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Can higher training practice dosage with treadmill slip-perturbation necessarily reduce risk of falls following overground slip?

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ABSTRACT

Background: Perturbation training is an emerging paradigm to reduce idiopathic falls (without clinical signs or symptoms) in older adults. While a higher threat dosage (intensity) in motor learning often directly relates to greater adaptation, retention, and generalization, little is known whether increasing the practice dosage (repetition) of slip-perturbation training would necessarily improve its outcomes.
Research question: Can higher practice dosage of treadmill slip-perturbation training lead to greater generalization to an overground slip immediately after the training?
Methods: Forty-five community-dwelling older adults (73.5 ± 5.6 years old) participated in the present study. They were conveniently assigned to three groups with equivalent treadmill walking duration: treadmill slip-perturbation training group with 40 practice dosage, 24 practice dosage, and zero practice dosage (without slip-perturbation). Later on during overground walking, all of them were exposed to the same generalization test (a novel slip on a walkway). Their recovery outcomes (fall, or no fall; balance loss, or no balance loss) and center of mass stability were compared.
Results: Higher practice dosage did not show significantly less incidence of fall, balance loss, or greater stability in comparison to lower practice dosage ($p > .05$). The present study showed that there was no evidence of dose-response relationship when the practice dosage was set above the 24 trials of practice dosage in treadmill slip-perturbation training.
Significance: Contrary to our hypothesis, increased practice dosage (40-slips) in treadmill slip-perturbation training from the commonly used threshold (24-slips) did not necessarily benefit immediate generalization from treadmill to overground walking among community-dwelling older adults.

1. Introduction

Falling is one of the most serious problems experienced by older adults in the United States and around the world, and creates a significant health threat in this population [1]. Slips are responsible for about 40% of all environmental falls leading to severe consequences such as hip fractures and traumatic brain injuries, which cause prolonged hospitalization or even death [1,2]. Falls are often directly or indirectly related to depression, isolation, and decreased physical activity and quality of life, leading to a state of morbidity and increased burden of care in otherwise healthy adults [1]. Therefore, understanding of fall-prevention approaches to reduce the risk of falls in older adults is necessary. One promising way to reduce slip-related falls is adaptive slip-perturbation training.

Recent studies have indicated that perturbation training is an emerging paradigm to reduce idiopathic falls among community-dwelling older adults [3,4]. Perturbation training works to improve the ability of a person to control his/her center of mass (COM) stability state, which is affected by COM position and its velocity relative to the base of support (BOS). This improvement in stability is achieved by training-induced motor learning, a process that includes adaptive acquisition, retention, and generalization of the acquired skills [5–7]. Previous research has found that fall-resisting skills acquired from adaptive perturbation training can be transferred to prevent falls under oil-lubricated slippery conditions [8]. Similarly, generalization has been shown to occur after different types of training: sit-to-stand [9], treadmill [5,10], and interlimb slip [11]. In addition, training-related reduction in laboratory-induced falls has also been shown to generalize to real-life fall reduction [3]. In a recent study on healthy young adults, significant generalization effects were observed during exposure to a novel overground slip following treadmill-perturbation training [5,10]. If the training effects induced by treadmill-perturbation training on the

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control of stability could be further modulated to improve generalization to reduce real-life falls, this type of training could be easily translated into the rehabilitation clinics because of the portability of treadmills; hence it could be more broadly applied to the frailer elderly who might not otherwise be able to tolerate greater dosages [4,12–14].

Practice dosage (repetition) and threat dosage (intensity) of the treadmill can be easily manipulated and precisely controlled [5]. Motor learning literature from locomotor studies indicated that improving practice dosage or threat dosage could result in improved training effects [7,15]. Thus, modulating treadmill slip-perturbation practice dosage and threat dosage may be important factors leading to the effectiveness of the training to update central nervous system (CNS) for better stability. In addition, literatures indicated that overtraining could improve motor learning in terms of generalization to other tasks and yield greater longer-term retention [8]. However, previous studies examining effect of the practice dosage on motor learning have provided mixed findings. Bhatt et al. [6,7] reported that retention of adaptive fall resistance skills could be enhanced with greater number of trials (twenty-four) incorporating both blocked and random practice during a session of training, compared to a single session of only five trials. Furthermore, it has been reported that a high practice dosage of functional extremity training can transfer to the untrained extremity, for the upper-extremity [16] as well as lower-extremity tasks [17]. In contrast to the previous findings, Huberdeau et al. [18] asserted that overtraining did not affect learning indicating that there was no difference in retention between 10 trials and 40 trials for a reaching movement. Similarly, Travlos et al. [19] claimed that continued overlearning does not enhance generalization from a training task to a similar task with changes in tracking distance and duration of arm (hand) movement. Further, Lang et al. [20] reported no difference when comparing low practice dosage and high practice dosage of task-specific training on an upper limb task in people with long-standing upper-limb paresis, post-stroke. Given these conflicting findings, the purpose of this study was, thus, to determine whether a higher practice dosages of treadmill slip-perturbation training would necessarily lead to greater generalization to overground context immediately after such training. Based on the principles of overlearning [3,7,21,22], we hypothesized that a treadmill 40-slip protocol would further improve the generalization effect of the standardized 24-slip protocol [23] when encountering a novel slip during overground walking, post-training.

2. Methods

2.1. Study design

Forty-five community-dwelling older adults (age = 74.5 ± 6.9, female = 34) participated in the present study. They were conveniently assigned to three groups with equivalent treadmill walking duration: treadmill training group with 24 practice dosage (TM_24, N = 15), with 40 practice dosage (TM_40, N = 15), and control group (N = 15) without slip-perturbation.

All participants were prescreened for neurologic, musculoskeletal, cardiopulmonary, and any other systemic disorders. Older adults with cognitive impairment (score < 25 on the Folstein Mini-Mental State Exam) [24], poor mobility (> 13.5 s on the Timed Up and Go test) [25], or symptomatic postural hypotension were excluded. All participants provided written informed consent, and this study was approved by the institutional review board at the University of Illinois at Chicago.

2.2. Experimental setup

A computer controlled treadmill (Active Step, Simbex, Lebanon, NH) was used to induce slip-perturbations in walking (Fig. 1a). The characteristics of treadmill slip-perturbation were designed to induce forward displacement of each subjects' BOS relative to their COM by a sudden acceleration of the backward-moving belt in the forward direction. Each subject began their trials by walking at steady state speed for approximately seven to ten steps in TM_24 and three to five steps in TM_40 before the onset of the first perturbation indicating that TM_24 spent about 25 s to complete a single slip-perturbation, while TM_40 spent about 15 s (Fig. 1b). The steady treadmill speed was chosen to best match their natural walking speed (v_0) at one of the four levels from −1.2 m/s, −1.0 m/s, −0.8 m/s, to −0.6 m/s (Table 1). The threat dosage (intensity) of each perturbation was determined by two factors, the acceleration of the belt (at two levels a: 5 or 6 m/s^2) and the duration of its application (at eight levels, Δt: 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, or 0.55 s). The final velocity (v_f) and slip distance (d) were obtained respectively using the following equations:

$$v_f = v_0 + \alpha\Delta t\ ; \quad d = \frac{1}{2}\alpha\Delta t^2$$

The generalization test was conducted on an overground walkway. A sliding device was embedded in the middle section of a 7-m walkway to induce slips during overground walking (Fig. 1c). This device consisted of a pair (i.e., right and left) of low-friction, passively movable platforms. Each platform was mounted to an aluminum track via ball bearings and placed on top of two tandem force plates bolted to the ground (AMTI, Newton, MA) for recording ground reaction forces. The movable platforms were originally locked and were only unlocked in a slip trial by a computer controlled release mechanism at the instance of participants' right heel strike on the right platform, without alerting the subjects. Once released, both right and left platforms could slide up to 90 cm. All subjects wore walking shoes and a full-body safety harness which was attached to a loadcell via a pair of shock absorbing ropes and then to a low friction ceiling mounted track to protect them from injuries.

2.3. Protocol

Every session for all groups started with three overground baseline walking trials. Then TM_24 and TM_40 groups received 24-repeated and 40-repeated "slips" on the treadmill, respectively. The trial sequence followed the principle of block-and-mixed practice [5,22,26]. Each block included four slip-perturbation trials, and subjects in training groups received progressively increasing threat dosage level of treadmill slip-perturbation (Fig. 1d). If subjects could not tolerate a higher threat dosage level during this progress, their remaining "slips" would stay at the same highest tolerable level (e.g., four, four, eight subjects' highest level of threat dosage was level 2, 3, 4, and fourteen subjects' one ended up with level 5). TM_40 had further reinforcement trials (more practice dosage trials at level 3, 4, and 5) before a cool-down session. The control group completed the same amount of walking time on the treadmill without perturbation. Finally, all subjects returned to the same overground walkway and received a novel-slip on overground after three to five natural walking trials. No subjects were informed where, when, and how the slip would occur during the overground test.

2.4. Data collection

Thirty reflective markers using a modified Helen Hayes marker set were placed on the subjects' body and the movable platforms [27]. The kinematics were recorded using an 8-camera motion capture system (Motion Analysis Corporation, CA and Qualysis, Sweden) at 120 Hz. Marker paths were low-pass filtered at marker-specific cut-off frequencies (ranging from 4.5 to 9 Hz) using fourth-order, zero-lag Butterworth filters [28]. The three-dimensional locations of joint centers, heels, and toes were computed from the filtered marker positions. Force plates, loadcell, and platform trigger-release onset signal were collected at 600 Hz and synchronized with motion data at the time of data collection.