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SYSTEMATIC REVIEW

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

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Abstract

Background Balance training is considered an important means to decrease fall rates in seniors. Whether virtual reality training (VRT) might serve as an appropriate treatment strategy to improve neuromuscular fall risk parameters in comparison to alternative balance training programs (AT) is as yet unclear.

Objective To examine and classify the effects of VRT on fall-risk relevant balance performance and functional mobility compared to AT and an inactive control condition (CON) in healthy seniors.

Data Sources The literature search was conducted in five databases (CINAHL, EMBASE, ISI Web of Knowledge, PubMed, SPORTDiscus). The following search terms were used with Boolean conjunction: (exergam* OR exer-gam* OR videogam* OR video-gam* OR video-based OR computer-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*).

Study Selection Randomized and non-randomized controlled trials applying VRT as interventions focusing on improving standing balance performance (single and double leg stance with closed and open eyes, functional reach test) and functional mobility (Berg balance scale, Timed-up and go test, Tinetti test) in healthy community-dwelling seniors of at least 60 years of age were screened for eligibility.

Data Extraction Eligibility and study quality (PEDro scale) were independently assessed by two researchers. Standardized mean differences (SMDs) served as main outcomes for the comparisons of VRT versus CON and VRT versus AT on balance performance and functional mobility indices. Statistical analyses were conducted using a random effects inverse-variance model.

Results Eighteen trials (mean PEDro score: 6 ± 2) with 619 healthy community dwellers were included. The mean age of participants was 76 ± 5 years. Meaningful effects in favor of VRT compared to CON were found for balance performance [$p < 0.001$, SMD: 0.77 (95 % CI 0.45–1.09)] and functional mobility [$p = 0.004$, SMD: 0.56 (95 % CI 0.25–0.78)]. Small overall effects in favor of AT compared to VRT were found for standing balance performance [$p = 0.31$, SMD: −0.35 (95 % CI −1.03 to 0.32)] and functional mobility [p = 0.05, SMD: −0.44 (95 % CI: −0.87 to 0.00)]. Sensitivity analyses between “weaker” ($n = 9$, PEDro ≤ 5) and “stronger” ($n = 9$, PEDro ≥ 6) studies indicated that weaker studies showed larger effects in favor of VRT compared to CON regarding balance performance ($p < 0.001$).

Conclusions Although slightly less effective than AT, VRT-based balance training is an acceptable method for improving balance performance as well as functional mobility outcomes in healthy community dwellers. VRT might serve as an attractive complementary training approach for the elderly. However, more high-quality research is needed in order to derive valid VRT recommendations compared to both AT and CON.

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Key Points

Virtual reality training notably improves balance and functional mobility in community-dwelling seniors compared to an inactive control condition.

Alternative training reveals slightly superior effects on balance and functional mobility compared to virtual reality training.

Larger effect sizes are relevantly driven by lower quality studies (PEDro score: ≤5).

1 Introduction

Biological aging is accompanied by physical deconditioning that contributes to an elevated fall risk [1]. About one-third of seniors aged >65 years fall once a year and half of those fall again within the subsequent year [2]. Falls are a leading cause of hospitalization due to injuries [3] and result in immense healthcare expenditures [4]. Declines in strength (explosive and maximal) and balance (static and dynamic) performance were reported to contribute to an increased fall risk [5]. Regular neuromuscular exercise in the context of fall prevention studies can result in meaningful reductions of fall events [6]. Applied exercise within a multimodal setting [7] should provide a moderate to high challenge to balance including, e.g., gradually reduced base of support, unstable surfaces, and sensory modulation [7, 8]. These fall preventive training criteria were recently extended to strength training on unstable surfaces (metastability) and trunk muscle training [9, 10]. Thus, neuromuscular fall prevention training should utilize a multimodal training setting with a variety of different and progressively challenging strength and balance tasks [11].

Virtual reality training (VRT) programs using commercial consoles (e.g., Nintento Wii, Playstation EyeToy, Microsoft Kinect, DanceDanceRevolution) are considered appealing, motivating, and encouraging exercise concepts in clinical and healthy populations [12–14]. This complementary and alternative training mode might bridge the gap between playing games and exercising, commonly termed "exergaming." Exergaming uses a virtual reality environment and has been employed to improve general physical fitness [15] and for therapeutic purposes (e.g., cardiac rehabilitation, neuro-rehabilitation) [16, 17]. Depending on the type of underlying body movements, the resulting energy expenditure of exergames commonly varies from light to moderate [18].

In recent years, VRT has also been applied to older populations. This approach seems to be a promising means to integratively tackle increasing cognitive and physical dysfunction in seniors [19]. The majority of available exergaming studies in seniors focused on balance and gait training. Stepping as well as static and dynamic balance tasks were playfully arranged within these training concepts [20]. Although the training regimes (type of exercise, duration, repetitions, and sets) vary between studies, most available studies revealed positive effects of exergaming on balance parameters in the elderly [12, 21].

Previous reviews did not perform meta-analytical statistics that distinguish between effects of VRT compared to (a) a control condition without any exercises and (b) an alternative exercise-based training regime (AT) that can also improve balance performance and functional mobility. Although the superiority of VRT compared to an inactive control seems obvious, such an approach, however, provides an estimate on the relationship between VRT and AT regarding improvements of fall-related balance and functional mobility outcomes. Future developments of how to set up exergaming (e.g., with regard to exercise type, duration, frequency, repetitions) might benefit from the present findings. As a consequence, the present meta-analytical review aimed at comparing effects of exergaming versus a control condition and/or versus an alternative balance-based exercise intervention.

The resulting objectives were:

1. To calculate and classify the effects of VRT compared to AT and CON in healthy community-dwellers
2. To comparatively describe the training characteristics of VRT and AT for older people
3. To provide recommendations for future research in the field of VRT in seniors.

2 Methods

2.1 Search Strategy and Study Selection

The reporting of this meta-analytical review was performed according to the PRISMA guidelines [22]. The literature search was independently conducted by two researchers (LD and RR). Searches for studies were conducted in five health-related, biomedical, and psychological databases (CINAHL, EMBASE, ISI Web of Knowledge, PubMed, and SPORTDiscus). The literature search was conducted from inception of the respective journal until 10 June 2015. Relevant search terms (operators) were combined with Boolean conjunction (OR/AND) and applied on three search levels (Table 1).

Citation tracking of the articles as well as hand searching of important primary articles and review articles were additionally carried out. After removing duplicates

Table 1 Levels and terms of the literature search process

Search level	Search terms with Boolean operators
Search #1	exergam* OR exer-gam* OR videogam* OR video-gam* OR video-based OR computer-based OR Wii OR Nintendo OR X-box OR Kinect OR play-station OR playstation OR virtua* realit* OR dance dance revolution
Search #2	#1 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*)
Search #3	#2 AND (old* OR elder* OR senior*)

the remaining studies underwent a manual screening process. Three search levels of screening (1) title, (2) abstract, and (3) full-text were applied. Irrelevant articles were excluded. According to the criteria listed below, a final inclusion/exclusion decision was made by three independent researchers (LD, RR, and OF).

The following inclusion criteria were used:

- Full-text article published in English in a peer-reviewed journal
- Prospective randomized-controlled and non-randomized controlled intervention study with pre-post testing
- At least one control group that either did not receive any intervention (CON) and/or received a comparative alternative exercise-based training program
- VRT served as the target interventional strategy
- Study included only healthy community-dwelling seniors without neurological, orthopedic, and/or cardiac conditions
- Exercise and video-based intervention program that intended to improve standing balance and/or functional outcomes
- Participants were at least 60 years of age.

The exclusion criteria were:

- Seniors with mental decline, chronic cardiac, orthopedic, and/or neurological conditions
- Hospitalized and/or institutionalized seniors
- Seniors with a serious fall event that led to medical attention (e.g., broken bones) within 1 year prior to the start of the study
- Inappropriate target outcome (see inclusion criteria)
- Study without comparison group (neither passive control nor traditional exercise group)

2.2 Assessment of Methodological Quality

The methodological quality of the included randomized controlled trials was rated using the PEDro scale. This scale comprises 11 dichotomous items (either yes or no). Studies were rated by two reviewers independently (LD and OF). After completing the evaluation, both examiners came to a consensus on every item. The raters were not blinded to study authors, place of publication, and results.

2.3 Data Extraction

Functional mobility outcomes (Timed-up and go test (TUG), Berg balance scale, Tinetti test) and balance performance indices (functional reach (FR), single leg stance with open eyes (SLEO) and closed eyes (SLEC), double leg stance with open eyes (DLEO) and closed eyes (DLEC) were extracted by two researchers (LD and RR). Data were transferred to an excel spread sheet. Relevant study information regarding author, year, number of participants, exergaming, and balance control intervention (weeks, frequency, duration per session, exercises including repetitions), and passive control condition were extracted. Available training characteristics (volume, frequency, intensity, type) were noted (Table 2).

2.4 Statistical Analysis

Standardized mean differences (SMD, with 95 % confidence intervals (CIs)) were computed separately for each study. Therefore, the difference of the target outcome between the intervention and the respective control condition including the pooled standard deviations were computed for each functional mobility or standing balance outcome. Standard errors were transformed to standard deviations by multiplying standard errors by the square root of the sample size. If studies only descriptively reported median, minimum, and maximum values [23–25], means and standard deviations were estimated using the formula described in detail by Hozo and colleagues [26]. Negative effects were symbolized with a minus sign. The Cochrane Review Manager Software (RevMan 5.3, Cochrane Collaboration, Oxford, UK) was used to compute the inverse-variance method according to Deeks and Higgins 2010 [27]. Analyses were conducted using the random effects model [28]. Forest plots were generated for the respective outcome measures. The magnitude of SMD was classified according to the following scale:

Table 2 Overview of the included studies

Reference	Study design	Sample: population; sample size (n); age, years (mean ± SD)	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Bateni (2012) [23]	Preliminary controlled trial, three arms	Healthy community-dwellers with history of falls, $n = 17$; 73 ± 14 year	BAL ($n = 6$) BAL + Wii ($n = 6$) Wii ($n = 5$)	Supervised training: (a) Wii, balance board (ski slalom, ski jump, table tilt) (b) BAL, traditional balance and strength training	4 weeks, 3 sessions/week (2 times 6 sessions = 12); each game 3 times/session	BBS	3
Bieryla and Dold (2013) [24]	Randomized controlled trial, two arms	Healthy, independently living seniors, $n = 12$; 82 ± 6 years	Wii ($n = 4$) CON ($n = 5$)	Supervised training: (a) Wii, balance board (yoga: half-moon, chair, warrior; aerobic: torso twist; balance: soccer heading, ski jump) (b) CON, continued daily activities	3 weeks, 3 sessions/week, 30 min/session	BBS FR TUG	5
Cho et al. (2014) [32]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 32$; 72 ± 1 years	Wii ($n = 17$) CON ($n = 15$)	Supervised training: (a) Wii, balance board (ski slalom, table tilt, balance bubble) (b) CON, no intervention	8 weeks, 3 sessions/week; 30 min/session = 10 min for each program	Postural sway path during DLEC, DLEO	4
Franco et al. (2012) [43]	Randomized controlled trial, three arms	Healthy, independently living seniors, $n = 32$; 78 ± 6 years	Wii ($n = 11$) BAL ($n = 11$) CON ($n = 10$)	Supervised training: (a) Wii, balance board (soccer heading, ski jumping, ski slalom, tight rope, table tilt, balance bubble) (b) BAL(MOB approach), 8 to 15 repetitions of each balance/strength exercise (c) CON, no intervention	3 weeks, 2 sessions/week (a) Wii: 13 min total playing time/session (b) BAL: 30-45 min/session	BBS Tinetti	5
Jorgensen et al. (2013) [33]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 58$; 75 ± 6 years	Wii ($n = 28$) CON ($n = 30$)	Supervised training: (a) Wii, balance board (ski slalom, tight rope, table tilt, perfect 10, penguin slide, standing rowing squats for strength) (b) CON, shoes with copolymer insoles	10 weeks, 2 sessions/week, 35 ± 5 min/session	TUG Postural sway velocity during DLEO	9
Jung et al. (2015) [51]	Randomized controlled trial, three arms	Healthy community-dwellers with history of falls, $n = 24$; 74 ± 3 years	LS ($n = 8$) Wii ($n = 8$) CON ($n = 8$)	Supervised training: (a) LS (7 positions based on back bridge on hands and knees, side bridge) (b) Wii (wakeboard, frisbee dog, jet ski, canoe game) (c) CON, no intervention	8 weeks, 2 sessions/week; 30 min/session, LS: 15 s, 3 sets, 7 exercises Wii: 3 favorite games, 3 times 10 min	BBS FR TUG	5

Table 2 continued

Reference	Study design	Sample: population; sample size (n); age, years (mean ± SD)	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Maillot and Perrot (2012) [34]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 32$; 73 ± 4 years	Wii ($n = 15$) CON ($n = 15$)	Supervised training: (a) Wii, balance board and controller (tennis, boxing, bowling, ski jump, soccer heading, marble game, ski slalom, hula hoop, trampoline) (b) CON, no treatment	12 weeks, 2 sessions/week; 60 min/session	TUG	7
Merriman et al. (2015) [30]	Pseudo-randomized controlled trial, two arms	78 % healthy community-dwellers, 22 % sheltered accommodation, partly a history of falls, $n = 76$; 73 ± 4 years	VRT ($n = 15$) CON ($n = 15$)	Supervised training: (a) VRT, two games comprising weight shifting ("apple tree", "sea scape") (b) CON, diary of daily activity (categories: light, medium, heavy)	5 weeks, 2 sessions/week; 30 min/session	BBS Postural sway accuracy during DLEO	3
Nicholson et al. (2015) [31]	Controlled trial, two arms	Healthy community-dweller, $n = 41$; 75 ± 5 years	Wii ($n = 19$) CON ($n = 22$)	Unsupervised training: (a) Wii, balance board and controller (soccer heading, penguin slide, ski slalom, ski jump, table tilt, snowball fight, perfect 10, tightrope walking) (b) CON, no treatment	6 weeks, 3 session/week; 30 min/session	TUG FR SLEO	5
Park et al. (2015) [35]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 30$; 73 ± 4 years	Wii ($n = 15$) BET ($n = 15$)	Supervised training: (a) Wii, balance board (soccer heading, snowboard slalom, table tilt) (b) BET (bouncing, pelvic tilting and circling, bridging feet on ball supine position)	8 weeks, 3 sessions/week; 30 min/session, Wii: 10 min each game BET: 20 + 10 min	TUG Postural sway path during DLEO	5
Pluchino et al. (2012) [41]	Randomized controlled trial, three arms	Healthy community-dwellers, $n = 40$; 76 ± 8 years	Wii ($n = 15$) BAL ($n = 8$) Tai Chi ($n = 11$)	Supervised training: (a) Wii, balance board (soccer heading, ski slalom, ski jump, table tilt, tight rope, river bubble, penguin slide, lotus focus) (b) BAL (14 drills: e.g., Stepping, walking uphill, obstacle walking, pivoting, standing, lifting weights, chair rise, stair climbing) (c) Tai-Chi (4 styles: Chen, Wu, Yang, Sun): slow and continuous movements with forward, backward steps, knee bends, weight shifts	8 weeks, 2 sessions/week; 60 min/session (5 min warm-up, 50 min main part, 5 min cool-down) Wii: 5 of 8 games a 10 min/session BAL: 7 of 14 drills with progressively increasing difficulty (BoS, speed, vision) Tai-Chi: 12 movement drills	TUG FR Postural sway velocity (DLEO) and path (SLEO)	6

Table 2 continued

Reference	Study design	Sample: population; sample size (*n*); age, years (mean ± SD)	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Rendon et al. (2012) [25]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 34$; 84 ± 5 years	Wii ($n = 16$) CON ($n = 18$)	Supervised training: (a) Wii, balance board (lunges, single leg extension, twists) (b) CON, no treatment	6 weeks, 3 sessions/week; 35–45 min/session	TUG	7
Schoene et al. (2013) [36]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 32$; 78 ± 5 years	DDR ($n = 16$) CON ($n = 18$)	Unsupervised training: (a) DDR, stepping (easy, medium, hard determines steps at various speeds with different objects and distraction) (b) CON, no treatment	8 weeks, 2-3 sessions/week, 15–20 min. One step session took ~5 min (15/16 participants exercised 8 weeks; 2.8 session attendance/week, 15 min per session)	Postural sway path during DLEO TUG	8
Schwenk et al. (2014) [37]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 30$, 85 ± 7 years	VRT ($n = 15$) CON ($n = 15$)	Supervised training: (a) VRT (ankle point to point reaching, obstacle crossing tasks) (b) CON, no treatment	4 weeks, 2 sessions/week, 45 min	TUG Postural sway area during DLEO	7
Singh et al. (2013) [38]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 36$, 63 ± 5 years	VRT ($n = 18$) CON ($n = 18$)	Supervised training: (a) Wii, balance board (soccer heading, ski slalom, table tilt, tight rope, perfect 10, tilt city, penguin slide) (b) BAL (Seidler and Martin protocol: one leg standing, free leg swinging, moving objects forward/backward/sideward, walking in place (sideways, backwards)	4 weeks, 2 sessions/week, 30 min + 5 min warm-up + 5 cool-down, Wii: individual level progression: beginner, advanced, experts BAL: progression via exercise speed, eyes open or closed, task complexity	TUG Postural sway index (OPI)	7
Szturm et al. (2011) [39]	Randomized controlled trial, two arms	Healthy community-dwellers, $n = 27$, 81 ± 7 years	VRT ($n = 13$) BAL ($n = 14$)	Supervised training: (a) VRT (COP shifting games: under pressure, memory match, balloon burst) (b) BAL, strength and balance training + gait re-education between bars + ergometer cycling (flexible Bands, leg weights: leg raises, squats, standing and sitting from chair)	8 weeks, 2 sessions/week, 45 min, progression via mat thickness, speed, target size	BBS TUG Standing time SLEO	7
Toulotte et al. (2012) [44]	Randomized controlled trial, four arms	Healthy community-dwellers, $n = 36$, 76 ± 7 years	PE; ($n = 9$) Wii ($n = 9$) PE + Wii ($n = 9$) CON ($n = 9$)	Supervised training: (a) PA (strength exercise, stepping, balance with open and closed eyes) (b) Wii (soccer heading, ski jump, yoga, game balls, tight rope)	20 weeks, 1 session/week, 60 min, progression via repetitions and difficulty	Tinetti	5

Table 2 continued

Reference	Study design	Sample: population; sample size (*n*); age, years (mean ± SD)	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Lai et al. (2013) [40]	Randomized controlled trial, two arms	Healthy community-dwellers, *n* = 30, 72 ± 5 years	VRT (*n* = 13) BAL (*n* = 14)	Supervised training: (a) VRT (stepping exercise) (b) CON, no treatment	6 weeks, 3 sessions/week, 30 min	BBS TUG Postural sway SLEO, DLEC and DLEO	7

BAL balance training, *Wii* Nintendo interactive gaming console, *VRT* virtual reality training, *LS* lumbar stability training, *BBS* Berg balance scale, *FR* functional reach test, *TUG* timed up and go test, *CON* control condition, *DLEC* double limb stance, eyes closed, *DLEO* double limb stance, eyes opened, *MOB* matter of balance training approach, *BET* ball exercise training, *OPI* overall postural performance index derived from medio-lateral and anterior-posterior sway, *COP* center of pressure, *PE* physical exercise, *DDR* Dance Dance Revolution, *SLEO* single limb stance, eyes open, *BoS* Base of support, SD standard deviation

0–0.19 = negligible effect, 0.20–0.49 = small effect, 0.50–0.79 = moderate effect and 0.80 = large effect [29]. To examine a potential publication bias a qualitative funnel plot evaluation was performed. Furthermore, risk-of-bias-related sensitivity analyses between "weak" (≤5 PEDro scale) and "strong" (≥6 of PEDro scale) studies were performed for standing balance and functional mobility outcomes. Statistical analyses were performed using the software package Statistica 10.0 and Cochrane Review Manager Software (RevMan 5.3, Cochrane Collaboration, Oxford, UK).

3 Results

3.1 Trial Flow

In total 4063 potentially relevant articles were found (Fig. 1). After removing duplicates, 2949 article titles were carefully screened for relevance. The abstracts of the remaining 153 potentially relevant articles were thoroughly studied. Fifty-four full-texts were further perused of which

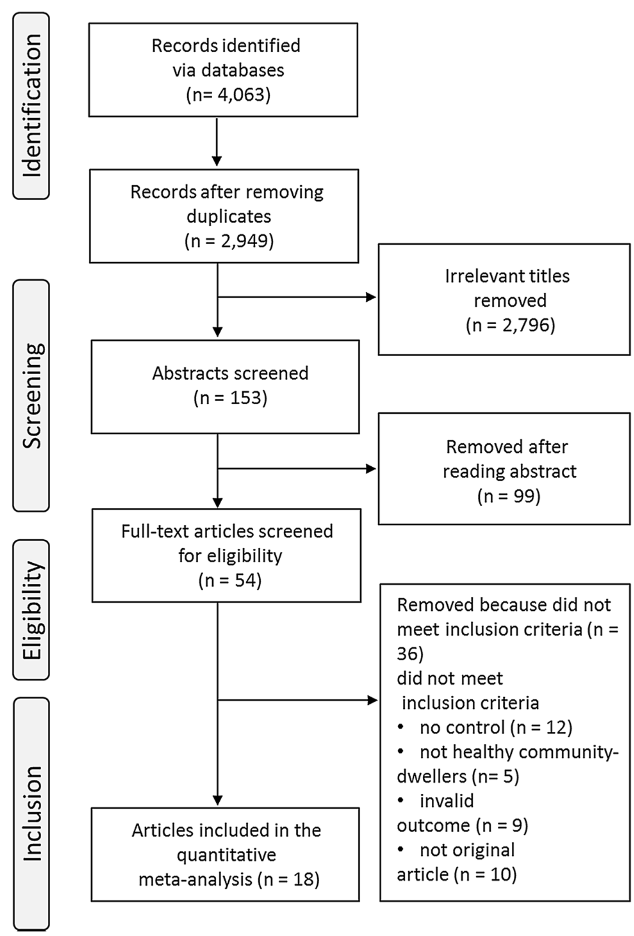


Fig. 1 Flow of study screening and selection

36 did not meet the inclusion criteria or were excluded according to the exclusion criteria. Eighteen studies were finally included in the quantitative meta-analysis. All studies were published in 2011 or later.

3.2 Study Population and Quality

Six hundred and nineteen healthy community dwellers with a mean age of 76 ± 5 years were enrolled in the 18 included trials. The mean sample size was 32 ± 10 ranging from 12 [24] to 76 [30] seniors. The sample sizes among the studies were not normally distributed (Kolmogorov–Smirnov test: $p = 0.003$). Trials comprised various study arms: passive control condition (total number of participants, $n = 183$), virtual reality training ($n = 275$), VRT + traditional balance training ($n = 15$), traditional balance training ($n = 61$), ball exercise training ($n = 15$), Tai Chi ($n = 11$), and specific physical activity ($n = 9$). We grouped balance training, ball exercise training, Tai Chi, and specific physical activity under the heading "alternative balance-based exercise training" ($n = 96$). The remaining participants underwent a combination of Wii and balance training ($n = 15$) or dropped out ($n = 50$, for reasons of illness, changed location, lack of attendance, or no reason available). Thus, 554 participants (619 − (15 + 50); 89 %) were considered in the final meta-analyses.

Only three of the 18 studies did not apply a standard randomization procedure for group assignment [23, 30, 31]. Thirteen trials used a two-armed design [24, 25, 30–40], four studies a three-armed design [23, 41–43], and one study a four-armed study design [44]. The mean study quality (PEDro score) was 6 (2), ranging from 3 [23, 30] to 9 [33] (Table 3). As blinding is difficult in exercise intervention studies most of the trials did not blind the participants, supervisors, or testing personnel. Four weak studies with a PEDro score of ≤5 did not report inclusion and exclusion criteria [23, 24, 30, 31].

3.3 Risk of Bias Assessment

3.3.1 Publication Bias

The funnel plots did not show a clear funnel-shape (Fig. 2). Studies with smaller sample sizes (higher standard errors) that normally build the basis of the funnel shape are missing. To a certain extent, it seems that studies with findings not favoring VRT and with larger typical errors (dots on the lower right side of the dashed mean line) are also lacking. The amount of studies on the left and right side of the dashed standardized mean difference (SMD) line is equally distributed, except for the comparison of VRT versus CON regarding functional mobility.

3.3.2 Sensitivity Analyses

We conducted sensitivity analyses on the basis of the PEDro score. Studies with a PEDro score of 5 and lower were labelled as "weaker" ($n = 9$) and studies with a PEDro score of 6 and higher as "stronger" ($n = 9$). With respect to functional mobility outcomes, only one study (VRT vs. AT [35]) and three studies (VRT vs. CON [37, 40, 45]), respectively, had "strong" study quality according to the PEDro scale. Thus, we only computed sensitivity analyses for balance performance indices separately for VRT versus CON and VRT versus AT. We found large differences between "weak" and "strong" studies when comparing VRT with CON ($p = 0.02$, $I^2 = 81$ %; Fig. 3). "Weak" studies showed a more pronounced effect in favor of VRT versus CON compared to "strong" studies. Interestingly, no statistically significant difference was found between "weak" and "strong" studies when comparing VRT versus AT ($p < 0.23$, $I^2 = 31$ %; Fig. 4). However, the effects in favor of AT compared to VRT were less clear in the subgroup of "strong" studies.

3.4 Data Analyses of Virtual Reality Training versus Control

Medium overall effects with narrow confidence limits were found for standing balance performance ($p < 0.001$, SMD: 0.70 (95 % CI 0.42–0.99), $I^2 = 53$ %; Fig. 3) and functional mobility outcomes ($p < 0.001$, SMD: 0.54 (95 % CI 0.24–0.84); $I^2 = 55$ %; Fig. 5) in favor of VRT compared to CON.

3.5 Data Analyses of Virtual Reality Training versus Alternative Treatment

Small overall effects were observed for standing balance outcomes ($p = 0.31$, SMD: −0.35 (95 % CI −1.03 to 0.32), $I^2 = 76$ %; Fig. 4) and functional mobility indices ($p = 0.05$, SMD: −0.44 (95 % CI −0.87 to 0.00), $I^2 = 63$ %; Fig. 6) in favor of AT compared to VRT.

3.6 Association Between Training Volume and Effect Sizes

When the number of total training sessions was multiplied by the duration of each session, moderate correlations between training volume and effect sizes were found for VRT versus AT regarding standing balance outcomes ($r = -0.71$, $p < 0.05$) and VRT versus CON regarding functional outcomes ($r = 0.73$, $p < 0.05$). VRT versus CON ($r = 0.23$, $p > 0.05$) for balance parameters and VRT versus AT ($r = -0.23$, $p > 0.05$) for functional outcomes did not reveal relevant correlations.

Table 3 PEDro criteria and sum scores of the included studies

Study and year	Eligibility specified	Subjects randomly allocated	Concealed allocation	Similar baseline values	Blinding of subjects	Blinding of therapist	Blinding of assessor	Dropout <15 %	Received treatment as allocated	Statistical between-group comparison	Point measures and variability provided	Sum (items 2 to 11)
Bateni 2012 [23]	–	–	–	–	–	–	–	√	√	–	√	3
Bieryla and Dold 2013 [24]	–	√	√	√	–	–	–	–	√	√	–	5
Cho et al. 2014 [32]	√	√	–	√	–	–	–	√	√	–	√	5
Franco et al. 2012 [43]	√	√	–	√	–	–	–	√	–	√	√	5
Jorgensen et al. 2012 [33]	√	√	√	√	√	–	√	√	√	√	√	9
Jung et al. 2015 [51]	√	√	–	√	–	–	–	√	√	√	–	5
Lai et al. 2013 [40]	√	√	–	√	–	–	√	√	√	√	√	7
Maillot and Perrot 2012 [34]	√	√	√	√	–	–	–	√	√	√	√	7
Merriman et al. 2015 [30]	–	–	–	–	–	–	–	–	√	√	√	3
Nicholson et al. 2015 [31]	–	–	–	√	–	–	–	√	√	√	√	5
Park et al. 2015 [35]	√	√	–	√	–	–	–	–	√	√	√	5
Pluchino et al. 2012 [41]	√	√	√	√	–	–	–	–	√	√	√	6
Rendon et al. 2012 [25]	√	√	√	√	–	–	√	–	√	√	√	7
Schoene et al. 2013 [36]	√	√	√	√	–	–	√	√	√	√	√	8
Schwenk et al. 2014 [37]	√	√	√	√	–	–	√	√	√	√	–	7

Table 3 continued

Study and year	Eligibility specified	Subjects randomly allocated	Concealed allocation	Similar baseline values	Blinding of subjects	Blinding of therapist	Blinding of assessor	Dropout <15 %	Received treatment as allocated	Statistical between-group comparison	Point measures and variability provided	Sum (items 2 to 11)
Singh et al. 2013 [38]	√	√	√	√	–	–	√	√	√	√	–	7
Szturm et al. 2011 [39]	√	√	√	–	–	–	√	√	√	√	√	7
Toulotte et al. 2012 [44]	√	√	√	–	–	–	–	√	√	√	–	5

4 Discussion

No previous reviews have pooled data for a meta-analysis that specifically determined the effects of VRT on balance and functional mobility outcomes in healthy community dwellers by comparing VRT with both an AT and an inactive control condition. Our meta-analytical approach provides an estimate whether VRT or AT induces superior effects on balance performance and functional mobility outcomes. As a consequence, one can indirectly conclude whether VRT can be considered an alternative or complementary training strategy to improve relevant fall-risk factors. We found that VRT can be employed to improve balance performance and functional mobility in healthy community dwellers. However, our meta-analyses revealed more pronounced effects in favor of AT regarding functional mobility outcomes when compared with VRT. Standing balance performance comparison only revealed small effects in favor of AT compared to VRT. Sensitivity analyses, however, indicated that the magnitude of the overall effect is mainly driven by comparatively weaker studies with a PEDro score of 5 and lower.

4.1 Comparison with Other (Systematic) Reviews

Most of the available reviews on VRT in the elderly have been published within the last 2 years [46–50]. The included studies provide notable heterogeneity regarding age (older adults to old seniors), clinical background (healthy to clinical conditions), institutionalization (independently living to residential care) of the elderly, study quality (many low quality trials to few high quality trials), target outcomes (cognition, physical function, psychosocial health, balance, flexibility), and interventional programs (no control, two to four arms, poor to detailed description of the interventional details—such as frequency, volume, intensity, type, repetitions, pause). However, our study also comprises notable heterogeneity in terms of multiple study arms, lack of blinding, and diverse AT program contents. The most recent review included 22 empirical studies that revealed positive effects of Wii-based exergaming on physical and cognitive function as well as psychosocial outcomes (depression, quality of life) in seniors between 61 and 86 years of age [50]. The exercise duration varied between 2–20 weeks. Training attendance ranged from 72–100 %. Clinical (e.g., patients suffering from Parkinson disease, Alzheimer disease or stroke) and healthy participants were considered. As with the current meta-analysis, study quality was variable (e.g., uncontrolled studies, lack of randomization, and blinding). In comparison, our study also included three non-randomized and 17 non-blinded studies. Blinding of exercise intervention has been

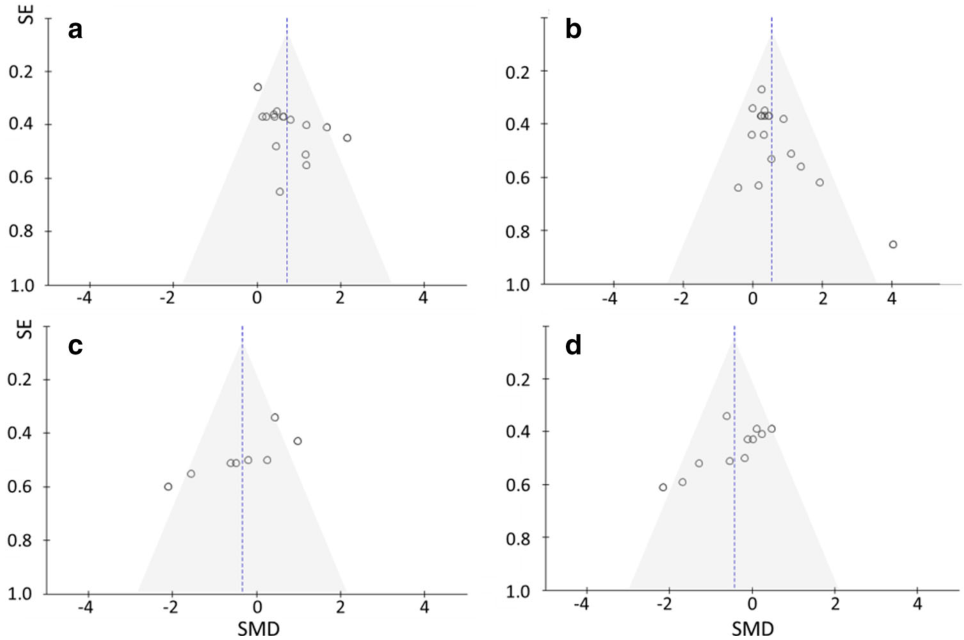


Fig. 2 Funnel plot for publication bias assessment: (**a**) standing balance VRT vs. CON; (**b**) functional mobility VRT vs. CON; (**c**) standing balance VRT vs. AT; and (**d**) functional mobility VRT vs. AT. The *dashed line* indicates the mean SMD. *VRT* virtual reality training, *CON* control, *AT* alternative exercise training, *SE* standard error, *SMD* standardized mean difference

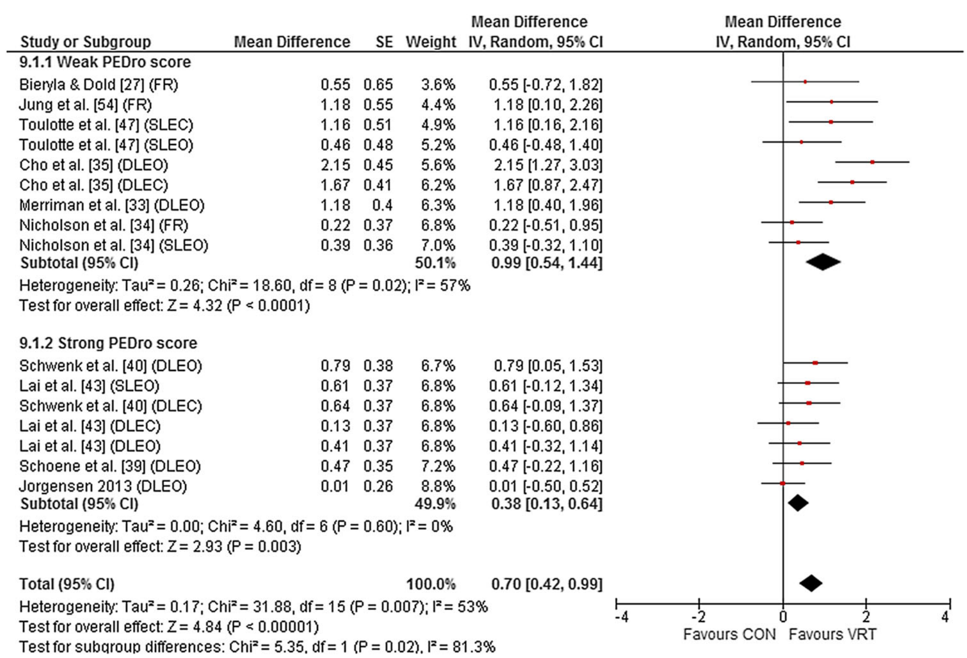
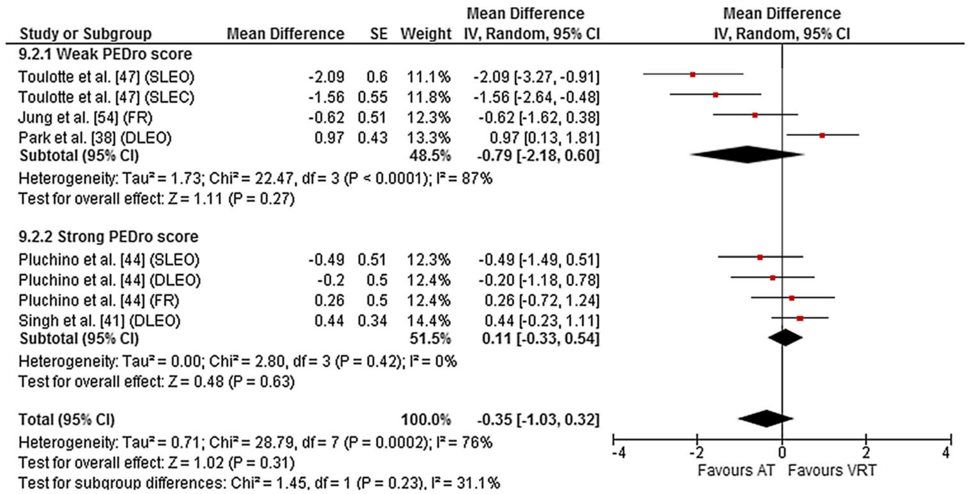


Fig. 3 Forest plots of the sensitivity analysis on standing balance performance between virtual reality training (VRT) vs. inactive control (CON) for "weak" and "strong" PEDro score studies. *SE* standard error, *IV* independent variable, *CI* confidence interval, *FR* functional reach test, *SLEC* single leg stance eyes closed, *SLEO* single leg stance eyes open, *DLEO* double leg stance eyes open, *DLEC* double leg stance eyes closed

frequently considered very challenging. The review article of Chao and colleagues concluded that Wii exercise can be feasibly employed as an adjunct therapy in therapeutic settings. However, a systematic meta-analytical comparison between an alternative exercise-based treatment and inactive control condition was not conducted. In line with our meta-analysis, the review by Bleakley and co-workers [49] also revealed evidence that interactive computer gaming beneficially affects physical and cognitive function in healthy community-dwelling and residential seniors with mild depressive symptoms, balance disorders, and a history of falls in a similar age range. Comparable to our study, the database was not large and included subjects varying in terms of clinical background and institutionalization. However, focusing on non-institutionalized healthy seniors without clinical conditions decreases variability of the data pool. Moreover, quantitative meta-analytical comparisons of VRT with alternative exercise programs (e.g., Tai Chi, strength and balance training, stabilization) is lacking [41, 43, 44, 51] and the study quality of the four cited studies

Fig. 4 Forest plots of the sensitivity analysis on standing balance performance between virtual reality training (VRT) vs. alternative exercise training (AT) for "weak" and "strong" PEDro score studies. *SE* standard error, *IV* independent variable, *CI* confidence interval, *FR* functional reach test, *SLEC* single leg stance eyes closed, *SLEO* single leg stance eyes open, *DLEO* double leg stance eyes open, *DLEC* double leg stance eyes closed



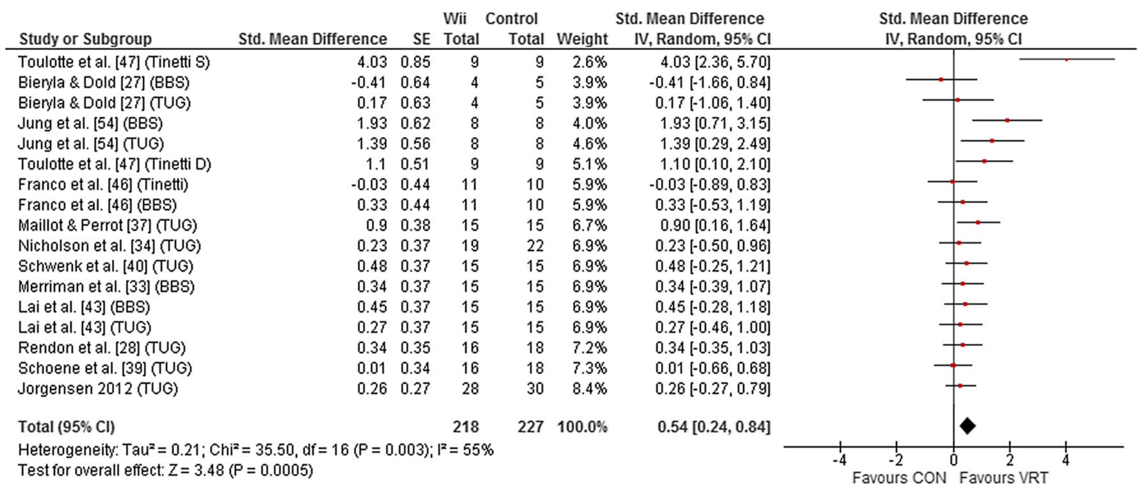


Fig. 5 Functional mobility outcomes for virtual reality training (VRT) vs. control (CON) groups. *SE* standard error, *CI* confidence interval, *Std.* standardized, *IV* independent variable, *BBS* Berg balance scale, *TUG* Timed up and go test

was considered moderate (5–6 of the PEDro score). This is also true for our comparison. Only 50 % of the studies included in our meta-analytical review met adequate study quality criteria above a PEDro score of 5. In this regard, Bleakley and colleagues though concluded that interactive video-gaming might be a safe and effective intervention for cognitive and physical function in seniors, but also called for more tailored, sustainable, motivational, and high quality trials (blinding outcome assessment, intention to treat analyses, subgroup analyses, and clear dosage recommendations) in the long term [49].

Another systematic review by Laufer and co-workers [12] concluded that Wii-based exercise training can be regarded as an appropriate balance training alternative compared to an AT in independently functioning older adults. Although Laufer and colleagues only considered trials with a PEDro score higher than 4, only three of the seven included trials comprised a comparison between Wii and an alternative exercise condition. Hence, this conclusion was obtained despite a lack of data and quantitative analyses. Corroboratively, a further review on balance improvements in healthy community dwellers by Molina and colleagues [48] emphasizing potential benefits of VRT on physical function in seniors also evaluated a small database and did not conduct quantitative analyses. However, Molina and colleagues also pointed to a lack of methodologically suitable studies (lacking data on minimal clinical important differences, inappropriate statistical analyses and lacking sample size estimations, unclear exercise prescriptions in terms of games and dosage). As comparisons to alternative exercise treatment are scarcely available to date, recommendations on the use of VRT as an alternative treatment approach (e.g., for physical function, cognition, balance, functional mobility) should be interpreted cautiously on the basis of the available randomized controlled trials. Most studies were conducted

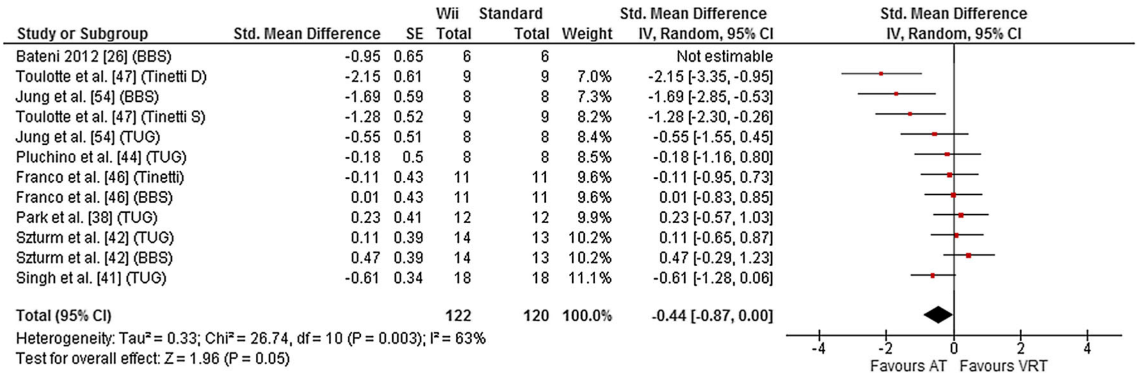


Fig. 6 Functional mobility outcomes compared between virtual reality training (VRT) and alternative treatment (AT). *SE* standard error, *CI* confidence interval, *Std.* standardized, *IV* independent variable, *BBS* Berg balance scale, *TUG* Timed up and go test

with seniors and more clinical applications have been called for. This conclusion has been further underpinned by Goble and co-workers [46]. Goble and colleagues found effects (partly moderate and large) of Wii-fit balance training on functional mobility (Berg balance scale, Tinetti test) and standing balance performance in neuro-rehabilitative settings. Goble and co-workers, however, called for VRT research on meaningful balance improvements in various clinical populations with larger sample sizes and multiple comparisons. Similarly, Schoene et al. [47] as well as Pichierri et al. [52] argued that limited high level evidence exists regarding the effects of interactive cognitive motor training (ICMT) on physical and cognitive function. Adequate longitudinal studies with clear endpoints (e.g., assessing fall rates) in the long term are needed.

4.2 Standing Balance Performance

VRT revealed a moderate effect on standing balance performance parameters compared to an inactive control condition. This effect clearly decreased after correcting for study quality. In contrast, AT showed small and slightly superior effects on balance performance compared to VRT. However, after adjusting for study quality this tendency disappeared.

4.2.1 Virtual Reality Training versus Control

The majority of the applied VRT games have been conducted on the Nintento Wii console using a stationary balance platform (force plate). Although functional aspects, such as stepping, obstacle and walking tasks were rarely considered within VRT concepts, meaningful effects on functional outcomes can be elicited by VRT [11, 20, 47, 52, 53]. In line with this point, VRT games require a dynamic and combined manipulation of the bodyweight. Simply standing still with a small center of pressure (COP) displacement and sway area or velocity is rarely required [54, 55]. As task execution of Wii-games differ depending on the game character, Wii games can be considered as functional. This statement is consistent with the task-specificity principle of neuromuscular training adaptations [55, 56]. Interestingly, Jung et al. [51] found very large improvements of FR performance [SMD: 1.8 (95 % CI 0.10–2.26)] after playing Wii games for 8 weeks twice a week, 30 min each. In turn, Nicholson et al. (2015) did not find meaningful improvements of FR [31]. Both studies had methodological limitations (Pedro score 5) and training outline (supervised vs. unsupervised) and volume (6 weeks vs. 8 weeks) differed in terms of functional demands and training volume. As neuromuscular training adaptations are considered task specific [55, 58, 59], VRT should comprise dynamic and functional balance demands. Otherwise, only small or absent transfer effects on upright standing with open or closed eyes can be achieved. Although standing balance testing during upright stance is often considered unspecific in terms of daily activities or fall-prone situations, there is evidence showing that sway velocity during static standing balancing provided notable predictive power for future fall events [59]. Moreover, simple standing balance tasks can be feasibly included into both VRT and traditional balance training approaches [7] designed according to current best practice recommendations for balance training in the elderly [8, 60] and multimodal agility-based approaches [11].

4.2.2 Virtual Reality Training versus Alternative Treatment

A small overall effect in favor of AT has been found. As this overall effect was mainly driven by weaker studies, the effect disappeared after adjusting for study quality. Only two studies comparing VRT and AT achieved PEDro scores above 5 [38, 41]. Both studies applied comparable training criteria in both the VRT and AT group. In this case, VRT and AT might be applied interchangeably in terms of standing balance performance improvements. However, the database for a conclusive statement on this issue is too small. Seniors' daily activities and functioning also rely on functional mobility with appropriate agility capacity enabling changes of movement patterns in time and space without losing balance [11, 61].

4.3 Functional Mobility

We found a moderate overall effect in favor to VRT compared to an inactive control condition. When comparing VRT with AT, functional mobility parameters seem to superiorly benefit from AT condition. Unfortunately, the overall quality of the studies addressing functional mobility outcomes was comparably low. Therefore, we refrained from conducting a quantitative sensitivity analysis in this regard.

4.3.1 Virtual Reality Training versus Control

Functional mobility outcomes seem to benefit from VRT using stationary balance training games compared to an inactive control condition. However, the effects sizes and confidence limits of studies with higher quality do not contribute to a clear picture. The largest effects have been shown by comparatively weaker studies [34, 44, 51]. These studies included comparably aged seniors of around 80 years. The applied games also required a certain amount of leg strength and reactivity. It seems reasonable to assume that increases of leg strength/power mainly account for the improvements of functional mobility. This assumption is in line with findings of Chen et al. [62] and Madureira et al. [63]. However, it needs to be noted that the participants included in these two studies were older women with meaningful clinical conditions (e.g., osteoporosis). It might be possible that transfer effects from standing balance games to functional mobility outcomes occur earlier and are more pronounced in frailer or older seniors having clinical conditions [57]. Interestingly, Singh and co-workers [38] found notable improvements of functional mobility (TUG, Ten step tests) after Wii-based VRT in female seniors. This finding is particularly interesting, since neuromuscular adaptations seem to be highly related to the trained task [56]. It seems that dynamic aspects and strength requirements of VRT training can provide notable stimuli to induce positive changes of functional mobility in seniors. These aspects should be further examined with regard to the population, training dosage, accompanied activities and clinical background conditions. To address these issues with certainty, studies examining performance related to strength, functional mobility, and standing balance independently after VRT in seniors are needed.

4.3.2 Virtual Reality Training versus Alternative Treatment

The overall effect on functional mobility favors AT compared to VRT. However, the largest effects in favor of AT have been derived from comparatively weaker studies [44, 51]. Jung and colleagues [51] applied lumbar stabilization as AT and Toulotte and co-workers [44] employed multimodal physical exercise as AT. Both AT programs included multimodal balancing, strength and stepping tasks that exceed the demands of stationary balance games of VRT. Higher quality trials showing trivial effect sizes [39, 41, 43] have used VRT programs that comprised similar training criteria and exercise characteristics compared to those of AT. Consequently, one might assume that VRT serves as an appropriate alternative training strategy in terms of functional mobility training [39]. However, Pluchino et al. [41] had a large dropout rate in the Wii-group and Szturm et al. [39] applied training tasks during their VRT session that were closely related to the Berg balance tests and Timed-up and go test in the evaluated cohorts. The generalizability of this assumption needs to be handled with caution.

4.4 Strengths and Limitations

The reporting of this systematic meta-analytical review was conducted according to the PRISMA statement [22]. This is the first meta-analysis that provides pooled effect sizes of VRT in comparison with an AT condition and an inactive control condition in healthy community-dwelling seniors. Sensitivity analyses enable a differentiation between studies with higher and lower quality as only a small number of studies could be identified for analysis. As a consequence, the "risk of bias assessment" should be interpreted cautiously when outcomes from one study are separately and multiply considered for calculation of the present meta-analysis. Thus, the weight of one study might be disproportionately high (e.g., VRT vs. AT: the cumulative weight of Pluchino et al. [41] is 37 %). However, this is a common meta-analytical procedure but should be taken cautiously into account, specifically in small databases.

Despite notable heterogeneity of the included studies (number of study arms, fallers vs. non-fallers, diverse alternative exercise programs), our findings provide a comprehensive, structured and quantitative view on current scientific evidence regarding the effects of VRT on balance and functional mobility outcomes. Previous systematic reviews also comprised notable heterogeneity and did not provide quantitative analyses, due to a lack of data and varying target outcomes among the included studies. The 18 studies included in this meta-analysis though provide a sufficient data pool for specific meta-analyses on overall and subgroup effects, however, considered AT programs here also comprise noteworthy heterogeneity (e.g., comparing Tai-Chi with lumbar spine training). This might bias the effects as these training interventions do not primarily promote balance performance. Despite diverse AT characteristics, the effects on balance performance are notably higher compared to VRT that is intended to specifically challenge balance. This finding might be due to the fact that lumbar training tackles core performance that can also beneficially affect balance performance. High quality studies, particularly on functional mobility outcomes are very rare. This is particularly true with respect to randomization and assignment of the respective study populations, types of interventions (content, dose, and duration), appropriate statistics (power analyses and analyses of covariance to take baseline differences into account) and study duration. Many studies do not exceed preliminary evidence level as sample size estimations and clear primary endpoints were not adequately reported. Studies using a clear endpoint (fall rate) are lacking. However, most of these studies focused on feasibility, safety, compliance, and effectiveness in terms of fall predictors (e.g., balance, gait speed, lower limb strength). Such studies are needed prior to the initiation of larger scaled studies. Also studies that compare motivation, adherence and fall-related outcomes in home-based VRT settings including AT are not available. The results of this review may then help to shape future studies.

5 Conclusion

The present systematic review and meta-analysis reveals evidence that VRT may serve as an appropriate complementary training approach in order to improve balance and functional mobility in healthy community-dwelling seniors. VRT programs should be conducted in line with current best-practice recommendation of balance training in fall prevention studies [8]. Structured and multimodal AT seems to be slightly superior compared to the majority of VRT regimes and higher training volumes over time seem to increase the effect sizes. However, the gap between VRT and AT is smaller when training volume, time and exercise character are similar in both settings. The potential of VRT regarding fall prevention training should be rated with caution. An interchangeable use of VRT and AT seems to be only indicated when training time volume and content is comparable. Most of the applied VRT games merely performed tasks without changes in space or stepping tasks with cognitive demands in enrichment environments [47]. Obstacle tasks, stepping tasks, strength, and dynamic balance requirements for the limbs and trunk muscles should be tackled within VRT concepts. Thus, the requirements for appropriate balance and strength training in fall prevention studies [5, 7, 9] could be implemented into VRT concepts. Such considerations could be easily translated into appealing, easy applicable, and potentially cost-effective video-based training regimes (including for the home setting) or intergenerational balance training targeting fall prevention in the elderly [1].

Compliance with Ethical Standards

This article was written according to the ethical standards of scientific writing and publishing.

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