Exercise-Based Fall Prevention: Can You Be a Bit More Specific?

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Trip-specific perturbation training reduces trip-related falls after laboratory-induced trips and, prospectively, in the community. Based on an emerging body of evidence, we hypothesize that using task-specific perturbation training as a stand-alone approach or in conjunction with conventional exercise-based approaches will improve the effectiveness of fall prevention interventions significantly. Key Words: accidental falls, aging, balance, fall risk, gait retraining, injury, motor learning

INTRODUCTION

In the United States, the number of fall-related injuries (15) requiring medical care and, possibly, fall-related deaths of older adults seems to be increasing. Exercise robustly and significantly decreases not only the rate of falls and fall risk by up to 30% compared with control groups but also fall-related fractures (13). Notably, the results of a systematic review and meta-analysis indicate that participation by older adults in exercise programs reduces the incidence of fall-related serious injuries (12). However, only a fraction of adults older than 65 yr actually engage in regular exercise (17) and, therefore, derive this benefit. Even if the participation rate in exercise programs by older adults was doubled, the current rate at which the size of the population of older adults is growing guarantees that the absolute number of falls will increase. This presents a related set of problems, the emergence of which can be predicted with great certainty. More falls will be associated with a proportional increase in fall-related morbidity and mortality secondary to injury. Given the predicted increase in the absolute number of expected injuries, even if the costs of delivering medical care were to remain at their present levels, the total health care and economic costs of these injuries must increase. Thus, it seems reasonable to ask if it is possible to improve the fall prevention effectiveness of exercise significantly.

This review presents a rationale for the clinical use of task-specific perturbation training as a stand-alone intervention or, alternatively, as an adjunct to conventional exercise-based approaches as a means to increase the effectiveness of fall prevention efforts significantly. The foundation of task-specific perturbation training is the specificity of training hypothesis. The hypothesis predicts that practicing the motor skill of avoiding a fall during conditions that mimic an actual fall will decrease fall risk. The degree to which the practiced motor skill influences performance of the actual motor skill is referred to as transfer. Transfer can influence both the performance of a motor skill that is different from the practiced motor skill and the performance of the practiced motor skill performed during different conditions.

In particular, fall prevention interventions that use treadmills to deliver large postural disturbances from which subjects must recover to avoid falling seem to be both effective and efficient for reducing fall risk and falls by older adults. Based on a related and growing body of evidence, we hypothesize that using task-specific perturbation training to reduce falls by older adults is superior to conventional exercise-based approaches. The hypothesis can be tested comprehensively using metrics such as the cost and time required to deliver the interventions but, perhaps most importantly, the success of the proposed intervention to reduce the number of fall-related injuries caused by trips, slips, and sideways-directed falls. These categories of falls account for a dominant percentage of falls by and injuries to older adults. The foundation of the hypothesis is that the effectiveness of conventional exercise to reduce falls seems to have reached its maximum or near maximum value. Considering that, by 2030, the population of older adults in the United States is estimated to reach 70 million, just a 5% increase in fall prevention effectiveness to 35% can account for 58,000 fewer serious injuries and nearly $600,000,000 saved in annual
medical care costs (Fig. 1). We have reason to believe that the effectiveness of task-specific perturbation training will be larger than 5%.

HOW EFFECTIVE IS EXERCISE IN REDUCING FALLS?

Specific types of exercise have been recommended formally as components of fall prevention programs for older adults for at least 10 yr (2). Aerobic-type exercises and exercises targeting balance, muscle strength/power, and improved gait are common elements of multifactorial fall prevention interventions. These multifactorial interventions reduce the monthly rate of falling by older adults (adjusted incidence rate ratio, 0.63; 95% confidence interval (95% CI), 0.49–0.83; (7)). However, the isolated effect of exercise is considerably smaller (adjusted incidence rate ratio, 0.86; 95% CI, 0.73–1.01; based on 19 trials; (7)).

The three most common exercise-based fall prevention interventions are multicomponent group exercise programs, group practice of Tai Chi, and individually prescribed multicomponent home-based programs. All three interventions decrease fall risk and rate of falling (13); on average, decreasing the rate ratios for fall risk and rate of falling by 25% and 31%, respectively (Fig. 2). However, a general limitation with regard to these metrics is that they reflect all-cause falls. Consequently, these metrics cannot provide information related to the specific type(s) of falls that may be most affected by the exercise. Between 50% and 60% of falls that occur during locomotion are caused by trips and slips (19). To our knowledge, the extent to which conventional exercise-based interventions affect these specific fall types has not been reported previously and, as a result, is not known. This also is true for falls that have a large laterally directed component to which older adults generally seem to be vulnerable (16). In the absence of such data, it remains an open question as to whether the percentage decrease in falls and the rate of falling attributed to conventional exercise-based interventions represent the lower attainable limits of fall prevention. It has been suggested recently that the maximum reduction may be between 30% and 40% (35). However, based on the results from our laboratory, we believe that it is possible to do even better, perhaps more than 50%.

WHY DOES GENERAL EXERCISE REDUCE FALLS?

It might be possible to increase the effectiveness of exercise-based fall prevention interventions beyond the present value by defining the mechanisms through which the interventions operate. To date, though, the mechanisms through which falls are reduced by exercise-induced improvements in, for example,
muscle strength and/or power, cardiovascular endurance, and balance, have not been defined. The overlap of the 95% CIs in Figure 2 indicates that the effectiveness of the three exercise methods does not differ significantly. This seems reasonable. Each intervention shares similar exercise outcomes, for example, increased muscle strength/power and improved balance, although the extent to which muscle strength/power and balance are affected by these interventions probably is different. These differences may underlie the inconsistencies with regard to the extent that any particular type of exercise has on fall risk. This, in turn, partially may reflect between-study differences with regard to important exercise programming parameters such as the delivery method (group vs individual), the frequency (how often) and duration (how long) of the exercise sessions, and the intensity (the difficulty) with which the exercises are performed.

Many of the mechanisms underlying the relationships between exercise and health are well-characterized, and there are reasonably clear exercise targets and expected dose-response relationships. However, this does not seem to be true for the relationship between exercise and fall prevention. We think that this knowledge gap may limit the extent to which the effectiveness of exercise-based fall prevention interventions may be more than just incrementally improved. However, we propose that the effectiveness of exercise-based fall prevention can be improved substantially by increasing the task specificity of the exercise. That is, in contrast to the focus on improving presumptive performance-related variables associated with fall risk, the extent to which the exercise itself mimics the task for which the training is being conducted must be increased.

WHY EXERCISE MAY NOT TRANSFER TO FALL PREVENTION

Epidemiological studies consistently report a significant relationship between lower extremity weakness and fall risk. This relationship may be stronger than for any other risk factor (32). This robust finding has served logically as a basis for the inclusion of muscle strengthening exercises in fall prevention interventions. Indeed, avoiding a fall after a laboratory-induced trip has been shown to be associated significantly with the maximum leg press strength of older adults (25). In a follow-up study, 16 wk of lower extremity resistance training significantly increased concentric, eccentric, and isometric knee extension, plantar flexion, and their rates of moment generation of older adults (28). However, these functional gains were not found to have influenced the support limb responses after a laboratory-induced trip. The authors concluded that increased lower extremity muscle strength and rate of moment generation “…was not transferred to the functional task of push-off after tripping…” Support limb push-off is notable for its contribution to a successful stepping response after a trip by reducing whole-body angular momentum caused by the trip (26). Notably, the extent to which angular momentum after a trip is reduced by support limb push-off is impaired in older adults (27).

In addition to the support limb, during the weight acceptance phase of the recovery step, the lower extremity muscle lature contributes significantly to arresting/reducing the whole-body angular momentum that results from the trip. It seems reasonable to expect that lower extremity strength and/or power contributes to the success of the recovery step itself, specifically during the weight acceptance phase. Indeed, after a laboratory-induced trip, the falls by some older adults were preceded by lower extremity buckling during the weight acceptance phase that, on average, corresponded to an 11-degree knee flexion (23) that likely involved eccentric contraction of the knee extensor muscles. Consequently, and in the absence of any data to the contrary, it seems reasonable to consider that the ability to generate eccentric muscle force and/or power may be a key performance variable with regard to successful performance of the initial recovery step. Either way, the extent to which strength and/or power increases subsequent to resistance training transfer to the recovery task remains an open question. An explanation for the possibly low transfer of lower extremity strength gains to performance of the stance limb (28) during recovery and/or the weight acceptance phase of the recovery step after an induced trip reflects the sensorimotor requirements and the environmental contexts that distinguish the tasks. These differences are of sufficient magnitude to qualify both as distinctly different motor skills.

Besides the obvious absence of a risk for falling while performing a leg press exercise as well as the between-task difference with regard to the orientation relative to vertical (i.e., gravity), despite similar body segment positions (Fig. 3), there are important sensorimotor conditions that differ considerably. During the cyclic concentric-eccentric contraction phases of the leg press exercise, while the hip and knee simultaneously extend/flex and the ankle plantar/dorsiflexes, the trunk remains in an essentially static position. At the time that the initial recovery step contacts the ground after an induced trip, the hip and knee joints simultaneously flex and the ankle joint dorsiflexes. However, depending on if the subject is destined to fall, or to not fall, the trunk is either flexing or extending, respectively, and at relatively high velocities (23). Given the position of the head on the trunk, the different trunk kinematics can cause considerable between-task differences in optic flow, as well as vestibular and otolith organ stimulation. These differences can bear direct and/or indirect effects on muscle activation and subsequent joint kinetics.

The biomechanical requirements of the two tasks are sufficient to assure distinctive lower extremity muscle activation patterns and, subsequently, distinctive joint kinetics. Consider, for example, that, just before recovery step completion after a laboratory-induced trip, the knee joint extension velocity can be relatively high (>500 degrees per second) and the knee joint stiffness is relatively low. However, at the time of recovery foot placement on the ground, the knee joint velocity has been arrested and the knee joint stiffness has been increased. Although uncontrolled knee flexion is undesirable after recovery step completion, the knee, as previously presented, does flex during the initial weight acceptance phase of the recovery step. This flexion occurs under the control of eccentric knee extensor contraction before the transition to concentric contraction of the same muscles. This sequential and rapid change in joint kinetics, and the underlying nervous system coordination of lower extremity muscle activation, is absent during the leg press exercise.
During motor learning, the nervous system undergoes structural and functional changes (10) that are specific to the demands of the task. The extent to which motor learning occurs can be enhanced by increasing training demands by including, for example, motor tasks possessing greater complexity and requiring more cognitive processing (6). The demands of the motor training subsequently determine the nature of the motor cortex and spinal cord changes (1) that include reorganization of motor maps and synaptic changes and that can be observed in as few as five training days (6). Collectively, these sensorimotor and environmental context differences create distinct boundaries between the conditions associated with avoiding a fall and those of performing exercises typically prescribed to decrease fall risk. These differences likely contribute to the apparent limited transfer of increased muscle strength, achieved through resistance exercise, to trip recovery (28).

WHY TASK-SPECIFIC PERTURBATION EXERCISE MAY BE EFFECTIVE

Task specific training involves practicing context-specific motor skills and receiving feedback regarding the performance. Motor skill performance during a “test” condition is enhanced when both the sensorimotor and environmental contexts of the “practice” and test conditions are similar. Ideally, the motor skills possess intrinsic and/or extrinsic value for the person engaged in the training. The extent to which training is task specific can be gauged by the degree to which a motor skill learned under practice conditions can be performed under different test conditions. Successful clinical use of task-specific exercise has been demonstrated for gait retraining (9,36,37) and for retraining transfers such as the sit to stand (5). These clinical successes, in which the training mirrors the desired functional activity, collectively suggest that task-specific perturbation training might be extended to fall prevention. The fall cause, for example, a fall caused by a slip or a trip, dictates the sensorimotor and environmental contexts. From the contextual differences, it follows that the ability to avoid falling after a trip or after a slip will require trip- or slip-specific training strategies, respectively. For example, after a trip (Fig. 3), the body rotates forward while translating in the same direction as the subject previously was walking. In contrast, during a slip, the body rotates backward while translation of the body continues in the forward direction (Fig. 4). Thus, there are differences in information derived from the visual, vestibular, and otolith systems. In addition, the tasks impose the need to perform either a backward-directed or forward-directed recovery step. These forward and backward steps differ with regard to multiarticular muscle activation timing and magnitude, as well as the maximum direction-specific ranges of motion (e.g., hip extension vs hip flexion). Therefore, the motor solution to avoiding an impending fall after a large postural disturbance and loss of balance is not only complex from the perspective of neuromuscular control, and time critical in light of the brief period available to execute the task successfully, but also strongly direction dependent. These considerations point to the value of task-specific perturbation training.

Task-specific perturbation training necessarily includes execution of whole-body motor skills that mimic the actual activity. In the present case, this includes stepping responses to avoid falls in the forward, backward, or sideways directions. The general task holds intrinsic and/or extrinsic value for older adults (“I don’t want to fall.”) and provides feedback, immediately, related to performance (“Whew! I didn’t fall.”). For older adults, the stepping responses certainly reside in the library of previously learned motor skills. Although the ability to execute the motor skill appropriately does, predictably, erode with aging, older adults retain the ability to learn, or re-learn in the present case, both simple and complex motor skills (4,11). However, compared with younger subjects, learning may require a longer time and, ultimately, the extent to which motor performance improves may be limited. Collectively, the growing body of evidence pointing to task-specific perturbation training as a means to decrease falls by older adults should not be surprising.

TASK SPECIFICITY APPLIED TO FALL PREVENTION

A common denominator in studies using task-specific perturbation training as a fall prevention intervention is the delivery of postural disturbances sufficient to require a stepping response to avoid a fall. (Note that there have been sizable...
between-study differences with regard to how a “fall” is defined. The methods of administering the disturbances include waist pulls (e.g., (30)), moving platforms (e.g., (24)), and treadmills. Each of these methods possesses advantages and disadvantages. Treadmills are a convenient and available technology through which, depending on the treadmill design, consistent and controllable postural disturbances may be delivered to subjects who are standing or, for some designs, walking at the time.

Treadmill-based training protocols have demonstrable effects on both stepping responses and the ability to avoid a fall. For example, frail older adults participated in a 6-month training protocol during which treadmill-delivered disturbances were caused by treadmill-belt decelerations while subjects were walking (34). During the 6-month follow-up period, the (all-cause) fall rate of the trained subjects was 20% lower than that of control subjects. Furthermore, compared with control subjects, fewer total (all-cause) falls and a longer time to first fall were reported. In another study, during a 2-month training protocol, men with Parkinson’s disease were subjected to treadmill-delivered postural disturbances (forward, backward, and sideways (29)). During a 2-wk follow-up period, the trained men had 50% fewer (all-cause) falls than the control subjects. In a third study, after a single-session training protocol during which healthy older adults practiced stepping responses after disturbances that caused a forward-directed motion simulating a trip, recovery kinematics were improved significantly after a laboratory-induced trip (3). In our initial study, the first of five disturbances that simulated a trip caused nearly 50% of the healthy older women to fall. However, nearly all of the women who fell after the first disturbance adjusted their stepping response kinematics and avoided falling on subsequent trials (20). This was followed by two studies of trip-specific perturbation training from our laboratory. In the first, healthy middle-aged and older women participated in a trip-specific multiple-week protocol consisting of treadmill-delivered disturbances that caused a forward-directed motion simulating a trip. The trip-specific training protocol reduced the relative risk of a fall after a laboratory-induced trip by more than 80% compared with the control group (14). In the second study from our laboratory, a 2-wk four-session protocol reduced the number of trip-related falls by nearly 50% (31).

The previous studies varied considerably with regard to their study designs including sample sizes, the ages of the subjects, the health and functional status of the subjects, the magnitudes of the delivered disturbances, the duration of the training protocol, the length of the follow-up periods, and the statistical significance of their results. Nevertheless, the combined results point favorably to the effectiveness of treadmill-based task-specific perturbation training for decreasing falls by older adults. In addition to the effect on fall risk, the above studies highlight that task-specific perturbation training possesses other qualities that merit mention. Compared with conventional exercise-based fall prevention interventions, the brevity of the task-specific perturbation protocols may contribute to reduced costs of delivery and increase the numbers of older adults who will elect to participate in the training. These possibilities contribute to the basis for the hypothesis that task-specific perturbation training is superior to conventional exercise-based fall prevention interventions.

A PATHWAY TO TEST THE HYPOTHESIS

Ideally, testing the hypothesis that task-specific perturbation training is superior to conventional exercise-based fall prevention interventions would take the form of a collaborative, multicenter, randomized clinical trial in which each site delivers the same task-specific perturbation protocol. The extent to which the results of such a study ultimately can be generalized to the overall population of older adults will depend on the ability of the multiple study sites to do so and, in addition, fully represent rural and urban environments, climates, and geographic regions, thereby assuring a maximally inclusive recruitment strategy. Clearly, this approach represents a complicated, time-intensive, and expensive undertaking.

At a more local level, subsequent to the initial success of our efforts focused on trip-related falls, we are now applying a similar approach to slip-related falls and sideways-directed falls. The inclusion of laterally directed stepping responses in the task-specific perturbation training protocol merits mention. Unlike trips and slips, the percentage of falls by older...
adults attributable to laterally directed loss of balance and failure of laterally directed stepping has not been reported. However, the laterally directed compensatory stepping ability of functionally independent community-dwelling older adults predicts prospectively measured (presumably all-cause) falls (16). Two studies specifically underscore the importance of the ability to perform laterally directed stepping responses. The first study included 206 patients who suffered a fall-related hip fracture and, of whom, 99 were not impaired cognitively. Of these noncognitively impaired subjects, 82 hip fractures were attributed to having fallen directly to their side (22). In a second study of 287 patients who suffered a fall-related upper extremity fracture (i.e., proximal humerus, elbow, or wrist), approximately 34% of the falls had a sideways-directed component (21). Thus, it seems reasonable that, to some extent, the inability to execute a laterally directed stepping response during these events was implicated. Similar to the recovery step after a trip, the ability to perform a laterally directed stepping response successfully is a composite of many performance-related variables, many of which are modifiable with training and for which training-related improvement may benefit performance of a laterally directed stepping response. For example, hypotheses regarding the reliance of the length and speed of a laterally directed step on overall response time, hip joint abduction range of motion, muscle strength, and/or muscle power remain legitimate and imminently testable. Overall, given the previously reported single-session trainability of laterally directed stepping responses (18), its inclusion in the task-specific perturbation intervention seems prudent.

To be included in the task-specific perturbation protocol, the elements directed at slip-related falls and sideways-directed falls must be shown to reduce those types of falls effectively. Our approach is to first establish efficacy in the laboratory where between-subject conditions can be better controlled. Similar to the approach successfully implemented with trip-related falls, if the number of slip- and sideways-directed falls is reduced significantly under laboratory-controlled conditions, testing of the effectiveness of the protocol will be extended to the community using a prospective design. Effective reduction of falls in the community will justify inclusion in the task-specific perturbation protocol.

We envision testing the hypothesis related to the superiority of task-specific perturbation training over that of conventional exercise-based fall prevention interventions by training groups of subjects with the task-specific perturbation protocol and comparing outcomes to those of groups trained using the three most common exercise-based fall prevention interventions. A minimum of a 12-month prospective period would follow the intervention during which all falls, their circumstances, and consequences would be reported. The primary outcome variables of the study include the number of injuries arising as a result of trip, slip, and sideways-directed falls and the number of (noninjurious) trip, slip, and sideways-directed falls. Secondary outcome variables include the specific fall types (injurious and noninjurious) and circumstances of fall-related injuries, the cost of medical care for fall-related injuries, and the time- and cost-effectiveness of delivering each of the interventions. Collectively, these represent the vitally important set of dependent variables on which the hypothesis may be tested.

In addition, to have decreased the number of prospectively measured trip-related falls significantly, with regard to the secondary outcome variables, our trip-specific perturbation protocol was demonstrably time effective. The protocol required just four training sessions for 2 wk, each lasting approximately 1 h (31). In contrast, the duration of the conventional exercise-based fall prevention interventions from which Figure 1 was constructed was 28.4 ± 16.9 wk (range, 6–52 wk; (12)). We also reported a low attrition rate for the intervention, 2.4%. In contrast, attrition rates from exercise programs, in general, of between 6% and 34% have been reported for older adults (33).

**WHAT IF IT DOES NOT WORK AND WHAT IF IT DOES?**

If it is not possible to improve the effectiveness of fall prevention interventions, then the growth of the population of older adults likely will be paralleled by an increase in fall-related mortality and morbidity. This will be accompanied by a similar (at best) increase in the costs of providing medical care for these injuries. In 2000, there were approximately 35 million adults 65 yr and older in the United States. This population is expected to reach 70 million by 2030. Based on the current statistics, 33% of these older adults, 23.1 million, will fall annually. Conventional exercise-based interventions could decrease this hypothetically by 30%. This translates to 6.93 million falls prevented. If the effectiveness of fall prevention interventions could be increased by just 5% (and we think that task-specific training can do much better than 5%), the predicted number of falls would be further decreased by 1.16 million. Between 5% and 30% of falls by older adults result in a serious injury such as fractures and head trauma (35). Conservatively, if only 5% of falls by older adults resulted in a serious injury, then the 5% increase in fall prevention effectiveness would decrease the number of serious injuries by 58,000. At an average current medical cost of $10,000 per serious injury (38), the 5% improvement would reduce the annual cost of providing medical care for serious fall-related injuries by $580 million. Thus, the absolute number of falls and, perhaps more importantly, injurious falls, the costs of medically caring for fall-related injuries, as well as the extent to which the quality of life for older adults, their caregivers, and family members are affected, are sensitive to even small changes in the effectiveness of fall prevention interventions. This is important at both the individual and societal levels.

Research related to task-specific perturbation training suggests, cautiously yet optimistically, that the positive effects of fall prevention interventions on falls and fall-related injuries can be improved. Nevertheless, a number of related general research questions that may be pursued in parallel can be identified. Of great importance is determining the extent to which task-specific training reduces fall-related injuries, the nature of injuries that are prevented, and if these benefits are conferred on all participants. For example, older adults who are robust physically may derive benefits from a task-specific perturbation protocol more rapidly than those who have greater impairment. However, older adults who are impaired, and consequently are at elevated risk for falls and fall-related
injuries, have much to gain from a task-specific perturbation protocol. The patient-specific and performance-centric nature of the task-specific protocol that we have designed (14,31) provides the flexibility to deliver a fall prevention intervention even to older adults with physical impairments. Thus, identifying the influence of patient-specific functional status on the effectiveness of task-specific perturbation training protocol is desirable. A plausible approach to this may be to characterize the relationships between the patient-specific functional status, training exposure, the size of the training effect, and the period over which the training effect is retained. This would help inform realistic clinical expectations for a specific older adult and, subsequently, may lead to improved delivery of task-specific perturbation training.

CONCLUSIONS

Overall, the collective literature provides an incentive, a rationale, and a framework for further systematic study to determine if task-specific perturbation training may be translated to a clinically viable method that can both synergize with and improve on the effectiveness of conventional exercise-based fall prevention interventions.

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UIC owns a patent on some of the technology used in the ActiveStep system and receives a part of the profits from sales of the ActiveStep system. As an inventor of the ActiveStep system, Dr. Grabiner receives the standard royalty distribution for a UIC inventor on any licenses for the ActiveStep system.

References


