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Effects of stepping exergames under stable versus unstable conditions on balance and strength in healthy community-dwelling older adults: A three-armed randomized controlled trial

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ABSTRACT

Objective: This non-blinded, three-armed randomized controlled trial aimed at comparing the effects of volitional step training under stable and unstable conditions on balance, mobility and strength adaptations.
Methods: Fifty-one healthy and active older adults (age = 69.4 ± 5.6 years; BMI = 27.4 ± 4.6, physical activity = 9.2 ± 5.1 h/week) were allocated to either volitional stepping (VOL), volitional stepping under unstable conditions (VOL + US) or a control group (CON) using the minimization method. Participants underwent eight weeks of exergames based step training with three sessions per week. Pre- and Post-testing included reactive balance (postural sway upon perturbation), functional balance (Y-balance test) and mobility (timed up and go test) to compare the effects of both intervention groups. Strength was tested using the heel rise test and isometric leg extension and leg curl assessment to compare transfer effects of the intervention groups.
Results: Data of 45 participants was finally analyzed. Adherence was 87 ± 5% in the VOL + US group and 86 ± 6% in the VOL group. No adverse events occurred. Increased reactive balance was observed in VOL + US only ($p < 0.05$, standard mean difference (SMD) = 0.3) whereas both intervention groups improved functional balance ($p < 0.05$, SMD = 0.5–1.0). Only VOL + US led to improved functional mobility performance under dual-task conditions ($p < 0.05$, SMD = −0.4). Both VOL + US and VOL significantly improved calf strength endurance ($p < 0.05$, SMD = 0.7–0.8), whereas isometric strength of the thigh muscles revealed no significant changes ($p > 0.05$). Explosive strength (rate of force development) showed insignificant but medium interaction effects of the leg extensors in favor of VOL + US ($p = 0.08$, $\eta_p^2 = 0.12$, SMD = 0.2).
Conclusion: Volitional step training is an appealing and effective training tool to improve functional balance and calf strength in healthy older adults. Unstable volitional stepping seems to be superior in improving reactive balance and functional mobility under dual-task conditions. It appears that the volitional stepping under unstable conditions requires motor skills relevant for preventing falls since it is more tasks specific when compared to volitional stepping under stable conditions.

1. Introduction

Falls are considered a major health burden with utmost priority in aging western societies that result in enormous direct and indirect costs on medical care, individual and society level (Florence et al., 2018). Every third senior falls once a year (rates: 0.3–1.6 per person annually, weighted mean 0.65) and half of those are recurrent fallers (Rubenstein, 2006). Numerous external (e.g., lighting conditions, slippery surfaces, obstacles) and internal (e.g., gait, strength, balance) risk factors have been identified to account for injurious fall events (Almeida et al., 2012). Besides maintaining and regaining adequate cardiovascular fitness and activity levels, improving surrogate parameters such as balance and strength has been found to play a crucial role in preventing falls and fall risk factors (Clemson et al., 2012).

The latest meta-analysis on balance training and fall rate ratios conducted by Sherrington et al. (2019) reported fall rate reductions of

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around 20% (Sherrington et al., 2019). Even higher rates can be achieved when balance training is highly challenging and training exceeds 3 h per week (Sherrington et al., 2019). This finding has been generally confirmed by a dose-response meta-analyses on the effects of balance training on balance performance (Lesinski et al., 2015). The majority of the employed balance exercises are, however, static and dynamic balance tasks, where sensory input (e.g., eyes open or closed) and ground surface (e.g., foam, mats, firm) are altered. These programs lack specificity, which impairs their effectiveness to reduce or prevent falls. A more specific form of balance training for falls prevention is step training. A recently published meta-analysis by Okubo et al. (2017) found that volitional and reactive step training can remarkably reduce fall rates by 50% (Okubo et al., 2017). Step training addresses the execution of correct, rapid and well-directed steps which is crucial to prevent falls. It reduces falls even more than general exercise, probably due to greater specificity, addressing neuropsychological and sensorimotor skills that help avoiding falls (Okubo et al., 2017). Reductions of laboratory-induced falls and improved choice reaction time, static, dynamic and functional balance performance were observed with step training. Stepping tasks also play a prominent role in training approaches based on exergames (Donath et al., 2016). Volitional step training under unstable conditions might offer an even more specific training approach compared to volitional stepping under stable conditions. Studies on traditional balance training under unstable conditions show that it is effective for older adults to improve static and dynamic balance (Martínez-Amat et al., 2013; Ogaya et al., 2011). Meta-analytical data on stroke patients even indicated a superiority of balance training under unstable conditions compared to training under stable conditions for static and dynamic balance (van Criekinge et al., 2018). However, there is a lack of knowledge regarding the effects of volitional step training under unstable conditions compared to stable conditions and an inactive control group.

Therefore, the two objectives of the present randomized controlled trial (RCT) were a) to compare the effects of volitional stepping exergames under stable and unstable conditions on a variety of reactive and dynamic balance and mobility tasks and b) to investigate potential transfer effects to leg strength. Our study adds knowledge on the effectiveness of step training (delivered in form of exergames) for falls prevention.

2. Materials and methods

2.1. Study design

The study was designed as an eight-week randomized controlled trial with three parallel arms. A flow chart describing the recruitment of participants and the study flow is presented in Fig. 1. Two intervention groups completed eight weeks of step training either volitional (VOL) or volitional with an additional unstable component (VOL + US). The control group (CON) received no intervention. The assessments were conducted prior to and after eight weeks of training. Participants of all groups received written information on their individual outcomes of both measurement points after the post-training assessment. Prior to study onset, all participants were fully informed about all experimental procedures of the study and signed an informed consent. The study was conducted according to the Declaration of Helsinki. The local ethics committee at the German Sport University Cologne gave ethical approval (approval number 134/2018). After the pre-assessment, participants were equally assigned to the three groups using the minimization method in order to counterbalance demographic variations between participants (Pocock, 1979) (strata: sex, age, BMI, 6-min walk, dynamic balance performance). The trial protocol was not registered prior to the start of the study in a clinical trial registry.

2.2. Participants

The sample as treated consisted of 45 men (n = 17) and women (n = 28) with a mean age of 69.4 ± 5.6 years. A total sample of 42 participants is needed to detect moderate changes for reactive balance performance at an α-level of ($p < 0.05$) with a study-power of 80%. We recruited 51 participants to account for an expected drop-out of 5–10%. Participants were recruited by advertisements placed in local newspapers in Cologne. Participants had to be healthy and older than 60 years. They needed to be retired and community-dwelling. Their blood pressure had to be medically adjusted if necessary. Exclusion criteria were any acute psychological, neurological, cardiovascular or orthopedic diseases. Furthermore, participants could not have symptomatic knee- or hip-prostheses and they could not participate if they regularly conducted sport activities (> 3 times per week as questioned subjectively). Baseline characteristics of participants are displayed in Table 1.

2.3. Intervention

VOL + US and VOL underwent supervised step training with their specific training protocol (volitional stepping exergames under stable and unstable conditions). Participants of both intervention groups trained on the Dividat Senso device (Senso, Dividat, Schindellegi, Switzerland), which is a training platform (1.13 m*1.13 m) with force sensors (strain gauges measuring at 50 Hz) that is linked to a screen (Fig. 2). The sensors can detect steps in four movement directions. For a diverse training of cognitive and motor abilities, eleven stepping exergames were part of the training intervention. In nine of eleven exergames ("Targets", "Divided", "Simon", "Flexi", "Snake", "Tetris", "Habitats", "Birds" and "Hexagon"), stepping was the major motor task and the following cognitive abilities were additionally addressed through the different games: divided and selective attention, visuospatial working memory, mental rotation and cognitive flexibility. Two games ("Ski" and "Rocket") had no additional cognitive task and addressed weight shifting and endurance as a major motor task respectively.

VOL trained on the Dividat Senso system, performing volitional step training under stable conditions. VOL + US trained on a stepping device that combined the Dividat Senso system with a swinging Posturomed system (Haider Bioswing, Pullenreuth, Germany). The Dividat platform, which is originally rigid, is suspended on eight steel springs, allowing the platform to swing freely along the horizontal plane. There is no movement induced by the platform itself. Sway is only induced when the participant steps and shifts the center of pressure. The degree of instability can be adjusted by fixating one to four springs. The maximum displacement of the platform is 70 mm to each side, 50 mm to the back and 30 mm to the front when all springs are loosened. Thus, VOL + US performed an unstable step training. This combined device will be described as Dividat Senso Swing from now on. Both, the original Dividat Senso and the Dividat Senso Swing are displayed in Fig. 2.

Training was carried out in small groups of three participants in both intervention groups and was guided by a qualified study assistant. Each training session lasted 40 min with a net gaming time of 10 to 12 min per participant. For every session, two to three games were preselected and were the same for both intervention groups. For VOL + US, the degree of instability was gradually increased over the eight weeks period by gradually loosening the springs. Starting with 3 fixed springs, one spring was loosened every two weeks.

Participants of the control group were asked to maintain their level of activity and received no intervention.

2.4. Testing procedure

Measurements were conducted before and after the eight-week

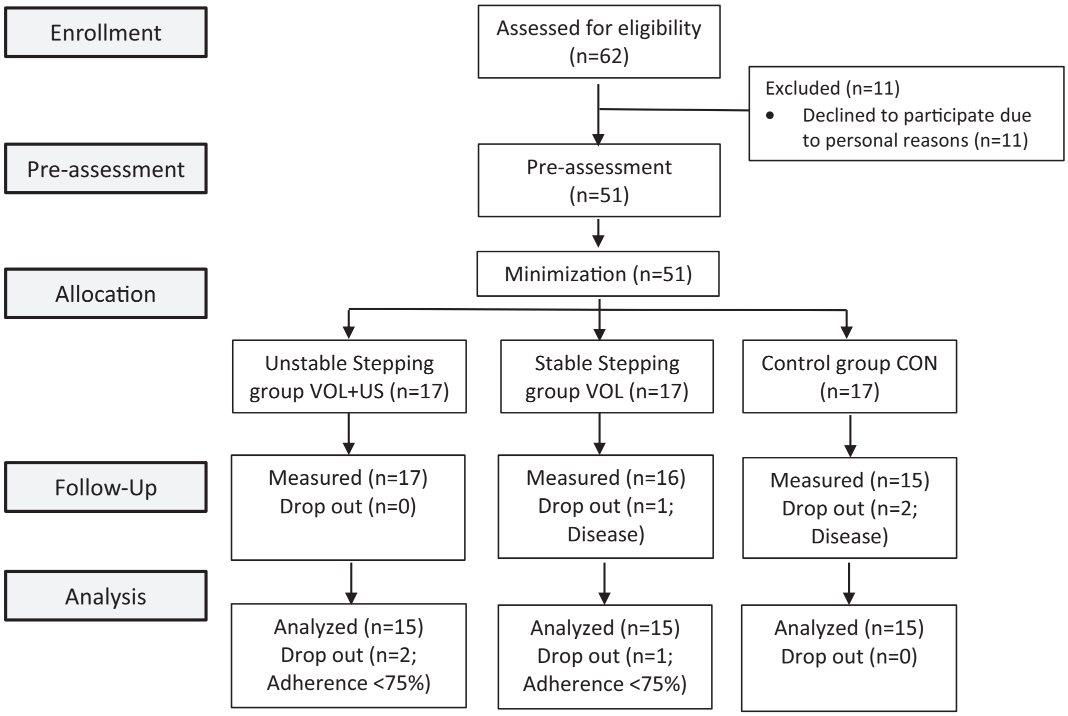

Fig. 1. CONSORT flow chart of the study.

Table 1
Baseline characteristics given as means (standard deviations). Note. VOL + US = volitional stepping under unstable conditions group, VOL = volitional stepping under stable conditions group, CON = control group, BMI = body mass index, Physical activity assessed by the Freiburger Physical Activity Questionnaire (Frey et al., 1999).

Characteristic	VOL + US (n = 15)	VOL (n = 15)	CON (n = 15)	p-Value
Gender, female/male [n]	5/10	6/9	6/9	p = 0.915
Age [years]	67.5 (5.1)	69.7 (6.2)	71.1 (5.2)	p = 0.197
BMI [kg/m^2]	27.1 (3.7)	29.1 (6.0)	26.2 (3.5)	p = 0.214
Physical activity [h/week]	11.1 (5.6)	7.6 (4.7)	8.8 (4.4)	p = 0.163
Falls (n, past 12 months)	3	2	2	p = 0.853

intervention period by the same investigators at a comparable time of the day. Due to restricted resources of the personnel, assessor blinding was not affordable. Participants were aware of the training mode of both groups but they did not see or try the training of the other group before the end of the study. Participants followed an instructed, standardized five-minute warm up procedure prior to the assessments that consisted of walking, stepping, skipping and squatting exercises. The warm up aimed at preparing participants lower extremities for maximal contractions during strength testing. For all tests, except the heel rise test, they performed one familiarization trial and two further trials which were averaged for further analysis. The heel rise test (Monteiro et al., 2017) was completed only once.

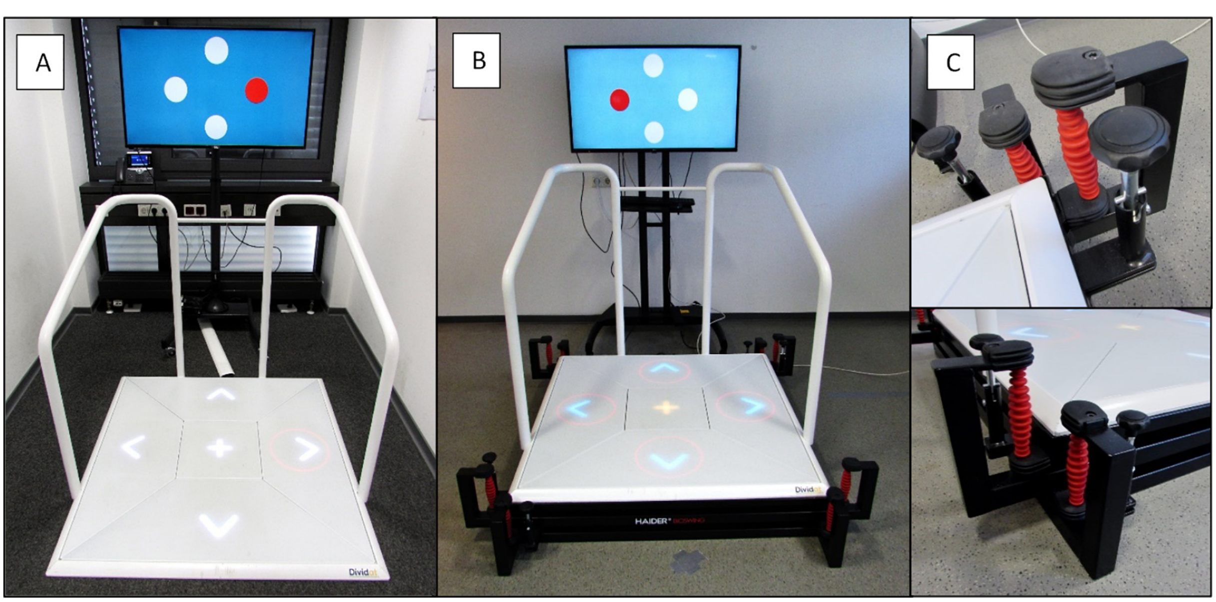

Fig. 2. A. original Dividat Senso; B. Dividat Senso Swing (combined with a Posturomed): C. Steel springs of the Dividat Senso Swing.

2.4.1. Adherence

Adherence was calculated as the percentage of the attended sessions (relative to total training sessions). Participants attending > 75% of all sessions were included in the analysis.

2.4.2. Balance measures

Reactive balance performance was tested without shoes on a two-dimensional platform (Posturomed, Haider Bioswing, Pullenreuth, Germany) as postural sway upon perturbation. The platform is mounted on eight springs. In its neutral position, the maximum range of motion in all directions is 70 mm. The platform was initially fixed in a stable position which was laterally shifted from the neutral position for 3.6 cm. The fixation was released 2 to 5 s after the participant had taken a stable two-legged shoulder-width stance with the hands on the hips, slight knee flexion and the gaze on a fixed point (1.5 m distance, 1.75 m height). The instruction was to reduce the induced pendular movement as fast as possible and remain in a stable position for 10 s. The amplitude of pendular movement was captured with an acceleration sensor below the platform at 50 Hz (MicroSwing® 6, Haider Bioswing, Pullenreuth, Germany). The total sway of the platform was calculated and reported in mm (DigiMax Posturomed, Software Version 1.0). Overall reliability of unexpected perturbed balance measurements is good (ICC = 0.71–0.97) (Schmidt et al., 2015).

Functional balance performance was assessed with the Y-balance test (Y balance test kit, Perform better, Graefelfing, Germany). Participants stood on the left leg on the center plate of the testing device. They were instructed to maintain one-legged stance and to reach out with the free leg in anterior, posteromedial and posterolateral direction as far as possible. Distance in cm was measured in all directions. The Y-balance test is a reliable assessment to use with older adults (ICC = 0.85–0.91) (Plisky et al., 2009).

The TUG served as a measure of functional balance and mobility and was performed in its original form but with participants walking as fast as possible without running (Podsiadlo and Richardson, 1991) and in motor dual-task condition, in which participants had to carry a cup of water as an additional task. Total duration was recorded. The TUG showed good agreement in time scores (ICC = 0.99) (Podsiadlo and Richardson, 1991).

2.4.3. Strength measures

Maximal strength (F_{max}) and the maximal rate of force development (RFD) were measured in isometric conditions in a leg extension and a leg curl machine (Edition-Line, gym80, Gelsenkirchen, Germany) with force transducers (mechaTronic, Hamm, Germany) at 200 Hz. Participants were instructed to push as hard and as fast as possible (Maffiuletti et al., 2016) against the fixed resistance. F_{max} and RFD were computed by the measurement/analysis software IsoTest (version 2.0, mechaTronic, Hamm, Germany).

Additionally, participants performed a heel rise test for assessment of calf strength endurance of the triceps surae. Participants were instructed to rise to toe stance as often as possible within 30s. A repetition was complete when participants placed their heels on the ground after rising to toe stance. The number of complete repetitions was manually counted and noted (Monteiro et al., 2017).

2.5. Statistical analysis

All data are presented as mean (M) ± standard deviation (SD). All statistics were analyzed using the Statistical Package for the Social Sciences (version 25.0; IBM SPSS, Chicago, USA). Potential differences of baseline characteristics (Table 1) were tested with a one-way analysis of variances (ANOVA). Several independent 3 (Group: VOL + US, VOL, CON) x 2 (Time: pre, post) repeated measures analyses of variances (rANOVA) were calculated for all outcome measures. Thereby, baseline values were included as covariate (Vickers and Altman, 2001). To estimate the practical relevance, effect sizes (partial eta squared, ηp^2) were calculated for the main effects. According to Cohen (Cohen 1988), a $\eta p^2 \geq 0.01$ indicates small effects, ≥ 0.059 medium effects and ≥ 0.138 large effects. In case of significant time x group interactions, estimated marginal means with Bonferroni correction were computed as post-hoc tests. For pairwise effect size comparison, standardized mean differences (SMD) were calculated. A SMD > 0.8 referred to large, $0.5 \leq \text{SMD} \leq 0.8$ moderate and < 0.5 small effects. A p-value < 0.05 was considered statistically significant.

3. Results

3.1. Adherence

Adherence was 87 ± 5% in the VOL + US group and 86 ± 6% in the VOL group.

3.2. Reactive balance

We found a large and significant time x group interaction effect ($p = 0.032$, $\eta_p^2 = 0.15$) for total postural sway upon perturbation. Post-hoc testing revealed a statistically significant improvement over time of VOL + US with a small effect size (SMD = 0.3). Effect sizes for pairwise comparison for VOL revealed only insignificant trivial effects (SMD < 0.2) (Fig. 3).

3.3. Functional balance and mobility

Very large and significant time x group interaction effects ($0.001 < p < 0.041$, $0.14 < \eta_p^2 < 0.28$) were observed for Y-balance testing (anterior and posteromedial) and TUG testing (with and without motor dual task). Post-hoc testing revealed significant improvements in both intervention groups (Table 2) for Y-balance testing (anterior and posteromedial). The standardized mean difference calculations for pairwise comparison with significant changes exposed moderate to large effect sizes for the Y-balance test (SMD = 0.5–1.0). Significant improvements in the TUG test were only present with motor interference conditions in the VOL + US with moderate effect size (SMD = −0.4).

3.4. Strength measures

Medium to large interaction effects were observed for repetitive heel rise testing ($p = 0.043$, $\eta_p^2 = 0.15$) and RFD during leg extension

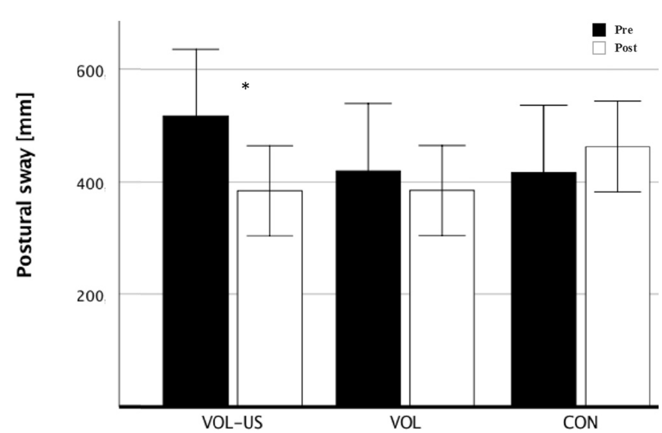

Fig. 3. Postural sway upon perturbation on the swinging platform for all groups during pre and post testing. Data are presented as means with standard deviations. *Significant difference between pre and post ($p < 0.05$). VOL + US = volitional stepping under unstable conditions group, VOL = volitional stepping under stable conditions group, CON = control group.

Table 2
Changes from pre to post testing for all groups during Y-balance testing (anterior: ANT; posterior-medial: PM; posterior-lateral: PL) and timed up & go (TUG) testing (without dual task = normal task: NT; with dual task using motor interference: DTm). Data are presented as means with standard deviations. Significant difference between pre and post (*p < 0.05; **p < 0.01).

		VOL + US		VOL		CON		rANOVA	
		Pre M (SD)	Post M (SD)	Pre M (SD)	Post M (SD)	Pre M (SD)	Post M (SD)	time x group	η_p^2
Y-balance [cm]	ANT	66.3 (13.1)	73.4* (13.2)	63.7 (15.6)	72** (15.7)	61.4 (15.2)	59.7 (18.1)	p = 0.008	0.21
	PM	100.7 (15.2)	108.9* (15)	98.8 (14.5)	112.9** (13.3)	94.3 (20.8)	92.3 (24.3)	p = 0.001	0.28
	PL	82.5 (15.7)	91.6* (13.8)	83.8 (15.1)	93.6* (17.4)	85.9 (19.8)	88.6 (20.7)	p = 0.297	0.07
TUG [sec]	NT	5.8 (0.8)	5.7 (0.7)	6.1 (1.1)	5.9 (1.1)	6.4 (1.4)	6.6 (1.3)	p = 0.041	0.14
	DTm	6.1 (0.8)	5.9* (0.8)	6.4 (1.2)	6.2 (1.2)	6.7 (1.3)	6.9 (1.2)	p = 0.008	0.21

Table 3
Changes from pre to post for all groups during repetitive heel rise testing and RFD during leg extension (RFD, rate of force development). *Significant difference between pre and post (p < 0.05).

	VOL + US		VOL		CON		rANOVA	
	Pre M (SD)	Post M (SD)	Pre M (SD)	Post M (SD)	Pre M (SD)	Post M (SD)	Time × group	η_p^2
Heel rise [rep]	35.1 (11.9)	43.9* (11.6)	26.4 (8.3)	35.7* (18.4)	26.7 (7.5)	26.7 (9.1)	p = 0.043	0.15
RFD, leg extension [N/s]	3825 (2543)	4436 (2590)	4211 (2200)	3397 (1642)	2255 (1306)	2524 (1298)	p = 0.084	0.12

($p = 0.08$, $\eta_p^2 = 0.12$). Maximal leg extension strength ($p = 0.66$, $\eta_p^2 = 0.01$), maximal leg curl strength ($p = 0.36$, $\eta_p^2 = 0.06$) and RFD during leg curl ($p = 0.93$, $\eta_p^2 = 0.004$) did not change significantly. Pairwise comparison for heel rise testing indicated larger effects for VOL + US (SMD = 0.8) compared to VOL (SMD = 0.7). RFD during leg extension revealed a small effect in VOL + US (SMD = 0.2), whereas VOL even showed a moderate negative effect (SMD = −0.4) (Table 3).

4. Discussion

To the best of the authors' knowledge this is the first study in older adults that investigated the effects of volitional stepping exergames under stable versus unstable conditions on highly relevant fall-preventive surrogates such as functional balance and mobility and strength in a three-armed randomized controlled trial. The aim of the randomized controlled trial was to compare the effects of both training regimes in terms of reactive and functional balance and mobility tasks and to investigate possible transfer effects on strength. We found that training with the Dividat Senso both in VOL + US and in VOL showed very high adherence levels slightly below 90% (Picorelli et al., 2014). Both stepping intervention groups significantly improved functional balance during Y-balance testing, but only the VOL + US group showed a significantly improved reactive balance performance during perturbed balance testing and timed up and go performance in motor dual task condition (DTm) after training. Both intervention groups significantly improved in the heel rise test with larger effects in favor of the VOL + US group. No significant changes were observed for F_{max} or RFD but medium interaction effects of the RFD of leg extensors were measured.

Recently published meta-analytical data showed that attendance is usually higher for technology-based training interventions (91%) when compared to traditional interventions (84%) in older adults, irrespective of study site, supervision or delivery method (Valenzuela et al., 2018). A study that compared step training and walking training with a duration comparable to this study, reported attendance rates of 91% for stepping and 84% for walking (Shigematsu et al., 2008). Thus, high adherence rates of this study can be attributed both to the step training itself and the technology-based training mode and are comparable to available literature. The technology-based training mode offers gaming with appealing and enjoyable components, enabling real-time feedback with the possibility of self-monitoring of participants' activities. These are relevant factors that have been shown to be positively related to adherence (Valenzuela et al., 2018).

Improvements of functional balance during TUG and Y-balance test are in line with several previous studies that reported on the effects of interactive step training on functional mobility (Garcia et al., 2016; Okubo et al., 2017; Schoene et al., 2014; Schoene et al., 2013). Especially with regard to the more pronounced effects of VOL + US on TUG (DTm), it is likely that the VOL + US training, as a sensorimotor training, improved proprioceptive acuity in multiple segments involved in postural control tasks (McCaskey et al., 2018). This might have led to a better ability to move while balancing objects using the upper extremities. Additionally, VOL + US training could be regarded as a dual-tasking activity since participants had to react to the stimulus on the screen and simultaneously react to the movement of the swinging plate they were standing on. This would make it more specific to TUG in dual-task conditions and explain improvements while there were none in VOL.

We also found significantly larger effects of VOL + US training for reactive balance, compared to VOL training. Reactive balance testing, where the ability to rapidly and accurately shift the center of mass is tested, does not include the same movement strategies like volitional stepping (Le Le Mouel et al., 2019). Although improvement of reactive balance usually requires very specific stimuli, there are studies that reported some transfer effects between reactive and sensorimotor balance training (Freyler et al., 2016). The VOL + US, again as a sensorimotor training, addresses reflex activity with a much larger proportion than the VOL training, which may have caused its larger effects on reactive balance (Aman et al., 2014; Rogers et al., 2003). Balance training seems to modify spinal reflexes specific to the trained task

(Taube et al., 2008). Thus, step training on an unstable platform transforms more to reactive balance testing on a swinging platform than step training on a fixed platform. Furthermore, it is possible that improvements in reactive balance in the VOL + US group is caused by motor-learning (Brueckner et al., 2019). Volitional stepping under unstable conditions provides participants with continuous large error signal which have been shown to enhance effects of learning and relearning.

Our *sec*ond aim was to investigate possible transfer effects of VOL and VOL + US to strength performance. Transfer effects of both types of step training to the heel rise test were found with higher standard mean differences for VOL + US. Referring to available literature, spinal and supraspinal adaptations are likely to be responsible for the detected changes. It seems reasonable to assume that VOL + US mimics sensorimotor training which alters spinal reflex activity, which can result in higher explosive strength after balance training (Behrens et al., 2015; Taube et al., 2008).

In this line of reasoning but with a lack of significance based on the sample size for explosive strength (RFD), medium interaction effects in favor of VOL + US were found, whereas F_{max} did not show significant changes nor notable interaction effects. Although there is little evidence on stepping specific interventions including strength as an outcome measure, existing literature also supports the transfer of stepping interventions on dynamic strength parameters only but not on isometric maximal strength (Okubo et al., 2017; Schoene et al., 2013; Shigematsu et al., 2008). Review data on spinal and supraspinal adaptations to balance training shows that among strength measures, balance training improves the RFD most efficiently and induces changes in F_{max} in impaired subjects rather than fit and active older adults (Taube et al., 2008). In our study, RFD in VOL even showed small negative effects. Although not significant, those findings might suggest that volitional stepping on stable ground does not induce stimuli to alter spinal reflex mechanisms that influence RFD performance, whereas unstable conditions offer more challenging and complex balance tasks and thus increase the spinal and supraspinal involvement to maintain balance.

Additionally, the muscles targeted in heel rise testing are more specific to the training in this study than muscles addressed in isometric strength measures. During voluntary stepping, single limb stance support is necessary before the actual stepping movement (Rogers and Mille, 2016). Ankle muscles are highly challenged during single limb stance, which could be even more pronounced under unstable conditions, supporting adaptations in calf but not in thigh strength.

Although the study offers first insights on the comparison of volitional step training under stable and unstable conditions, it has feasibility study character. It did not include assessments which allowed a further interpretation of the mechanisms that play a role in the observed effects and some limitations need to be addressed. The participants were all healthy and active community dwellers, who did not necessarily mimic a critically fall prone population. Additionally, baseline testing of functional mobility (TUG) indicated that all participants performed well and fall rates of the past year were comparably low (see Table 1). This might be attributed to the recruitment, which was done by newspaper announcements, probably mostly approaching those, who are taking active care on their physical fitness. Training on the Dividat Senso is also applicable for fragile older adults because it is equipped with a stable hand rail. However, whether a more deconditioned target group would be capable of training on the unstable combined device needs to be addressed in further research. Additionally, the sample size was relatively small, females were overrepresented, the intervention period was rather short, and no follow-up data is available to address whether adaptations change after discharge. With regard to the data that was captured, there were some relevant baseline differences despite using the minimization method for group allocation. Future studies should allocate subjects to the study arms after completing all baseline measures. VOL + US showed the lowest reactive balance performance at baseline, which might have contributed to significant improvements. Although significant, effect sizes were only small. On the contrary, their baseline heel rise performance was comparably high and, still changing significantly after training. Additionally, future trial protocols should be registered in a clinical trial registry prior to the start of the study in order to minimize publication bias and selective outcome reporting. They should enable highest level of blinding of assessors and coaches, as it guarantees high study quality (e.g. PEDro and Consort) of randomized controlled trials.

Although participants were rather young and active in this trial, adherence was high. Even higher adherence can be expected in a target group that is more obviously benefitting from the training. Also, there were no adverse events occurring during the intervention period or the measurements. Net training time was only 10 to 12 min per participant per session. Still, effects on balance performance and even some transfer effects on dynamic strength were measured. The training device in use is originally made for individual training which would result in a much higher net training time and thus might even increase training adaptations.

5. Conclusion and future directions

The present RCT demonstrates that volitional stepping exergames under stable and unstable conditions is a feasible training tool with high adherence rates to improve functional balance and calf strength. However, VOL + US seems to be superior to VOL when it comes to reactive balance and functional mobility (DTm) performance. VOL + US, as a sensorimotor training, might benefit from a transfer between reactive and sensorimotor training and might address reflex activity more than VOL. It also leads to more pronounced effects on ankle strength, probably due to higher spinal and supraspinal adaptations.

Therefore, stepping exergames, especially under unstable conditions, improve factors that are relevant for falls prevention, such as balance, functional mobility and strength, because they offer a high specificity that might offer necessary motor skills to recover balance from trips and slips.

Further studies should address a more fragile target group with a larger sample size and longer intervention period up to one year. Also, the net training time should be increased by using the Dividat Senso Swing device for individualized training. Further, it needs to be addressed, if improvements really have an impact on the occurrence of falls in real life scenarios.

Statement of ethics

The authors have no ethical conflicts to disclose.

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Declaration of competing interest

Declarations of interest: none.

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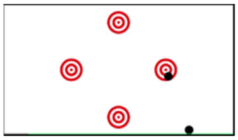
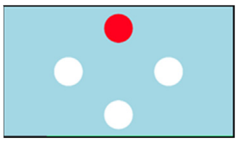
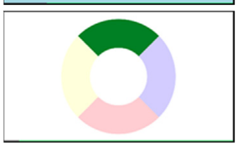
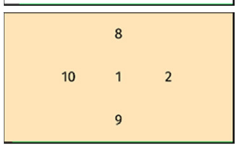
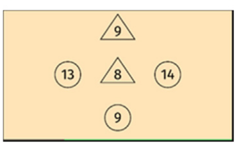
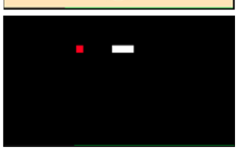
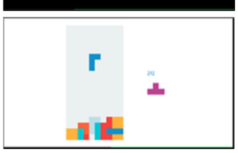
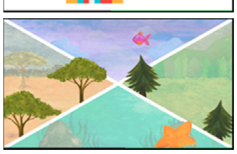
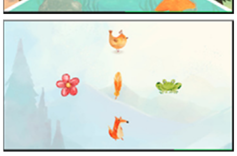
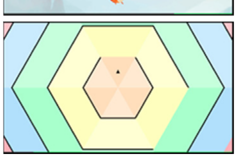
Appendix A. Overview over the Dividat Senso games

Game	Screenshot	Description
Targets		Four targets are displayed and black circles “fly” randomly from all directions across the screen. When the black circle hits the center of a target, the participant has to step in the respective direction of the target. The “Bullseye” (perfect match of the center) results in highest scoring.
Divided		Four white dots are displayed on the screen. As soon as a dot randomly turns red, the participant has to quickly step in the respective direction. In between the appearance of red dots, a high or a low acoustic signal is sometimes presented, requiring a step forward (high) or backward (low).
Simon		In the memorization phase, a sequence of acoustic signals is played. The respective movement directions are simultaneously indicated by lighting up the corresponding color in the circle. In the subsequent recall phase, the participant has to reproduce the sequence by stepping in the respective directions in the right order. The sequence starts with one signal and after each successful recall, the sequence adds one more signal.
Flexi	 	a) A number is displayed in the center of the screen, surrounded by four additional numbers. Starting from the number in the center, the participant steps in the direction of the number that is the next in line. In the top example, stepping to the right “2” would be correct. b) In a higher level of the game, the numbers are additionally framed by different shapes (e.g. triangles, circles). Starting from the number in the center, the participant steps in the direction of the number that is next in line and is surrounded by a different shape. In the lower example, stepping backwards to the “9” in a circle would be correct.
Snake		A white snake winds its way over the screen and is supposed to “eat” the red squares occurring at random places on the screen. The snake is navigated by the participant by stepping to the required direction. With each “eaten” square, the snake becomes longer. The snake is not allowed to touch its own tail.
Tetris		Different shapes “fall” from the top of the screen. The participant has to rotate the shapes by 90° per step (forward) and to shift them (step right or left). All segments need to be placed without or with a minimum of gaps at the lower edge of the screen. As soon as a row is complete, it disappears and the top rows move down. The game is over if a row touches the top of the screen.
Habitats		Four habitats are presented on the screen. An animal appears in one of the habitats. The participant has to step in the respective direction only if the animal fits the habitat. In this example, a fish appears in the upper “sky” habitat, where it does not fit. Thus, the participant is not required to step.
Birds		Different items are displayed - one in the center of the screen and four surrounding it. One of the four items always matches the one presented in the center. The participant is supposed to step in the respective direction. In this example, the “feather” belongs to the bird, so stepping forward would be correct.
Hexagon		Hexagons in increasing sizes are displayed on the screen. In the inner of the center hexagon, a small black arrow is shown. The hexagon shapes move down while the arrow stays at its place. The participant has to turn the hexagons left or right by stepping in the respective direction, so that the open side of the hexagon is at the top and the arrow does not touch a wall of a hexagon, while it moves down.

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