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Perturbation exercises during treadmill walking improve pelvic and trunk motion in older adults—A randomized control trial

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ABSTRACT

Background: Most falls among older adults occur while walking. Pelvic and trunk motions are required to maintain stability during walking. We aimed to explore whether training that incorporates unexpected loss of balance during walking that evokes balance recovery reactions will improve pelvic, thorax, and trunk kinematics at different walking speeds.

Methods: Fifty-three community-dwelling older adults (age 80.1 ± 5.6 years) were randomly allocated to an intervention group (n = 27) or a control group (n = 26). Both groups received 24 training sessions over 3 months. The intervention group received unexpected perturbation of balance exercises during treadmill walking, while the control group performed treadmill walking only. The primary outcome measures were the pelvic, thorax, and trunk motion. The secondary outcome measures were stride times, length, and width.

Results: Compared to control, participation in the intervention program led to improvement in pelvic and trunk transverse rotations especially at participants' preferred walking speed. No improvement where found in pelvic list while thorax transverse rotation improved in both groups.

Conclusions: Pelvic and trunk transverse motion, parameters previously reported to deteriorate during aging, associated with gait stability and a risk factor for falls, can be improved by gait training that includes unexpected loss of balance.

1. Introduction

One of the major problems associated with aging is an increased susceptibility to falling (Peel, 2011). Falling is the sixth most common cause of death in older adults varying from 0.3 falls a year per older adult living in the community to 3 falls for high-risk older adults (Rubenstein, 2006), and may result in acute injuries (Centers for Disease Control & Prevention, 2017). Minimizing falls is critical for maintaining function, and reduce disability in older adults. Many falls in older adults occur during walking (Robinovitch, Feldman, & Yang, 2013), and inability to recover from unexpected loss of balance during walking i.e., slips and trips (Luukinen et al., 2000), transitions from static to dynamic activities (Lord, Ward, Williams, & Ansety, 1993), and instable gait (Verghese, Holtzer, Lipton, & Wang, 2009; Weiss, Brozgol, & Dorfman, 2013; Toebes, Hoozemans, Furrer, Dekker, & van Dieën, 2012). Older adults show lower gait speed, shorter and wider strides, higher stride frequency, low hip extension torque during push-off (Judge et al., 1996), high stride variability (Hausdorff, Rios, & Edelberg, 2001), and declines in pelvic and trunk motion (Gimmon et al., 2015).

Older adults had differences in gait characteristics compared with younger adults (Gimmon et al., 2015) and with older adults who reported a recent fall (Barak, Wagenaar, & Holt, 2006). Recently, we observed that these changes in walking patterns in the older adults coincided with an increased stride frequency, a smaller stride length, decreased pelvic rotation, and reduced counter rotation in the thorax, resulting in decreased trunk rotation (Gimmon et al., 2015). Pelvic and trunk rotation are required for gait stability (Lamoth, Beek, & Meijer, 2002). More specifically, pelvic transverse rotation contribute to step length by reducing the need for a large hip flexion during walking (i.e., pelvic step), and reduces the movement of COM (Liang et al., 2014). Pelvic transverse rotation as well as pelvic list rotation are required for the control of the displacement of the center of mass (COM) for efficient energy expenditure (Lin, Gfoehler, & Pandy, 2014). Moreover, the momentum of pelvic transverse rotation and the trunk counter rotation, resulting in a smoother and more stable gait (Stokes, Andersson, &

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Forssberg, 1989). Insufficient trunk stability found to be associated with an increased risk of falls (Menz, Lord, & Fitzpatrick, 2003). Consequently, there is a need for developing effective balance exercises that can improve balance recovery responses as well as gait stability in older adults (i.e., improved altered pelvic and trunk rotations).

Balance exercises that include unexpected loss of balance during walking target those skills. These exercises facilitate explicitly the automatic balance responses such as cross over and side step stepping that require large functional pelvic and trunk motion. This may improve both gait stability and the ability to respond effectively to a loss of balance when fall is initiated pelvic and trunk motion. Information about how to improve functional pelvic and trunk motion during walking as well as the potential benefits of perturbation gait training to improve these parameters during walking have been minimally investigated.

Several studies trained balance recovery responses by performing perturbation exercises (Pai & Bhatt, 2007; Yang, Bhatt, & Pai, 2013; Kurz et al., 2016; Melzer & Oddsson, 2013; Mansfield, Peters, Liu, & Maki, 2010; Shimada, Obuchi, Furuna, & Suzuki, 2004). Trial-and error based workout led to adaptive improvements in balance recovery strategies (Pai & Bhatt, 2007), and generalization to "real life situations", i.e., reduction in over 40% of laboratory-induced falls among older adults and 50% reduction in annual risk of falls (Pai, Bhatt, Yang, & Wang, 2014). Fall prevention programs are usually directed towards 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, is to direct preventive efforts towards older adults who have not yet fallen. By improving the age related decline in gait stability (i.e., improved altered pelvic and trunk movements) and the ability to respond effectively to a loss of balance we may reduce the risk for fall. It is still unclear, however, whether this type of training impacted dynamic gait parameters, especially in respect to pelvic and trunk motion.

Principles of physical training and exercise include: awareness, continuity, motivation, overload, periodicity, progression and specificity. A successful balance and gait training must live by these rules otherwise, a training effect should not be expected. To be functionally useful, improving balance recovery responses and pelvic and trunk rotations during gait should preferably be designed into training intervention that closely mimic real life walking and losses of balance. This provides a specific challenge to the successful performance of functional tasks and may improve functional pelvic and trunk motion.

In the current study we examine whether perturbation training focused on evoking automatic balance recovery strategies during gait are able to improve pelvic and trunk motion that require for effective stepping responses during walking. Specifically, we targeted well-defined aspects of gait characteristics: (Peel, 2011) pelvis transverse rotation, (Rubenstein, 2006) pelvis list rotation, (Centers for Disease Control & Prevention, 2017) thorax transverse rotation, and (Robinovitch et al., 2013) trunk transverse rotation. We chose these outcome measures because previous studies demonstrated impairments in these specific characteristics of gait in older people (Gimmon et al., 2015) and older adults with a history of falls (Menz et al., 2003). Considering that automatic stepping responses during gait, especially cross-over stepping and lateral stepping responses, require ability to perform pelvic and trunk rotations, we hypothesize that older adults will significantly improve functional pelvic and trunk rotations during walking by participating in a treadmill gait training program that incorporates unexpected loss of balance.

2. Methods

This is an additional analysis of a previously reported RCT, where we found that voluntary stepping and postural stability was improved by participating in perturbation training (Kurz et al., 2016). Fifty–three older adults from two protected housing institutes were recruited. The

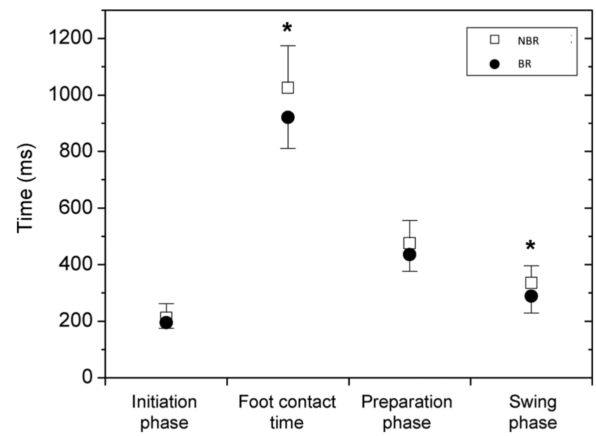

Fig. 1. Voluntary step execution times for BR (●) and NBR (□).
Placement of symbols indicates mean values; the whiskers of each plot indicate ± 1 standard deviation. * Indicates significant differences between groups ($p < 0.05$) based on independent *t*-test for each Voluntary Step Parameter.

eligibility criteria were: 70 years or older; independent walkers; score higher than 24 in Mini-Mental examination; no severe focal muscle weakness; no blindness; no neurological disorders; no metastatic cancer. Out of 72 seniors who were assessed for eligibility, 19 were excluded (see Fig. 1). All subjects provided a medical waiver signed by their primary care physician clearing them to participate in moderate physical exercise. The study was approved by the Helsinki Committee of Barzilai University Medical Center, Ashkelon, Israel (ClinicalTrials.gov Registration number #NCT01439451).

2.1. Study design

After signing an informed consent statement the subjects were randomized to two sites (27 and 26 subjects, respectively). In the first site, 14 subjects were randomly allocated to the intervention group and 13 to the control group. In the second site 13 subjects were randomly allocated to the intervention group and 13 to the control group using computer random allocation software (Random allocation software version 1.1, Isfahan Iran).

2.2. Perturbation training programs

Both intervention and control group subjects received a treadmill gait training program, with and without perturbations, respectively. All patients were treated two times per week for a period of 24 weeks. A mechatronic device that provides unexpected horizontal anterior-posterior and medio-lateral translations during treadmill walking was used (Shapiro & Melzer, 2010). Subjects in both groups were instructed to walk on a treadmill, at their own preferred walking speed with their hands free to swing. They wore a loose safety harness that allowed the subject to walk and to execute balance recovery reactions, but could arrest the fall if needed (Kurz et al., 2016; Shapiro & Melzer, 2010). The treadmill speed was increased until the subject said "It's too fast" and then treadmill speed decreased until the subject said "It's too slow". The midpoint of their self-reported speed was their "preferred treadmill speed". While the control group subjects walked with no perturbation the intervention group received unannounced anterior, posterior, right, or left perturbations during walking. The therapist instructed the subjects to walk as naturally as possible. The perturbations were given in random order at 24 progressively more challenging training levels of difficulty with respect to the platform's displacement, velocity, and acceleration of perturbation. Each session lasted 20 min, included 3 min warm-up treadmill walking, 14 min of perturbations gait training and 3 min of cool down walking. During each session, the listed platform translation unannounced perturbations were delivered in an