Archives of Gerontology and Geriatrics xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial

Ori Elbar [a,b], Irit Tzedek [a,b], Elisha Vered [a], Gali Shvarth [a], Michael Friger [c], Itshak Melzer [a,*]

[a] *Schwartz Movement Analysis & Rehabilitation Laboratory, Department of Physical Therapy, Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel*
[b] *Hydrotherapy Center in Sha'ar HaNegev, Israel*
[c] *Department of Epidemiology and Health Services Evaluation, Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel*

ARTICLE INFO

Article history:
Received 19 June 2012
Received in revised form 3 August 2012
Accepted 5 August 2012
Available online xxx

Keywords:
Aging
Falls
Balance control
Water exercises
Step execution

ABSTRACT

This study evaluated the effects of a water exercise training program that includes perturbation exercises (WEP) to improve the speed of voluntary stepping reaction in older adults. Speed of voluntary stepping considered as an important skill to prevent a fall when balance is lost. In a single-blinded randomized controlled trial with a crossover design thirty-six independent old adults (64–88 years old) were divided into two groups. Group A received WEP for the first 12 weeks, followed by no intervention for the second 12 weeks. Group B did not receive intervention for the first 12 weeks and received WEP for the second 12 weeks. Voluntary Step Execution Test and postural stability in upright standing (eyes open and closed conditions) were measured at baseline, 12 weeks, and 24 weeks. A significant interaction effect between group and time was found for the step execution, due to improvement in initiation phase and swing phase durations in the WEP group. Also significant improvement in postural stability parameters in eyes open and closed conditions is noted. The present results indicate that the primary benefit of WEP that include perturbations to induce stepping, was a reduction in voluntary stepping times. The WEP generalized to a better control of balance in up-right standing.

1. Introduction

In older adults (65 years old and older) about one out of three individuals fall at least once a year (Tinetti, Speechley, & Ginter, 1988). Falls may result in acute injuries, including traumatic brain injuries (Rutland-Brown, Langlois, Thomas, & Xi, 2006), spinal cord injuries (Kent & Pearce, 2006), hip fractures (Kannus et al., 1996), and even death (Masud & Morris, 2001). Consequently, there is a general need for developing cost-effective interventions that can prevent the occurrence of falls. However, fall prevention programs are usually directed toward high-risk populations although age-related deterioration of balance function that leads to an increased risk of falling affects all older adults. Therefore, a better way to decrease the number of fall-related injuries may be to also direct preventive efforts toward older adults who have not yet fallen.

A rapid step is the most important protective postural strategy since it can prevent a fall from occurring. It can arise from large perturbations (e.g., slips, trips and collisions), but is also frequently recruited at lower magnitudes of perturbation or as a consequence of volitional movement, self-induced perturbation such as turning, bending, and reaching (Maki & McIlroy, 1997). The time to complete voluntary stepping was found to be related to falls. It was found to be slower in older adults who reported falls retrospectively compared with non-fallers (Melzer, Kurtz, Shahar, Levi, & Oddsson, 2007), and in older adults monitored for one year prospectively (Melzer, Kurz, & Oddsson, 2010) and even older adults who were injured as a result of fall compared with non-injured fallers (Melzer, Kurz, Shahar, & Oddsson, 2009). Improving the ability to step quickly, to a loss of balance determines whether a fall occurs in older adults (Melzer, Kurtz, et al., 2007). Studies show that compared to young adults, older people also showed reduced step length (Luchies, Alexander, Schultz, & Ashton-Miller, 1994), an increased frequency of collisions between the swing foot and stance leg during lateral perturbations (Maki, Edmondstone, & McIlroy, 2000), and an increased frequency of multiple-step responses (Luchies et al., 1994; Maki et al., 2000; McIlroy & Maki, 1996), with a lateral second step following the forward or backward step (McIlroy & Maki, 1996). All the above results may suggest that targeting stepping speed may reduce the

---

* Corresponding author at: Schwartz Movement Analysis & Rehabilitation Laboratory, Department of Physical Therapy, Recanati School for Community Health Professions, Faculty of Health Sciences, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel. Tel.: +972 8 647 7573; fax: +972 8 647 7683.
E-mail address: itzikm@bgu.ac.il (I. Melzer).

0167-4943/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.archger.2012.08.003

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

risk of falls in older subjects. Consequently, there is a clinical need for developing interventions to improve the stepping speed, thus reducing the risk for falls in older adults.

A common misunderstanding appears to be that strength training per se should improve balance function. A Cochrane Review (Latham, Anderson, Bennet, & Stretton, 2003) of 62 Randomized Control Trials including a total of 3674 subjects found no statistically significant effects of strength training on objective clinical measures of balance function, or on physical disability measures. The results are not surprising; according to the principles of training, training of balance or stepping as a skill must incorporate exercises that closely mimic and provide a challenge to the successful performance of functional tasks. Rogers, Johnson, Martinez, Mille, and Hedman (2003) showed that a three-week period of either voluntary or waist-pull-induced step training reduced step initiation time. Mansfield, Peters, Liu, and Maki (2010) used a balance-specific intervention that using a perturbation platform that moves suddenly and unpredictably during standing or walking in place. Their perturbation-based training led to reductions in frequency of multi-step reactions, foot collisions. However, the above-mentioned studies (Mansfield et al., 2010; Rogers et al., 2003) utilized expensive equipment (e.g., moving-platform or waist pulls) that would not be available to older adults or even in rehabilitation clinics. Recently, Melzer and Oddsson (2012) showed that functional balance training that includes perturbations can improve voluntary stepping in independent older adults. The present study aimed to test whether a water-based training program (WEP) that includes perturbation of balance specifically targeted compensatory and voluntary stepping skills are able to improve speed of stepping. To evoke stepping reactions during training, pushes were made by the instructors or classmates to evoke balance-recovery stepping reactions against the water resistance. The subjects were instructed to respond to the pushes by stepping as quickly as possible, if required.

To date, only a few studies have examined the effects of WEP on balance control in older adults. These studies demonstrated that following WEP training there was increased Berg Balance Score (Douris et al., 2003), improved leaning balance (Lord, Matters, & St George, 2006; Lord, Mitchell, & Williams, 1993) and Functional Reach (Simmons & Hansen, 1996), and improvement in the step test (step 7.5 cm high and return to the floor as many times as possible over a period of 15 s) and quality of life, but not fear of falling (Devereux, Robertson, & Briffa, 2005). To our knowledge, no studies have directly addressed the potential of using perturbation-based exercises to counter specific impairments in compensatory and voluntary stepping responses. Using deep-water-running exercise Kaneda, Wakabayashi, Sato, Uekusa, and Nomura (2008) in an elegant study were able to demonstrate improvements in postural-sway distance and tandem-walking time in a group of 15 older adults that appeared to counteract normal age-related balance deterioration. However, their study was not designed to improve the speed of stepping. To be functionally useful, balance-related strength should preferably be designed into the water balance training intervention, by training in a water environment; water resistance may produce overload for stepping and thus specifically improve the speed of stepping. We hypothesize that subjects who undergo a WEP that includes perturbation exercises will show greater improvements in the ability to step rapidly, compared to control subjects who undergo no training.

2. Methods

2.1. Study population

A randomized cross-over trial was conducted with 36 healthy volunteers, average age 69.5 (range 64–88 years, SD 4.8) who ambulate independently. Subjects were recruited from the community of the Sha'ar Hanegev council through the internal brochure of the Yahdav elderly center. The water-based exercise program (WEP) consisted of 24 sessions, each 40 min long; 8–9 subjects participated in each training group, twice a week over a period of 12 weeks. Using a concealed randomization method utilizing sealed envelopes, the 36 subjects were randomly allocated to 2 groups by investigators who were not involved in data collection, treatment implementation, or data analysis. A senior physiotherapist from Community Physiotherapy Services enrolled the participants and coordinated the randomization and allocation. Subjects in group A started with a 12-week WEP program, followed by a 12-week control no training period. Group B subjects began with an initial 12-week control period without training, followed by 12 weeks of WEP intervention (Fig. 1). Baseline assessments were done before randomization (t0); subjects then performed assessments after 12 weeks (t1), and after 24 weeks (t2).

A short interview examined whether the subjects met the inclusion–exclusion criteria. Participants were excluded if they had received physiotherapy, hydrotherapy, or attended community exercise classes in the past six months, had orthopedic surgery within the prior year, showed an indication of cognitive impairment (Mini-Mental Score < 24), score of 45 and over on the Berg Balance Scale, this range of Berg scale score corresponded to individuals with low risk of falls (Shumway-Cook, Gruber, Baldwin, & Liao, 1997). The Berg Balance Test scores the participant on 14 tasks graded on a 0–4 scale (maximum 56) to evaluate balance under different conditions (Berg et al., 1989) had severe focal muscle weakness or paralysis, serious visual impairment, severe peripheral or compression/entrapment neuropathies, any neurological disorders causing balance or motor problems, or cancer (metastases or under active treatment). Prior to their inclusion, all subjects received medical clearance from their

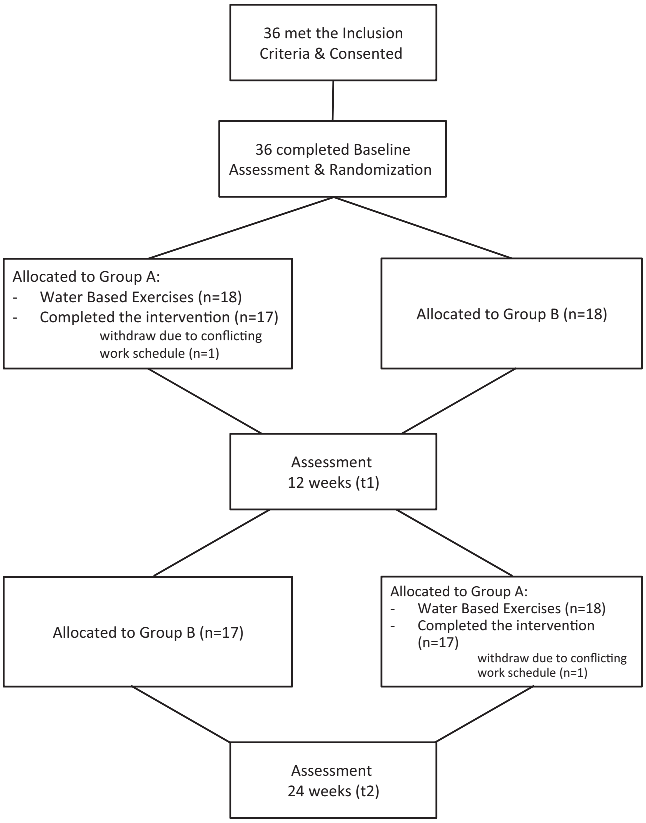

Fig. 1. Study design and flow of participants through each stage of the trial.

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

primary care physician to participate in the study and provided informed consent in accordance with approved procedures by the Helsinki Committee in Soroka University Medical Center (Clinical Trials Registration number #NCT00708136). All the assessments were conducted by two physical therapists who were blinded to the experimental allocation and did not participate in the training sessions.

2.2. Sample size

The sample size requirement was based on voluntary step execution (i.e., foot contact time), our primary outcome parameter. For calculations, the probability of type I error was 0.05, and probability of type II error was 0.2. In Melzer and Oddsson (2004) the voluntary step execution times of healthy older adults were 298 ms longer in comparison with young adults, suggesting that the perturbation-based training may reduce fall risk if it yields net reductions that exceed any reductions in the control group by these quantities. Using this net reduction value (298 ms), in combination with the initial variance estimates (standard deviations (SDs) of 332 ms), it was determined that 24 participants per group would be required. However, it was decided to include 36 participants in the cross-over study design due to reported attrition rates from 10% to over 35% in different populations of elderly individuals (McMurdo, Millar, & Daly, 2000; Topp, Mikesky, Wigglesworth, Holt, & Edwards, 1993). In the current study we have used an attrition rate of 33%. Thus, to account for the expected attrition rate we planned to test 36 persons ($36 \times 0.67 = 24$).

2.3. The water-based training program

Intervention was conducted in a group format with 8–10 subjects in each group. Sessions were led by one licensed physical therapist and assisted by one licensed hydrotherapies. The WBE training program performed at five progressively more challenging levels of difficulty with respect to strength and balance function as described in detail (Melzer, Elbar, Tsedek, & Oddsson, 2008). While subjects stand in the water and maintain a stable upright stance over the base of support (BOS), water movement and turbulence overloading the postural control systems during standing and reaching movement (while feet are fixed on the pools floor) and during change of support movement (e.g., stepping). For standing exercise (levels 1 and level 2 exercises), this relative motion of water causing displacement of either the body's Center of Mass (COM) (via water motion and turbulence) or the BOS (standing on unstable balls or a "noodle" placed underneath the subject's feet on the pool floor), these exercises in water might cause perturbed balance (e.g., during leaning, turning, reaching) thus challenging the balance control system. During gait exercises (exercise levels 3 and 4), the water can create disturbance due to water resistance motion and turbulence act to perturb the COM (e.g., simulate tripping) and BOS perturbations (e.g., simulate slipping due to a slip on the pools floor). Additional exercises (level 5) such as perturbation exercises were provided by the instructors or classmates to evoke balance-recovery stepping reactions against the water resistance. The perturbation methods may fulfill the fundamental biomechanical requirement (disruption of the COM–BOS relationship) and elicit postural and stepping reactions that are similar in many respects to land-based training. Hence, it is possible that the training benefits derived using water-based training that includes perturbation exercises may generalize to the reactions evoked outside the water. It is important to note that exercises were adjusted by the therapist throughout the program to match each subject's ability and to be continuously challenging but never dangerous. The goal of each session in the current program is to constantly challenge the postural control system and stepping responses with exercises. Training programs should be tailored to the individual needs and abilities of the participant. This process requires interaction with the instructors and was not based on a "cookbook" approach to training. As in any type of training, for improvement to occur it is crucial to maintain a progressive and specific training load for each of the participants. Progressions were made when the individuals have reached adaptation. On each level the instructor modified an exercise to be more or less challenging for each participant. During all the exercises, the instructor and the lifeguard were nearby and fully alert to the security of each participant.

2.4. Outcome measures

The following standardized functional tests were administered before and after the training program.

2.4.1. Voluntary Step Execution Test

Subjects were instructed to stand upright and barefoot on a force platform viewing an "X" displayed on a screen 3 m in front of them and to step as quickly as possible (step length 50–60 cm) following a tap cue on their heel (Melzer & Oddsson, 2004; Melzer, Shtilman, Rosenblatt, & Oddsson, 2007). Center of pressure (COP) and ground reaction force data were collected with a Kistler 9287 force platform (Kistler Instrument Corp., Amherst, NY), sampled at a frequency of 100 Hz. A total of 9 trials were conducted, forward, sideways, and backward (three trials in each direction). The average across all directions was used for statistical analysis. Analysis of step execution data extracted specific temporal events using a program written in MatLab (Math Works Inc., Cambridge, MA). The following events were extracted from the ground reaction force data: (a) the tap cue; (b) the step initiation; (c) the foot-off; (d) the foot contact; (e) preparatory phase, which was calculated as the time from step initiation to foot-off; (f) swing phase, which was calculated as the time from foot-off to foot contact; and (g) time to foot contact, which was calculated as the time from the tap cue to foot-contact. The procedure has previously been described in detail (Melzer & Oddsson, 2004). Voluntary Step Execution Test–Re-test reliability was good to excellent across all parameters and test conditions for old adults (interclass correlation coefficient = 0.62–0.88) (Melzer, Shtilman, et al., 2007).

2.4.2. Postural stability

Evaluation of postural control was made using the traditional postural sway measures. Subjects were instructed to stand upright and barefoot on a force platform in a standardized stance, their feet abducted 10° and their heels separated mediolaterally by 6 cm and hands crossed behind their back. Ten 30-s quiet-standing trials in eyes open and 10 trials in eyes closed (blindfolded) conditions were obtained for each participant. Subjects were instructed to stand as still as possible during the trials. COP and ground reaction force data were collected with a Kistler 9287 force platform (Kistler Instrument Corp., Amherst, NY). The force platform data were sampled at a frequency of 100 Hz and stored on a hard disk for later processing. Force platform data were analyzed using automatic code written in Matlab (Math Works Inc., Cambridge, MA, USA) to extract three commonly used COP traditional parameters of postural stability: (1) mediolateral COP sway range (ML-sway range in mm) determined as the maximum distance the COP trajectory pass in the mediolateral direction; (2) anterior–posterior COP sway range (AP-sway range in mm) determined as the maximum distance the COP trajectory pass in the anterior–posterior direction; (3) sway area (mm^2) of the COP points determined as the area enclosed by the COP trajectory per unit time. These parameters were computed for each trial, and then

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

averaged for each set of 10 trials to obtain an average value for each parameter and for each subject, in each experimental condition. Reliability correlation coefficients for postural sway measures showed excellent reliability (>0.90). Tests with closed eyes were more reliable than tests with eyes open (Bauer, Gröger, Rupprecht, & Gassmann, 2008).

2.5. Data and statistical analyses

Outcome parameters found to be normally distributed using Shapiro–Wilk's statistic to test normality of the variables for both groups (Shapiro & Wilk, 1965). Differences in baseline outcome measures between groups were analyzed using the *T*-test; in cases where parameters were not normally distributed, the Mann–Whitney *U* test was used. The following findings would support the hypothesis that the WE program was beneficial in terms of our primary outcome measures—the voluntary step execution times (step initiation phase, preparatory phase, swing phase and time to foot contact), and the secondary outcomes the postural stability in eyes open and eyes closed conditions (ML sway, AP sway, and mean sway area): (1) during the first 12 weeks (t0–t1), group A should show a greater improvement than group B; (2) during the second 12 weeks group B should show a greater improvement (t1–t2) than during the control period (t0–t1) and compared with group A. General Linear Model (GLM) with repeated measures was used to analyze for main effects of training (WEP vs. control) and time (first 12 weeks vs. second 12 weeks), and the interaction effect between training and time. The level of significance was set at 0.05.

For each outcome, the effect size (ES) of Hedge's *g* and the 95% confidence interval (CI) were calculated. The ES of *g* was calculated by taking the difference between the means of group A and group B during their WEP training period and the mean of group A and group B during the control period divided by the average population SD. To estimate the SD for *g*, baseline estimate SDs of groups A and B were pooled. The following guidelines were used when interpreting correlation magnitudes: 0.0–0.2 was considered small, 0.2–0.5 was considered moderate, and 0.5–0.8 was considered large (Hedges & Olkin, 1985). All data analyses were performed using SPSS Professional Statistics, version 14 software, for Windows.

3. Results

A total of 36 subjects met the inclusion criteria, consented to participate, completed baseline assessments, and were randomly allocated to either group A or group B (see Fig. 1). Thirty-four subjects completed the intervention. Two subjects (one from group A, and one from group B) withdrew from training during the WEP period due to a conflicting work schedule and low motivation. Thus, 35 subjects participated in assessments at t1, and 34 participated in assessments at t2. Groups A and B were comparable at baseline for all variables (Table 1). Analyses at t0, t1, and t2 presented in Tables 1–3 were performed only on those subjects with complete data sets ($N = 34$).

A subject's attendance in the WEP program was recorded at each session to monitor compliance. Of the 34 subjects, 9 attended all treatment sessions, 8 missed 1 session, 10 missed 2 sessions, 3 missed 3 sessions, and 4 missed 4 sessions. One subject in group A and 1 in group B dropped out after t0 and t1, respectively, did not attend any WEP sessions.

In Table 1, the baseline characteristics and baseline parameters of all dependent variables are presented for all subjects for groups A and B separately. Baseline characteristics and baseline parameters for almost all dependent measures of subjects in group A did not differ significantly from those in group B, apart from number of medications taken/day (Table 1).

3.1. Effect on stepping

A significant interaction effect between group and time was found for the foot contact time, step initiation- and swing-phases

Table 1
Baseline characteristics of study participants and main variables expressed in total and groups.

Variable	All subjects	Group A	Group B	*p*-Value
Age (years)	69.6 ± 4.8	69.58 ± 5.2	69.64 ± 4.5	0.97
Weight (kg)	74.1 ± 13.3	77.3 ± 7.6	72.9 ± 5.9	0.54
Number of medication/day	3.0 ± 0.4	3.9 ± 2.3	2.1 ± 1.9	0.02
Mini-Mental Score	28.4 ± 0.2	28.6 ± 0.9	28.3 ± 0.6	0.68
Berg Balance Score	54.5 ± 3.3	54.2 ± 4	55.13 ± 3	0.79
Foot contact time (ms)	807.6 ± 167	838.1 ± 149	775.2 ± 184	0.24
Mean sway area eyes open (mm^2)	87.3 ± 39.7	93.5 ± 50	80.6 ± 23	0.29
Mean sway area eyes closed (mm^2)	128.6 ± 73	141.6 ± 81	114.7 ± 70	0.36

Values are mean ± SD.
Abbreviations: kg: kilogram; ms: milliseconds; mm^2: millimeter squared.

Table 2
Voluntary Step Execution Test parameters during single task condition (mean ± SD), group comparisons.

Step execution variable	Group	Baseline (t0)	12 weeks (t1)	24 weeks (t2)	ANOVA (t0–t2) T × G
Step initiation phase (ms)	A	165 ± 29	149.3 ± 25	154.7 ± 25	
	B	176.4 ± 31	167 ± 33	140.7 ± 27	$F = 3.85$, $p = 0.05$
Foot-contact time (ms)	A	838.1 ± 149	705.4 ± 110	697.5 ± 111	
	B	775.2 ± 184	749.8 ± 131	691.7 ± 110	$F = 9.5$, $p = 0.003$
Preparation phase (ms)	A	385.8 ± 85	323.5 ± 60	302.5 ± 56	
	B	356.9 ± 59	322.2 ± 59	332.5 ± 85	$F = 0.075$, $p = 0.78$
Swing phase (ms)	A	287.3 ± 62	231 ± 54	241.1 ± 66	
	B	242 ± 135	263.5 ± 73	218.4 ± 86	$F = 10$, $p = 0.002$

Results of statistical analysis for all subjects between groups A and B, with respect to voluntary step execution times during the first 12 weeks (t0–t1) and during the second 12 weeks (t1–t2).
Abbreviations: G: group; T; time; ms: milliseconds.

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

Table 3
COP-based measures of postural stability with eyes open and eyes closed conditions (mean ± SD) group comparisons.

Postural stability variables	Group	Baseline (t0)	12 weeks (t1)	24 weeks (t2)	ANOVA (t0–t2) T × G
Eyes open					
ML sway range (mm)	A	36.6 ± 9	33 ± 9.1	38.6 ± 8.4	
	B	35.8 ± 8.3	31.5 ± 9.3	25.8 ± 12.8	$F = 5.65$, $p = 0.05$
AP sway range (mm)	A	30.9 ± 7	29.8 ± 7.1	32.6 ± 8.2	
	B	30.4 ± 4.9	28.6 ± 7.1	27.2 ± 6.5	$F = 3.26$, $p = 0.07$
Sway area (mm^2)	A	93.5 ± 50	86.9 ± 62	102.7 ± 51	
	B	80.6 ± 23	73.9 ± 31	56.7 ± 32	$F = 4.28$, $p = 0.04$
Eyes closed					
ML sway range (mm)	A	45.4 ± 13.3	38.6 ± 11.6	44.9 ± 13	
	B	40.2 ± 11.8	34.7 ± 9.6	29.2 ± 15.8	$F = 5.54$, $p = 0.02$
AP sway range (mm)	A	37.8 ± 10.5	34.3 ± 10.1	40.4 ± 10.3	
	B	36.5 ± 7.1	31.6 ± 6.3	30.8 ± 8.8	$F = 4.99$, $p = 0.02$
Sway area (mm^2)	A	141.6 ± 81	113.2 ± 80	143.7 ± 71	
	B	114.7 ± 70	91.0 ± 52	75.1 ± 49	$F = 4.84$, $p = 0.03$

Results of statistical analysis for all subjects between groups A and B, with respect to postural stability during the first 12 weeks (t0–t1) and during the second 12 weeks (t1–t2).
Abbreviations: G: group; T: time; mm: millimeters; mm^2: millimeters squared.

($p = 0.003$, $p = 0.05$, and $p = 0.002$, respectively) (see Table 2). An ES for the step initiation phase, foot contact time, and swing phase of 1.0, 0.47, and 0.63, respectively, are consistent with these significant findings (medium to large effect size).

3.2. Effect on postural stability

An interaction effect between group and time reached significance for sway area and ML sway range in eyes open condition ($p = 0.04$ and $p = 0.05$, respectively). An ES for the sway area of 0.42 and 0.88 for ML sway range in eyes open condition is consistent with these significant findings (medium to large effect size). In addition, Table 3 shows a significant interaction effect between group and time for all postural stability parameters in eyes closed condition, which indicates a significantly improved status after the intervention period (WEP) compared with the control period. ES for the sway area and ML sway range, in eyes closed condition were 0.41 and 0.5, respectively, showing a medium effect size.

No significant interaction effect between group and time was observed for the Berg Balance Score. The BBS score was 0.69 ± 0.26 higher after the intervention period and 0.19 ± 0.25 after the control periods ($p = 0.21$).

4. Discussion

The findings of our present study partially support our main hypothesis in that gains were observed in the voluntary step execution times. Also, postural stability in both eyes open and especially during eyes closed condition was improved; however, the clinical measure of balance, the Berg Balance Score was not improved during the intervention phase (WEP), compared with the control phase. We considered the clinical relevance of our significant findings. The Voluntary Step Execution Test discriminates between young and older adults (Melzer & Oddsson, 2004; Melzer, Shtilman, et al., 2007), between fallers and non-fallers (Melzer, Kurtz, et al., 2007), and between older adults who were injured from falls compared with those who were not injured as a result of their fall (Melzer et al., 2009). In a study of 100 older adults, Melzer, Kurz, and Oddsson (2010) found that foot-contact times during the single- and dual-task conditions are significant ($p = 0.035$, $p = 0.022$, respectively) predictors for prospective falls with an Odds Ratio of 8.7 and 5.4, respectively. In the present study step execution was measured in single task condition, the mean gain in foot contact time in single task condition was 133 ms faster for group A, and 58 ms faster in group B, post-WEP training. These findings support the potential for WEP perturbation-based balance training to reduce fall risk by improving the ability of older adults to step rapidly when balance is lost.

The present results indicate that the primary benefit of WEP training was a reduction in the swing phase duration and in the step initiation phase. There are a number of possible mechanisms for the observed training effects. The swing phase incorporates the actual motor execution of the task when the leg is lifted and moved rapidly to the target location. The duration of the swing phase is mainly dependent on neuromotor mechanisms related to the build-up of muscle force and power to move the leg. It appears that the improvement in the speed of swing phase duration was largely due to an improvement in muscle strength and power, resulting from the resistance provided by the water during WEP. Although electromyography activity (EMG) was not measured in the current study, the possible mechanism for the reduction in the swing phase duration may be interpreted as an increase in hip flexors muscle activity after training. This is supported by Kaneda, Sato, Wakabayashi, Hanai, and Nomura (2008) reporting that water walking showed significantly greater muscle activation in the rectus-femoris during swing phase compared to land walking. They also showed higher activity in biceps femoris, during water walking in the forward and backward swing phase (Kaneda, Sato, et al., 2008; Kaneda, Wakabayashi, Sato, & Nomura, 2007). Our results suggest that water viscosity requires the subject to exert greater force during stepping exercises and that the perturbation-WEP training provides sufficient overload to increase lower limb strength, thus improve the speed of leg lifted and moved rapidly during stepping.

The duration of the step initiation phase is mainly dependent on peripheral sensory detection and afferent nerve conduction time followed by central neural processing and efferent nerve conduction time. Since sensory detection thresholds and nerve conduction velocities cannot be changed by training, it appears that the improvement in duration of the step initiation phase after WEP was largely due to an increase in the speed of the central neural processing time and to strengthening of the specific neuromotor pathways responsible for planning and executing the stepping movement. Thus, a more rapid and effective reallocation of cognitive resources, due to training, may have contributed to improved ability to step rapidly as found in previous work (Maki & McIlroy, 2007; Woollacott & Shumway-Cook, 2002; Zettel,

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

Holbeche, McIlroy, & Maki, 2005). Because the central processing demands are directly related to the novelty and difficulty of the motor task, the reduced step initiation phase indicates higher processing speed due to training. This is supported by Marigold et al. (2005) who found that agility training demonstrated greater improvement in step reaction time and paretic rectus-femoris postural reflex onset latency than the stretching/weight-shifting group. Also Gatts and Woollacott (2006) found that Tai Chi training significantly reduced Tibialis Anterior response time of the perturbed leg. They concluded that Tai Chi training enhanced neuromuscular responses controlling the ankle joint of the perturbed leg. Although perturbation-based training did not specifically target postural stability in up-right standing, we found a modest improvement in postural stability. The findings showed that postural sway was reduced post-WEP training; similar improvement in the postural stability after an intervention of water exercise including deep water running found also in Kaneda, Sato, et al. (2008). This provides clear evidence that some benefits of WEP training generalized to better control of balance in up-right standing. The generalizability of improvements in postural stability in eyes closed condition also found in the study suggests that individuals who completed WEP perturbation training were subsequently less visually dependent. This may be due to enhanced feedback control, based on somatosensory information regarding their feet. In elderly persons with age-related declines in sensation, training may have resulted in a sensory ''re-weighting'' so as to rely more on information from less-impaired senses; thus older adults were able to better detect changes in the movement of the COP under their feet. Gatts and Woollacott (2006) found that Tai Chi balance training significantly reduced occurrence of co-contraction of ankle antagonist muscles in upright standing, this shows that feedback control can be changed by training.

Although some effects of perturbation WEP training on stepping and balance control were found, it appears that there were no benefits for performance aspects of balance control (e.g., Berg Balance Score). Although this lack of improvement could be due to ceiling effects (e.g., the subjects showed relatively high levels of physical function and mobility, mean BBS scores of 54.5 during baseline), it may reflect the specificity-of-training principle and the need for therapists to tailor balance training programs to target specific aspects of balance control. Stepping response was specifically targeted in the current study.

Future training programs should target less independent elderly persons, balance-impaired old and older adults who suffer from falls and clinical populations to determine the extent to which the present results apply to higher-risk populations. Also, to explore whether the training gains were maintained in comparison with post-intervention measurements, to determine whether a maintenance program is required to retain the training benefits. Further work is needed to determine whether WEP reduce the number of falls. Indirect evidence is provided by previous retrospective (Melzer, Benjuya, & Kaplanski, 2004; Melzer, Kurz, & Oddsson, 2010; Melzer, Kurtz, et al., 2007; Melzer, Kurz, Shahar, & Oddsson, 2010) and prospective (Maki, Holliday, & Topper, 1994; Melzer et al., 2009) studies demonstrating associations between the variables that were improved by training (faster stepping response and lower ML-sway range) and fall risk. These biomechanical considerations also provide reason to believe that the training benefits may help prevent falls. The improvement in the ability to step rapidly will help to ensure that individuals are able to complete the step in sufficient time to prevent a fall.

5. Conclusions

The present results indicate that water exercises that include perturbations to induce stepping are an effective intervention to counter age-related reduction in voluntary stepping speed, which in known to be associated with increased fall risk.

Conflict of interest statement

The authors declare that they have no competing interests, any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Authors' contributions

OR was involved in experimental design, conducting experiments, subjects recruitment, data analysis and interpretation as well as drafting the manuscript. IT was involved in subjects' recruitment and responsibility for the day-to-day operations of the research project. EV and GS conducted the tests. MF was involved in the statistical planning and statistical analysis. IM was the PI of the research he was involved in planning as well as data analysis and interpretation and drafting of the manuscript.

Acknowledgments

The authors would like to acknowledge the contribution of the management of the Hydrotherapy Center in Sha'ar HaNegev. We would also like to thank the Sha'ar Ha'negev council and their members who volunteered for this research study.

References

Bauer, C., Gröger, I., Rupprecht, R., & Gassmann, K. G. (2008). Intrasession reliability of force platform parameters in community-dwelling older adults. *Archives of Physical Medicine and Rehabilitation, 89*, 1977–1982.

Berg, K. O., Wood-Dauphniee, S. L., Williams, J. T., & Gayton, D. (1989). Measuring balance in the elderly: Preliminary development of an instrument. *Physiotherapy Canada, 41*, 304–311.

Devereux, K., Robertson, D., & Briffa, N. K. (2005). Effects of a water-based program on women 65 years and over: A randomized controlled trial. *Australian Journal of Physiotherapy, 51*, 102–108.

Douris, P., Southard, V., Varga, C., Schauss, W., Gennaro, C., & Reiss, A. (2003). The effect of land and aquatic exercise on balance scores in older adults. *Journal of Geriatric Physical Therapy, 26*, 3–6.

Gatts, S. K., & Woollacott, M. H. (2006). Neural mechanisms underlying balance improvement with short term Tai Chi training. *Aging Clinical and Experimental Research, 18*(February (1)), 7–19.

Hedges, L., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Kaneda, K., Sato, D., Wakabayashi, H., Hanai, A., & Nomura, T. (2008). A comparison of the effects of different water exercise programs on balance ability in elderly people. *Journal of Aging and Physical Activity, 16*(October (4)), 381–392.

Kaneda, K., Wakabayashi, H., Sato, D., & Nomura, T. (2007). Lower extremity muscle activity during different types and speeds of underwater movement. *Journal of Physiological Anthropology, 26*(March (2)), 197–200.

Kaneda, K., Wakabayashi, H., Sato, D., Uekusa, T., & Nomura, T. (2008). Lower extremity muscle activity during deep-water running on self-determined pace. *Journal of Electromyography and Kinesiology, 18*(December (6)), 965–972.

Kannus, P., Parkkari, J., Sievänen, H., Heinonen, A., Vuori, I., & Järvinen, M. (1996). Epidemiology of hip fractures. *Bone, 18*(Suppl. 1), 57–63.

Kent, A., & Pearce, A. (2006). Review of morbidity and mortality associated with falls from heights among patients presenting to a major trauma centre. *Emergency Medicine Australasia, 18*, 23–30, (Review).

Latham, N., Anderson, C., Bennet, D., & Stretton, C. (2003). Progressive resistance strength training for physical disability in older people. [Protocol] Cochrane Musculoskeletal Injuries Group. *Cochrane Database of Systematics. Review 1*, (2): CD002759, Review. Update in: Cochrane Database Syst Rev. 2009;(3):CD002759.

Lord, S., Mitchell, D., & Williams, P. (1993). Effect of water exercise on balance and related factors in older people. *Australian Journal of Physiotherapy, 39*, 217–222.

Lord, S. R., Matters, B., & St George, R. (2006). The effects of water exercise on physical functioning in older people. *Australasian Journal on Ageing, 25*, 36–41.

Luchies, C. W., Alexander, N. B., Schultz, A. B., & Ashton-Miller, J. (1994). Stepping responses of young and old adults to postural disturbances: Kinematics. *Journal of the American Geriatrics Society, 42*, 506–512.

Maki, B. E., Edmondstone, M. A., & McIlroy, W. E. (2000). Age-related differences in laterally directed compensatory stepping behavior. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 55*, M270–M277.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *Journal of Gerontology, 49*(2), M72–M84.

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003

Maki, B. E., & McIlroy, W. E. (1997). The role of limb movements in maintaining upright stance: The "change-in-support" strategy. *Physical Therapy, 77*, 488–507.

Maki, B. E., & McIlroy, W. E. (2007). Cognitive demands and cortical control of human balance recovery reactions. *Journal of Neural Transmission, 114*, 1279–1296.

Mansfield, A., Peters, A. L., Liu, B. A., & Maki, B. E. (2010). Effect of a perturbation-based balance training program on compensatory stepping and grasping reactions in older adults: A randomized controlled trial. *Physical Therapy, 90*, 476–491.

Marigold, D. S., Eng, J. J., Dawson, A. S., Inglis, J. T., Harris, J. E., & Gylfadóttir, S. (2005). Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. *Journal of the American Geriatrics Society, 53*(March (3)), 416–423.

Masud, T., & Morris, R. O. (2001). Epidemiology of falls. *Age and Ageing, 30*, 3–7.

McIlroy, W. E., & Maki, B. E. (1996). Age-related changes in compensatory stepping in response to unpredictable perturbations. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 51*, M289–M296.

McMurdo, M. E., Millar, A. M., & Daly, F. (2000). A randomized controlled trial of fall prevention strategies in old peoples' homes. *Gerontology, 46*, 83–87.

Melzer, I., Benjuya, N., & Kaplanski, J. (2004). Postural stability in the elderly: A comparison between fallers and non-fallers. *Age and Ageing, 33*, 602–607.

Melzer, I., Elbar, O., Tsedek, I., & Oddsson, L. I. E. (2008). A water-based training program that include perturbation exercises to improve stepping responses in older adults: Study protocol for a randomized controlled cross-over trial. *BMC Geriatrics, 8*, 19.

Melzer, I., Kurz, I., & Oddsson, L. I. (2010). A retrospective analysis of balance control parameters in elderly fallers and non-fallers. *Clinical Biomechanics (Bristol, Avon), 25*, 984–988.

Melzer, I., Kurtz, I., Shahar, D., Levi, M., & Oddsson, L. I. E. (2007). Application of the voluntary step execution test to identify elderly fallers. *Age and Ageing, 36*, 532–537.

Melzer, I., Kurz, I., Shahar, D., & Oddsson, L. I. (2009). Predicting injury from falls in older adults: Comparison of voluntary step reaction times in injured and noninjured fallers—A prospective study. *Journal of the American Geriatrics Society, 57*, 743–745.

Melzer, I., Kurz, I., Shahar, D., & Oddsson, L. I. (2010b). Do voluntary step reactions in dual task conditions have an added value over single task for fall prediction? A prospective study. *Aging Clinical and Experimental Research, 22*, 360–366.

Melzer, I., & Oddsson, L. I. E. (2004). The effect of a cognitive task on voluntary step execution in healthy elderly individuals. *Journal of the American Geriatrics Society, 52*, 1255–1262.

Melzer, I., & Oddsson, L. I. (2012). Improving balance control and self-reported lower extremity function in community-dwelling older adults: A randomized control trial. *Clinical Rehabilitation July 26 (Epub ahead of print).*

Melzer, I., Shtilman, I., Rosenblatt, N., & Oddsson, L. I. (2007b). Reliability of voluntary step execution behavior under single and dual task conditions. *Journal of NeuroEngineering and Rehabilitation, 4*, 16.

Rogers, M. W., Johnson, M. E., Martinez, K. M., Mille, M. L., & Hedman, L. D. (2003). Step training improves the speed of voluntary step initiation in aging. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 58*, 46–51.

Rutland-Brown, W., Langlois, J. A., Thomas, K. E., & Xi, Y. L. (2006). Incidence of traumatic brain injury in the United States, 2003. *Journal of Head Trauma Rehabilitation, 21*, 544–548.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3/4), 591–611.

Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The effect of multidimensional exercises on balance, mobility and fall risk in community-dwelling older adults. *Physical Therapy, 77*(1), 46–57.

Simmons, V., & Hansen, P. D. (1996). Effectiveness of water exercise on postural mobility in the well elderly: An experimental study on balance enhancement. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 51*, M233–M238.

Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *New England Journal of Medicine, 319*, 1701–1707.

Topp, R., Mikesky, A., Wigglesworth, J., Holt, W., Jr., & Edwards, J. E. (1993). The effect of a 12-week dynamic resistance strength training program on gait velocity and balance of older adults. *Gerontologist, 33*, 501–506.

Woollacott, M. H., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture, 16*, 1–14.

Zettel, J. L., Holbeche, A., McIlroy, W. E., & Maki, B. E. (2005). Redirection of gaze and switching of attention during rapid stepping reactions evoked by unpredictable postural perturbation. *Experimental Brain Research, 165*, 392–401.

Please cite this article in press as: Elbar, O., et al., A water-based training program that includes perturbation exercises improves speed of voluntary stepping in older adults: A randomized controlled cross-over trial. Arch. Gerontol. Geriatr. (2012), http://dx.doi.org/10.1016/j.archger.2012.08.003