece, Czech Republic and Brazil. None of the

Table 1: Components of postural control operational definitions adapted from Sibley et al. (2015)

Six components of SFPC		Operational Definitions	Does the game:
1. Biomechanical constraints: degrees of freedom, strength, limits of stability	1	Functional Stability	Test the ability to move the centre of mass as far as possible in the AP and ML directions within the base of support?
	2	Underlying Motor Systems	Test strength and coordination sufficiently through the physical activity of the game?
	3	Static Stability	Test the ability to maintain position of the centre of mass in unsupported stance when the base of the support does not change (May include wide stance, narrow, 1-legged stance, tandem, any standing condition)?
2. Orientation in space: perception of gravity, verticality	4	Verticality	Test the ability to orient appropriately with respect to gravity (e.g. evaluation of lean)?
3. Movement strategies: reactive, anticipatory, voluntary	5	Reactive Postural control	Test the ability to recover stability after an external perturbation to bring the centre of mass within the base of support through corrective movements (e.g. ankle, hip, and stepping strategies)?
	6	Anticipatory Postural Control	Test the ability to shift the centre of mass before a discrete voluntary movement (e.g. stepping-lifting leg, arm raise, head turn)?
4. Control of dynamics: gait, proactive	7	Dynamic Stability	Test the ability to exert ongoing control of centre of mass when the base of the support is changing (e.g. during gait and postural transitions)?
5. Sensory strategies: integration, reweighting	8	Sensory Integration	Test the ability to reweight sensory information (vision, vestibular, somatosensory) when input altered?
6. Cognitive processing: attention, learning	9	Cognitive influences	Test the ability to maintain stability while responding to commands during the task or attend to additional tasks (e.g. dual-tasking)?

AP = Anteroposterior, ML = Mediolateral

additional publications were translated. Title, abstract and full text screening were conducted by one reviewer (RT) and checked by another (GB). Reference lists of included trials were searched for additional publications.

2.2 Data extraction

Specific details pertaining to the interventions, populations, study methods and quality assessment from the original search exist in a previous publication and therefore was not repeatedly extracted. Search strategy, study characteristics and quality assessment for the additional publications from April 2016 to December 2017 were extracted. The extracted intervention features were as follows: exergame characteristics (console, game, scoring, difficulty/progression) movement characteristics elicited during exergame training based on the 9 operational definitions by [18].

2.3 Data Analysis

A rating scale was created based on nine operational definitions of the SFPC (Table 1). For each exergame and each component of the SFPC, movements were rated according to the following Likert scale: yes = 1, mostly = 0.75, somewhat = 0.5, less likely = 0.25 and no = 0. The movements required to drive each exergame were rated by two reviewers (RT and GB). GB is an expert in exergaming research and practice. In particular, exergaming to train postural control in older adults, sedentary and healthy populations, development of exergaming for Parkinson's disease. RT has experience in postural control interventions in an ageing population and the

implementation of novel exergaming systems. Once all movements were individually rated for each individual exergame, the mean (SD) was calculated for each publication. The reviewers discussed movement ratings together based on inter-rater reliability and re-evaluated for alterations in judgements. If the exergames used were not stated in the publication, the authors were contacted. With no response, movements could not be rated or scored for that publication.

3.0 Results

Results of the initial search strategy, evidence level and quality assessment please refer to [16]. Results of the additional search strategy, evidence level and quality assessment can be found in supplementary file 1. All but one publication described the exergames used, whereby the author was contacted and failed to respond. Some, but not all exergames were described in that publication [26]. Table 2 presents the characteristics of equipment and exergames used in the interventions.

Table 2: Characteristics of equipment and games used in exergaming interventions

Author and Date	Systems and apparatus used	Games	Game Duration	No. of Levels/ game	Scoring Procedure / level
Pluchino et al., 2012	Nintendo Wii Fit + Wii Balance Board	Soccer heading, ski slalom, ski jump, table tilt, tightrope walk, river bubble, penguin slide, snowboard slalom, lotus focus (Cool down game)	1st day: 7 minutes each, 2nd day: 5/8 games for 10 minutes each,	3 levels – Beginner, Professional & Expert	1-4 on each level
Ray et al., 2012	Nintendo Wii Sports and Fit, Wii Balance Board, Weighted Vest start at 2lbs and incremented 2 lbs / 2 weeks until 10lbs.	Wii Sports: Bowling + weighted Vest. Wii Boxing + weighted Vest. Wii Fit Plus games but no details of which games etc. Just stated balance and bodyweight shifting.	N/A	N/A	N/A
Toulotte et al., 2012	Nintendo Wii Fit + Wii Balance Board	Soccer heading, ski Jump, yoga, Ski Slalom, table tilt and tightrope walker.	G2: 1hr, G3: 30 minutes. Not stated how long per game.	3 levels - Beginner, Professional & Expert	1-4 on each level
Merriman et al., 2015	Laptop + Wii Balance Board used as interface device with Virtools 4.0 (Dassault Systems)	Custom Designed Games x 2. Apple Catch & Bubble Burst. Designed for older adults.	N/A	4 levels of difficulty	Apple Game: apple caught = 1 point, Bubble Pop: No. of bubbles popped per level
Sato et al., 2015	Microsoft Kinect	Apple game, tightrope standing, balloon popping, one-leg standing.	Apple Game, tight rope standing game: 90 secs. Balloon Popping Game: 40-90 secs.	Apple Game & Tight Rope: 3 levels of difficulty. Balloon popping game: 4 levels of difficulty.	N/A
Whyatt et al., 2015	Laptop + Wii Balance Board used as interface device with Virtools 4.0 (Dassault Systems), Zimmer frame for safety	Custom Designed Games x 4: Apple Catch, Bubble Pop, Avoid the Shark, and Smart Shrimp	N/A	4 levels of difficulty based on speed and position.	Continuous score throughout the games and were also presented with a final game score at the end of each level.
Lai et al., 2013	The Xavix Measured Step System ((XaviX port, one step mat)	N/A	N/A	N/A	Time standing, time exercising and total virtual distance travelled recorded during exercise.
Singh et al., 2013	Nintendo Wii Fit + Wii Balance Board	Ski Slalom, Table Tilt, Penguin Slide, Soccer Heading, Tight Rope Walk, Perfect 10 and Tilt City.	N/A	3 levels - Beginner, Professional & Expert	1-4 on each level
Chow and Mann, 2015	Xbox 360 Kinect	"Tiger Woods PGA Tour 13"	30-45 minutes/ game (10 holes/game)	10-hole gaming mode	N/A
Bieryla. 2016	Xbox 360 Kinect	Game 1: Your Shape-Fitness Evolved, Zen Sessions (Tai Chi and Yoga based exergame). Game 2: Kinect Adventures, 20,000 Leaks (Crab Crazy), Rally Ball (Peek A Boo) & Reflex Ridge (Collector)	15 minutes Game 1, 15 minutes Game 2.	N/A	N/A
Boon Chong & Yong Hao. 2016	Nintendo Wii + Wii Balance Board + Resistance bands	WiiActive (EA Sports Active): Run and Walk, Boxing, Inline skating, Biceps Curl, Triceps Kickbacks, Squats and Calf raise, Knee Crunch, Dancing, Shoulder Press, basketball, lunging, baseball, shoulder raises and tennis.	20 minutes per session	3 Levels for each individual game. Easy, Medium and Hard.	Number of repetitions/ goals or points scored.

Monteiro-Junior, R. S., et al. (2017)	Nintendo Wii controller + Wii balance board	Wii Fit Plus: Rowing Squat, Penguin Slide, Basic Run Plus. EA Sports Active: Bump and Set, Heavy Bag and Dance Basic 1 (Volleyball, Boxing & Dancing).	Performed each game once per session. 30 – 45 minutes per session.	Wii Fit Plus: 3 levels - Beginner, Professional & Expert. EA Sports Active: N/A	Wii Fit Plus: 1-4 on each level. EA Sports Active: N/A
Padala et al., 2017	Nintendo Wii + Wii balance board	Wii Fit: Half Moon, Torso Twist, Deep breathing, Ski slalom, penguin slide, tight rope walk, table tilt, balance bubble, Perfect 10	45 minutes	3 levels - Beginner, Professional & Expert	1-4 on each level
Konstantinidis et al., 2016	Fit For All: Nintendo Wii controller + Wii balance Board, Stationary mini-bike	Hiking, Cycling, Ski Jump, Arkanoid, Apple Tree, Fishing, Mini-golf, weightlifting and resistance gaming exercises	N/A	Each session has a difficulty level comprised of two components; intensity and gameplay difficulty. 4 levels from light exercise to intense physical exercise.	N/A
MaixnerovÁ, Svoboda, XaverovÁ, DupalovÁ, & Lehnert, 2017	Nintendo Wii Fit + Wii balance board	Penguin Slide, Table Tilt & Balance Bubble	Each game 5 minutes each	3 levels - Beginner, Professional & Expert	1-4 on each level
Nicholson et al., 2015	Nintendo Wii Fit + Wii balance board	Soccer heading, penguin slide, ski slalom, ski jump, table tilt, snowball fight, perfect 10, and tightrope walking	30 minutes	3 levels - Beginner, Professional & Expert	1-4 on each level
Park et al., 2015	Nintendo Wii Fit + Wii balance board	Soccer Heading, Snowboard Slalom, and Table Tilt	10 minutes on each game for a total of 30 minutes.	3 levels - Beginner, Professional & Expert	1-4 on each level
Tange et al., 2012	Nintendo Wii Fit + Wii balance board	Wii Fit, Wii Sports. Table Tilt is the only game mentioned	N/A	3 levels - Beginner, Professional & Expert	1-4 on each level

N/A = Not Applicable; G2 = group 2; G3 = group 3

3.1 Consoles and Games

Of the eighteen publications, eleven used the Nintendo Wii™ with commercially available exergames (Wii Fit™, Wii Sports™ and/or EA Sports Active™) [26-36]. The most frequently used commercial exergame for the Wii Fit™ was "Table Tilt" used in eight publications, followed by; "Penguin Slide" in six publications. "Soccer Heading", "Ski Slalom" and "Tight Rope Walk" were all used in five publications. "Ski Jump" and "River Bubble" were used in three publications. Yoga based games on the Wii™ and "Perfect 10" were both used in two publications and the rest of the commercially available exergames were only used once in a given publication. Three publications utilised a custom design set up, whereby two used a Wii Balance Board™, a laptop computer with custom designed exergames for older adults and two exergames; "Apple Catch" and "Bubble Burst" [37, 38]. "Avoid the Shark" and "Smart Shrimp" were also used in one of the publications. Another publication used a custom designed platform called "Fit For All" which utilised a Wii Nun chuck™ and a Wii Balance Board™ among other equipment, to navigate web-based custom designed exergames; "Hiking", "Cycling (Stationary mini-bike)", "Ski Jump", "Arkanoid", "Apple Tree", "Fishing" and "Mini-golf" [39]. Three publications used a Microsoft Kinect™ camera, one with a custom designed set up with "Apple Game", "Tight Rope", "Balloon Pop" and "One Leg Standing" games [40], which seem to be closely related to the commercially available exergames of the Nintendo Wii Fit™. The other two Kinect™ based set ups used the Xbox 360 with commercially available exergames; "Tiger Woods" [41], "Your Shape: Fitness Evolved" and "Kinect Adventures" [42]. One publication utilised a Xavix Measured Step System (XMSS). The games available with the XMSS were; "Step Lively", "Vigorous Step", "Jackies Action Run", "Dash" and "Reflex". Information pertaining to exergames used in this publication was sourced elsewhere as no details of the games used were declared in the publication [43]. The publications utilising Wii Sports™ did not describe the games, duration, levels, scoring method or the movements necessary [26, 32].

3.3 Movement Characteristics

Of the eighteen publications, eleven described the movements, four from custom designed exergames [37-40] and seven from commercially available exergames [27, 31, 33-35, 42, 43]. It should be noted that some publications described the movements in more detail in the control group than in the exergaming group [26,

28, 29, 31]. “Weight shifting”, “Side to side”, “Medio-lateral”, “anterior-posterior”, “COP displacement” “arm raise” and “leg raise” were the most commonly used terms to describe the movements to perform the exergames whereby more detail was given in the custom designed exergames which included the reasoning behind movements to drive the game. For this reason, an additional document was created to describe the internal game environment for most exergames and where possible, movements required to drive each exergame and scoring method. Where this was not provided, a hyperlink to a YouTube™ video is provided. This can be found in supplementary file 2.

3.4 Exergaming movements evaluated using the SFPC

The overall mean (SD) movement rating score for the eighteen included publications was 4.99 ± 1.27 of a possible 9 points, which when expressed as a percentage is 55 ± 8%. The overall mean scores expressed as a percentage for each operational definition of the SFPC for included publications were as follows: static stability (92%), cognitive influences (dual tasking) (92%), verticality (90%) and anticipatory postural control (84%). Functional stability (57%) and underlying motor systems (55%) were trained in just over half of the exergames. The least trained aspects of the SFPC were dynamic stability (29%), reactive postural control (0%) and sensory integration (0%). Some publications that used commercial "off the shelf" consoles and exergames or a custom set up with commercial apparatus (Wii Balance Board™) restricted training mainly to static stability due to a static BoS and this was reflected in the score. This was also the case for a publication that used a custom designed exergame with a Kinect™ camera, whereby the nature of the movements to drive each game required only static BoS and reaching tasks. The highest scoring publication used the commercially available “Your Shape- Fitness Evolved” and “Kinect Adventures” exergame which used a Kinect™ camera set up [42]. With reference to the SFPC, this review has shown that exergaming does encourage individuals to stand up (3), lean while standing (4), move upper limbs and turn heads (6) and dual-task while standing (9), to some extent move the body forwards, backwards and sideways (1), and coordinate movements (2) but hardly at all to kick, hop, jump or walk (7) and does not force a postural reaction from a physical force to the individual (5) nor mimic actual changes in sensory context (8). Results for movement ratings relative to the SFPC can be observed in Table 3.

Table 3. Ratings for movements trained in Exergaming interventions relative to the Systems Framework for Postural Control

	Operational Definition of the Systems Framework for Postural Control									
Publication	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total/9**
Pluchino et al., 2012 *										
Wii Fit -Soccer Heading	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Slalom	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Jump	0.50	0.63	1.00	1.00	0.00	0.00	0.00	0.00	1.00	**4.13**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Tightrope Walk	0.50	0.50	1.00	1.00	0.00	1.00	0.63	0.00	1.00	**5.63**
River Bubble	1.00	0.25	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.50**
Penguine Slide	0.50	0.25	1.00	1.00	0.00	0.75	0.25	0.00	1.00	**4.75**
Snowboard Slalom	0.50	0.25	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Mean										**5.00**
SD										**0.51**
Ray et al., 2012 *, **										
Wii Sports - Bowling	0.00	0.13	1.00	0.63	0.00	0.00	0.13	0.00	0.63	**2.50**
Wii Sports - Boxing	0.25	0.38	1.00	0.63	0.00	0.75	0.13	0.00	0.75	**3.88**
Mean										**3.19**
SD										**0.97**
Toulotte et al., 2012 *										
Wii Fit -Soccer Heading	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Slalom	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Jump	0.50	0.63	1.00	1.00	0.00	0.00	0.00	0.00	1.00	**4.13**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Tightrope Walk	0.50	0.50	1.00	1.00	0.00	1.00	0.63	0.00	1.00	**5.63**
Yoga	1.00	0.88	1.00	0.75	0.00	0.00	0.50	0.00	1.00	**5.13**
Mean										**5.02**
SD										**0.54**
Merriman et al., 2015 ***										
Apple Catch	0.50	0.25	1.00	1.00	0.00	1.00	0.00	0.00	0.88	**4.63**
Bubble Pop	1.00	0.38	1.00	1.00	0.00	1.00	0.38	0.00	0.88	**5.64**
Mean										**5.13**
SD										**0.71**
Sato et al., 2015 ****										
Apple Game	0.50	0.25	1.00	1.00	0.00	1.00	0.13	0.00	0.88	**4.75**
Tightrope Standing	1.00	0.25	1.00	1.00	0.00	1.00	0.25	0.00	0.88	**5.38**
Balloon Popping	0.25	0.63	1.00	1.00	0.00	1.00	0.38	0.00	0.88	**5.14**

One-leg Standing	0.25	0.75	1.00	0.88	0.00	1.00	0.38	0.00	1.00	**5.26**
Mean										**5.13**
SD										**0.27**
Whyatt et al., 2015 * **										
Apple Catch	0.50	0.25	1.00	1.00	0.00	1.00	0.13	0.00	1.00	**4.88**
Bubble Pop	1.00	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.63**
Avoid the shark	1.00	0.50	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.75**
Smart Shrimp	1.00	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.63**
Mean										**5.47**
SD										**0.40**
Lai et al., 2013 *** **										
XMSS - Step Lively	0.63	0.75	1.00	1.00	0.00	1.00	0.75	0.00	1.00	**6.13**
Vigoros Step	0.50	0.75	1.00	1.00	0.00	0.88	0.63	0.00	1.00	**5.76**
Jackie's Action Run	1.00	1.00	1.00	1.00	0.00	1.00	0.88	0.00	1.00	**6.88**
Dash	0.50	0.75	1.00	1.00	0.00	0.88	0.63	0.00	0.00	**4.76**
Reflex	0.25	0.63	1.00	1.00	0.00	1.00	0.75	0.00	1.00	**5.63**
Mean										**5.83**
SD										**0.77**
Singh et al., 2013 *										
Wii Fit -Soccer Heading	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Slalom	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Tightrope Walk	0.50	0.50	1.00	1.00	0.00	1.00	0.63	0.00	1.00	**5.63**
Penguin Slide	0.50	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.13**
Perfect 10	0.75	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.38**
Tilt City	0.50	0.25	1.00	1.00	0.00	1.00	0.13	0.00	1.00	**4.88**
Mean										**5.18**
SD										**0.32**
Chow and Mann, 2015 ** **										
Tiger Woods PGA tour	0.25	0.38	1.00	1.00	0.00	0.50	0.13	0.00	0.50	**3.76**
Mean										**3.76**
SD										**N/A**
Boon Chong & Yong Hao, 2016 *										
EA Sports Active - Heavy Bag	0.25	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Targets and Heavy bag (Boxing)	0.25	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Targets	0.25	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
WBB Targets and Heavy Bag	0.25	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Dance	0.50	0.25	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**5.75**
WBB Dance	0.50	0.25	1.00	1.00	0.00	1.00	0.38	0.00	1.00	**5.13**
Kickups	0.50	0.88	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.38**
Run, knees and kickups	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**7.00**
Run	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**7.00**
Upper body (resistance band) - Biceps curl	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Shoulder press	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**

Triceps Kickback	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Upright Row	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Bent over row	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Shoulder raise - Front	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Shoulder raise - Lateral	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	**1.50**
Lower body - Alternating Lunges	0.88	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.88**
Alternating Side Lunges	0.63	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.63**
Knee crunch	0.63	0.88	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.50**
Squats	0.50	1.00	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Squat holds	0.50	1.00	1.00	1.00	0.00	0.75	0.00	0.00	1.00	**5.25**
Sports - Shooting and passing (Basketball)	0.25	0.25	1.00	1.00	0.00	1.00	0.50	0.00	1.00	**5.00**
Inline Skating	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**7.00**
Backcourt (Tennis)	0.50	0.25	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
WBB Tennis	0.50	0.25	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Pitching and Batting (Baseball)	0.50	0.25	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**5.75**
Mean										**4.57**
SD										**2.05**
Padala et al, 2017*										
Wii Fit - Ski Slalom	0.50	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.00**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Tightrope Walk	0.50	0.50	1.00	1.00	0.00	1.00	0.63	0.00	1.00	**5.63**
Penguin Slide	0.50	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.13**
Perfect 10	0.75	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.38**
River Bubble	1.00	0.25	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.50**
Yoga	1.00	0.88	1.00	0.75	0.00	0.00	0.50	0.00	1.00	**5.13**
Mean										**5.32**
SD										**0.24**
Bieryla, 2016****										
YourShape - Fitness Evolved - Zen Session	1.00	0.88	1.00	0.50	0.00	0.00	0.25	0.00	1.00	**4.63**
Kinect Adventures - 20,000 Leaks	1.00	0.88	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.88**
Rally Ball	1.00	0.88	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.88**
Reflex Ridge	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**7.00**
Mean										**6.34**
SD										**1.15**
Monteiro-Junior et al, 2017*										
Wii Fit - Rowing Squats	0.38	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.50	**4.88**
Basic run plus	0.50	1.00	1.00	1.00	0.00	1.00	0.50	0.00	1.00	**6.00**
Penguin Slide	0.50	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.13**
EA Sports Active - Bump and Set (Volleyball)	0.50	0.75	1.00	1.00	0.00	1.00	0.50	0.00	1.00	**5.75**
Heavy Bag (Boxing)	0.25	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.75**
Dance	0.63	0.38	1.00	1.00	0.00	1.00	1.00	0.00	1.00	**6.00**
Mean										**5.42**
SD										**0.57**
Nicholson et al., 2015 *										
Wii Fit -Soccer Heading	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**

Ski Slalom	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Ski Jump	0.50	0.50	1.00	1.00	0.00	0.00	0.00	0.00	1.00	**4.00**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Tightrope Walk	0.50	0.50	1.00	1.00	0.00	1.00	0.63	0.00	1.00	**5.63**
Penguin Slide	0.50	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.13**
Perfect 10	0.75	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.38**
Snowball Fight	0.50	0.25	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.00**
Mean										**5.05**
SD										**0.51**
Park et al., 2015 *										
Wii Fit -Soccer Heading	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**4.88**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Snowboard Slalom	0.50	0.38	1.00	1.00	0.00	1.00	0.13	0.00	1.00	**5.01**
Mean										**5.13**
SD										**0.33**
Konstantinidis et al., 2016* **										
Fit for All - Hiking (Aerobic)	1.00	0.50	1.00	1.00	0.00	1.00	0.50	0.00	0.75	**5.75**
Cycling (Seated Aerobic))	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.75	**1.25**
Ski Jump	0.50	0.50	1.00	1.00	0.00	1.00	0.00	0.00	0.75	**4.75**
Arkanoid	0.50	0.50	1.00	1.00	0.00	1.00	0.00	0.00	0.75	**4.75**
Apple tree	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	0.75	**4.63**
Fishing	0.50	0.38	1.00	1.00	0.00	1.00	0.00	0.00	0.75	**4.63**
Mean										**4.29**
SD										**1.55**
Maixnerova et al. 2017*										
Wii Fit - Penguin Slide	0.50	0.38	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.13**
River Bubble	1.00	0.25	1.00	1.00	0.00	1.00	0.25	0.00	1.00	**5.50**
Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Mean										**5.38**
SD										**0.21**
**Tange et al., 2012 *, ** **										
Wii Fit - Table Tilt	1.00	0.50	1.00	1.00	0.00	1.00	0.00	0.00	1.00	**5.50**
Wii Sports - Boxing	0.25	0.38	1.00	0.63	0.00	0.75	0.13	0.00	0.75	**3.89**
Mean										**4.70**
SD										**1.14**
Overall mean	**0.57**	**0.55**	**0.92**	**0.90**	**0.00**	**0.84**	**0.29**	**0.00**	**0.92**	**4.99**
Overall SD	**0.31**	**0.26**	**0.27**	**0.28**	**0.00**	**0.35**	**0.35**	**0.00**	**0.18**	**1.27**

*= Nintendo Wii + Balance Board + Wii Fit, **= Nintendo Wii + Wii Sports, ***= Laptop + Wii Balance Board, ****= Kinect, *****= other specialised technology.

4.0 Discussion

This systematic review aimed to evaluate the movements trained with the consoles used in exergaming interventions based on the components of the SFPC.

4.1 Main Findings

To our knowledge, this work represents the first attempt to synthesize the literature on movements trained in exergaming interventions with respect to an established theoretical framework for PC. The primary finding of this review is that of the included publications, no console and exergame setup trained all components of the SFPC. The consoles with a custom designed exergame or commercial exergames used "off the shelf" equipment. This makes it affordable yet not facilitative or tailored to the older individual which is well established [44]. The exergames used with the consoles were both commercially available and custom designed for older adults, yet still failed to train all components of the SFPC. Specifically, the perception of standing upright, reacting to a physical perturbation, control of dynamic balance such as postural transitions or dynamic balance during gait and essential sensory strategies to integrate or reweight information is not currently trained sufficiently no matter the set up or exergame used. These are all contributing components in multifactorial balance deficits and risk of falls [20]. Identifying postural-based training needs can help aid the specificity of targeted interventions which are contributing factor to effective fall reduction programmes [2].

The highest scoring set up was the Xbox 360™ and Kinect camera™ with exergames “Your Shape - Fitness Evolved” and “Kinect Adventures”, which are exergames that use whole body movements and stepping actions with various game components. It must be noted that the score was higher than that of other commercially available consoles due to the whole body movements and stepping actions required to drive the game. This contributed to forward and sideways leaning as well as the control of balance with a changing BoS, which are also integral components of a balance training programme that has previously shown a 35% reduction in falls and falls related injury [45]. The raised platform of the Wii™ failed to utilise stepping actions outside the BoS, thus only training static and dynamic balance within the limits of stability. Training the ability to stand up is important for conducting daily activities and is known to show increasing difficulty with age [46], but the likelihood of a fall increases once the BoS begins to change or when the limits of stability are compromised [20, 47]. Individuals incapable of walking unsupported for long periods may benefit from the nature of standing

exergames to strengthen the supporting muscles whilst simultaneously utilising attention to perform postural transitions. This form of dual-tasking may prove useful in rehabilitation programmes for individuals not able to perform more complex dual tasks and may aid improvements in lower limb strength [48]. The "Tightrope Walk" exergame on the Wii™ did involve a changing BoS via alternating stepping actions on the raised platform, which was the highest scoring exergame for the Wii™. A Kinect™ camera set up used a commercial golfing game and another with a custom designed exergame. This setup is equipment free and permits more movement, yet does not always train dynamic balance outside the BoS. This setup is promising in its ability to utilise whole body movements without restriction to a platform, but the selected exergame used must encompass the necessary stepping movements in its design in order to target that component of PC. Step direction, size, length and speed all contribute to prevention of stumbling in everyday life alongside strengthening the lower limbs in older adults [49]. All publications in this review responded to additional tasks whilst trying to maintain and coordinate PC (dual-tasking). Exergames prove to be beneficial in this regard [50]. The magnitude of its benefit in conjunction with the SFPC remains unclear as the ability to differentiate the cognitive demand of each exergame was not explored in this review. It is known that that an increase in cognitive processing occurs with physical and cognitive task complexity [51]. Cognitive demands of exergames must be introduced slowly and sparingly for individuals with slower cognitive function [52].

All exergames trained the ability to orient appropriately with respect to gravity as all participants remained standing for all movements in all exergames. Individuals that suffer from a tilted perception of visual vertical such as those that have suffered a stroke or individuals with lesion of the "vestibular cortex" in the brain [21] may not benefit from this form of training as it unknown if changes occurred in their perception of vertical due to playing exergames.

Exergames, no matter the equipment used, did not train components of reactive PC. Reactive PC is initiated in response to an external perturbation (as low as within 100 milliseconds). The lack of a physical perturbation to an individual during gameplay means that corrective stepping actions are not strategically implemented. This fails to train the action of bringing the CoM back within the BoS once limits of stability are compromised, which is a fundamental mechanism of fall prevention [20]. Multi-directional stepping actions are the required response and guidelines that can prompt corrective movements such as stepping behaviour during exergames have been proposed [49]. Individuals that perform stepping actions during exergames are responding to on-screen cues

and not physical perturbations, however, it can be argued that the motor control for the postural response is being trained via stepping actions [50]. Exergaming may help train the correct movement strategy selection and the magnitude of the response while responding to onscreen cues. Individuals have previously influenced postural responses with intention, expectation and experience [20]. The intention to play, expectations of the next movement required in the game and the general experience of playing exergames could have an effect on these responses.

Dynamic stability was component of PC minimally trained as there were no exergames that required a user to exert control of posture during gait, which would be impractical for the Kinect™ due to the spatial requirements within the range of the camera. Increasing dynamic contexts comes greater risk of falls and research has previously stated that balance training should be the primary focus in fall prevention programmes with walking as an additional component [5]. It is not physically possible to train dynamic stability with a changing BoS with the Wii™ balance board set up. Consoles that used a raised platform only trained this component within the BoS. The Kinect™ allows for more free movement than the Wii™, but the chosen exergames failed to consider movements outside the BoS in their design due to movements required to drive the game being static in nature. Some exergames did elicit postural transitions (steps, hops, skips) which do require the BoS to change from one posture to another. Fall prone individuals tend to have greater variability in moving from one posture to another which is typically when a fall can occur [20].

Another component of postural control not trained was sensory integration which involves integrating and reweighting information to other alternative sensory inputs when one input is disturbed (visual, vestibular or somatosensory). The importance of being able to re-weight sensory information from one sensory context to another is a key factor as falls can occur when there is a deficit in one of the senses (eyes, ears and body sensory feedback) [20]. It is not currently practical or safe to train PC via exergames in unsupervised environments that prohibit sensory inputs due to an increase in fall risk during training. However, with higher levels of cognitive task difficulty occurring during exergaming, there is higher domain resource competition in cognitive processing, which focuses attention on sensory integration [24] and it can be argued that by training at a higher level of cognitive function, attentional processes related to inhibitory control are engaged when sensory integration requirements are high [53].

4.2 Strengths and Weaknesses of the review

This review aimed to eliminate bias by following a strict protocol based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. There may have been a publication bias as mainly published articles were included in this review (all but one article) and as all articles were written in English, a language bias may have also been present. The population of focus in this review is limited to the healthier older adult over the age of 60 and cannot directly offer recommendations for those with disabling conditions and balance impairments. The movements rated in this review were based on movements described in the included publications and where movements were not described, an additional document was created whereby information on the movements and game environments were explored and documented by the lead researcher (RT). This was created by searching and observing web-based videos of individuals playing with the exergames and observing the movements during the games.

4.4 Implications for current best practice

Components of the SFPC should be considered when choosing apparatus and designing exergames for older adults and exergames that track movement compliance should be used, where possible, and rated during exergame training to monitor correct form and distinguish capabilities of older individuals. Future exergaming interventions should closely match movements in the exergaming group with that of the control group [54]. The movements should also be based on informed guidelines from current best practices and where possible incorporate movements that are theoretically linked to training deficits in PC. An exergame platform (Mira Rehab^{TM}) currently exists that considers older adults in its design and incorporates movements based on well-established balance training programmes [13, 55] with a strong cognitive element, that are tailored to the older adults interest, monitor progression and can be reviewed on a regular basis by a clinician via a digital platform of feedback. This exergame has been used for rehabilitation of balance outcomes in a pilot study with a small sample of participants [56] and in a recent research study exploring motivational determinants of older adults exergame participation in assisted living facilities to improve physical function and reduce fall risk [57]. Older adults appear to respond well to exergames through enjoyment and perceived improvement in physical and mental health [57].

5.0 Conclusions

A movement rating system is proposed in conjunction with an established theoretical framework. Not all elements of the framework are trained in exergaming interventions no matter the setup or the design of exergame. There are inherent limitations which remain a drawback of using this method to train postural control. Components of PC cannot be trained due to the unavailability of specialist equipment and spatial impracticalities that compromise safety of older adults. Other elements demand external physical input to test reactions of the PC system, which can't be accounted for in digital games. Exergames that elicit stepping actions and whole body movements outside the BoS better meet the requirements for training PC according to this framework. The design of exergames for the older adult must consider all trainable components of the SFPC in full by considering the full extent of the movement in each component.

Contributors

Robin Tahmosybayat carried out the initial search and drafted the manuscript.

Katherine Baker structured the review and helped draft the manuscript.

Alan Godfrey structured the review and helped draft the manuscript.

Nick Caplan structured the review and helped draft the manuscript.

Gill Barry was the second reviewer to carry out the quality assessment and movement ratings on the relevant articles with Robin Tahmosybayat, and helped to draft the manuscript.

All authors critically revised the paper, and read and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This research is funded as part of a PhD programme within the Faculty of Health and Life Sciences at Northumbria University, Newcastle Upon Tyne, UK, but the preparation of this review did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Provenance and peer review

Peer review was directed by Margaret Rees independently of Alan Godfrey (one of the authors and Guest Editor of the Maturitas special issue Modern Medicine for Healthy Ageing), who was blinded to the process.

Acknowledgements

This research is funded as part of a PhD programme within the Faculty of Health and Life Sciences at Northumbria University, Newcastle Upon Tyne, UK.

Appendix A. Supplementary Data Files

6.0 References

1. Sterling, D.A., J.A. O'Connor, and J. Bonadies, *Geriatric falls: injury severity is high and disproportionate to mechanism.* Journal of Trauma and Acute Care Surgery, 2001. **50**(1): p. 116-119.
2. Rubenstein, L.Z., *Falls in older people: epidemiology, risk factors and strategies for prevention.* Age and ageing, 2006. **35**(suppl 2): p. ii37-ii41.
3. Spaniolas, K., et al., *Ground level falls are associated with significant mortality in elderly patients.* Journal of Trauma and Acute Care Surgery, 2010. **69**(4): p. 821-825.
4. Gill, T.M., et al., *Association of injurious falls with disability outcomes and nursing home admissions in community-living older persons.* American Journal of Epidemiology, 2013. **3**(178): p. 418-425.
5. Sherrington, C., et al., *Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations.* New South Wales public health bulletin, 2011. **22**(4): p. 78-83.
6. Shumway-Cook, A., et al., *The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults.* Physical therapy, 1997. **77**(1): p. 46.
7. Borel, L. and B. Alescio-Lautier, *Posture and cognition in the elderly: interaction and contribution to the rehabilitation strategies.* Neurophysiologie Clinique/Clinical Neurophysiology, 2014. **44**(1): p. 95-107.

8. Agmon, M., et al., *A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults.* Clin Interv Aging, 2014. **9**: p. 477-492.
9. Bleakley, C.M., et al., *Gaming for Health: A Systematic Review of the Physical and Cognitive Effects of Interactive Computer Games in Older Adults.* Journal of Applied Gerontology, 2015. **34**(3): p. 166-189.
10. Donath, L., R. Rössler, and O. Faude, *Effects of Virtual Reality Training (Exergaming) Compared to Alternative Exercise Training and Passive Control on Standing Balance and Functional Mobility in Healthy Community-Dwelling Seniors: A Meta-Analytical Review.* Sports Medicine (Auckland, N.Z.), 2016. **46**(9): p. 1293–1309.
11. Bateni, H., *Changes in balance in older adults based on use of physical therapy vs the Wii Fit gaming system: a preliminary study.* Physiotherapy, 2012. **98**(3): p. 211-216.
12. van Diest, M., et al., *Exergaming for balance training of elderly: state of the art and future developments.* Journal of Neuroengineering and Rehabilitation, 2013. **10**: p. 101.
13. Campbell, J. and M. Robertson, *Otago Exercise programme to prevent falls in older adults. A homebased, individually tailored strength and balance retraining programme.* Otago Medical School, University of Otago, 2003.
14. Skelton, D.A. and S.M. Dinan, *Exercise for falls management: Rationale for an exercise programme aimed at reducing postural instability.* Physiotherapy theory and practice, 1999. **15**(2): p. 105-120.
15. Gillespie, L.D., et al., *Interventions for preventing falls in older people living in the community.* The Cochrane Library, 2012.
16. Tahmosybayat, R., et al., *A systematic review and meta-analysis of outcome measures to assess postural control in older adults who undertake exergaming.* Maturitas, 2017.
17. Skjæret-Maroni, N., et al., *Exergaming in Older Adults: Movement Characteristics While Playing Stepping Games.* Frontiers in Psychology, 2016. **7**.
18. Sibley, K.M., et al., *Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review.* Archives of physical medicine and rehabilitation, 2015. **96**(1): p. 122-132. e29.
19. Horak, F.B., D.M. Wrisley, and J. Frank, *The balance evaluation systems test (BESTest) to differentiate balance deficits.* Physical therapy, 2009. **89**(5): p. 484.
20. Horak, F.B., *Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?* Age and ageing, 2006. **35**(suppl 2): p. ii7-ii11.
21. Karnath, H.-O., S. Ferber, and J. Dichgans, *The neural representation of postural control in humans.* Proceedings of the National Academy of Sciences, 2000. **97**(25): p. 13931-13936.
22. Maki, B.E., M.A. Edmondstone, and W.E. McIlroy, *Age-related differences in laterally directed compensatory stepping behavior.* The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 2000. **55**(5): p. M270-M277.
23. Bugnariu, N. and J. Fung, *Aging and selective sensorimotor strategies in the regulation of upright balance.* Journal Of Neuroengineering And Rehabilitation, 2007. **4**: p. 19-19.
24. Huxhold, O., et al., *Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention.* Brain research bulletin, 2006. **69**(3): p. 294-305.
25. Moher, D., et al., *Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement.* Annals of Internal Medicine, 2009. **151**(4): p. 264-269.
26. Ray, C., et al., *The Effects of a 15-Week Exercise Intervention on Fitness and Postural Control in Older Adults.* Activities, Adaptation & Aging, 2012. **36**(3): p. 227-241 15p.
27. Pluchino, A., et al., *Pilot Study Comparing Changes in Postural Control After Training Using a Video Game Balance Board Program and 2 Standard Activity-Based Balance Intervention Programs.* Archives of Physical Medicine and Rehabilitation, 2012. **93**(7): p. 1138-1146.

28. Toulotte, C., C. Toursel, and N. Olivier, *Wii Fit® training vs. Adapted Physical Activities: which one is the most appropriate to improve the balance of independent senior subjects? A randomized controlled study.* Clinical Rehabilitation, 2012. **26**(9): p. 827-835 9p.
29. Singh, D.K.A., et al., *Effects of balance-focused interactive games compared to therapeutic balance classes for older women.* Climacteric, 2013. **16**(1): p. 141-146.
30. Nicholson, V.P., et al., *Six weeks of unsupervised Nintendo Wii Fit gaming is effective at improving balance in independent older adults.* Journl of Aging and Physical Activity, 2015. **23**(1): p. 153-158.
31. Park, E.-C., S.-G. Kim, and C.-W. Lee, *The effects of virtual reality game exercise on balance and gait of the elderly.* Journal of Physical Therapy Science, 2015. **27**(4): p. 1157-1159.
32. Tange, H., et al. *A pilot with Exergames in Elderly Homes*. in *23rd International Conference of the European Federation for Medical Informatics: User Centred Networked Health Care*. 2012.
33. Boon Chong, K. and P.U.A. Yong Hao, *Effects of Wii Active exercises on fear of falling and functional outcomes in community-dwelling older adults: a randomised control trial.* Age & Ageing, 2016. **45**(5): p. 621-628.
34. Monteiro-Junior, R.S., et al., *Virtual Reality-Based Physical Exercise With Exergames (PhysEx) Improves Mental and Physical Health of Institutionalized Older Adults.* Journal Of The American Medical Directors Association, 2017. **18**(5): p. 454.e1-454.e9.
35. Padala, K.P., et al., *Efficacy of Wii-Fit on Static and Dynamic Balance in Community Dwelling Older Veterans: A Randomized Controlled Pilot Trial.* Journal Of Aging Research, 2017. **2017**: p. 4653635-4653635.
36. MaixnerovÁ, E., et al., *The effect of balance therapy on postural stability in a group of seniors using active video games (Nintendo wii).* Journal of Physical Education & Sport, 2017. **17**(2): p. 735-739.
37. Merriman, N.A., et al., *Successful balance training is associated with improved multisensory function in fall-prone older adults.* Computers in Human Behavior, 2015. **45**: p. 192-203.
38. Whyatt, C., et al., *A Wii Bit of Fun: A Novel Platform to Deliver Effective Balance Training to Older Adults.* Games for Health Journal, 2015. **4**(6): p. 423-433.
39. Konstantinidis, E.I., et al., *Design, Implementation, and Wide Pilot Deployment of FitForAll: An Easy to use Exergaming Platform Improving Physical Fitness and Life Quality of Senior Citizens.* Ieee Journal of Biomedical and Health Informatics, 2016. **20**(1): p. 189-200.
40. Sato, K., et al., *Improving Walking, Muscle Strength, and Balance in the Elderly with an Exergame Using Kinect: A Randomized Controlled Trial.* Games for Health Journal, 2015. **4**(3): p. 161-167.
41. Chow, D.H.K. and S.K.F. Mann, *Effect of Cyber-Golfing on Balance Amongst the Elderly in Hong Kong: A Pilot Randomised Trial.* Hong Kong Journal of Occupational Therapy, 2015. **26**: p. 9-13.
42. Bieryla, K., *Xbox Kinect training to improve clinical measures of balance in older adults: a pilot study.* Aging Clinical & Experimental Research, 2016. **28**(3): p. 451-457.
43. Lai, C.-H., et al., *Effects of interactive video-game based system exercise on the balance of the elderly.* Gait & Posture, 2013. **37**(4): p. 511-515.
44. Skjaeret, N., et al., *Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy.* International Journal of Medical Informatics, 2016. **85**(1): p. 1-16.
45. Robertson, M.C., et al., *Preventing injuries in older people by preventing falls: A meta‐analysis of individual‐level data.* Journal of the American geriatrics society, 2002. **50**(5): p. 905-911.
46. Tinetti, M.E., M. Speechley, and S.F. Ginter, *Risk factors for falls among elderly persons living in the community.* New England journal of medicine, 1988. **319**(26): p. 1701-1707.

47. Rogers, M.W. and M.L. Mille, *Timing paradox of stepping and falls in ageing: not so quick and quick (er) on the trigger.* The Journal of physiology, 2016.
48. Yogev‐Seligmann, G., J.M. Hausdorff, and N. Giladi, *The role of executive function and attention in gait.* Movement disorders, 2008. **23**(3): p. 329-342.
49. Skjaeret, N., et al., *Designing for Movement Quality in Exergames: Lessons Learned from Observing Senior Citizens Playing Stepping Games.* Gerontology, 2015. **61**(2): p. 186-194.
50. De Bruin, E., et al., *Use of virtual reality technique for the training of motor control in the elderly.* Zeitschrift für Gerontologie und Geriatrie, 2010. **43**(4): p. 229-234.
51. Schoene, D., et al., *The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review.* BMC geriatrics, 2014. **14**(1): p. 107.
52. Barry, G., B. Galna, and L. Rochester, *The role of exergaming in Parkinson's disease rehabilitation: a systematic review of the evidence.* Journal of Neuroengineering and Rehabilitation, 2014. **11**.
53. Redfern, M.S., et al., *Attention influences sensory integration for postural control in older adults.* Gait & posture, 2001. **14**(3): p. 211-216.
54. Barry, G., et al., *Exergaming (XBOX Kinect™) versus traditional gym-based exercise for postural control, flow and technology acceptance in healthy adults: a randomised controlled trial.* BMC Sports Science, Medicine and Rehabilitation, 2016. **8**(1): p. 25.
55. Skelton, D., et al., *Tailored group exercise (Falls Management Exercise—FaME) reduces falls in community-dwelling older frequent fallers (an RCT).* Age and ageing, 2005. **34**(6): p. 636-639.
56. Verhoeven, K., *Commercial and customized exergames improve balance in older persons in a community center: a pilot study.* 2017.
57. Meekes, W. and E.K. Stanmore, *Motivational Determinants of Exergame Participation for Older People in Assisted Living Facilities: Mixed-Methods Study.* Journal of Medical Internet Research, 2017. **19**(7).