Step Training Improves the Speed of Voluntary Step Initiation in Aging

Mark W. Rogers,1,2,3 Marjorie E. Johnson,1 Kathy M. Martinez,1 Marie-Laure Mille,1 and Lois D. Hedman1

Departments of 1Physical Therapy and Human Movement Sciences and 2Physical Medicine and Rehabilitation, and 3Buehler Center on Aging, The Feinberg School of Medicine, Northwestern University, Chicago, Illinois.

Background. Falls related to balance dysfunction are among the major problems of older individuals. The timing characteristics of protective voluntary stepping are critically related to effective balance recovery and are often delayed and slowed with age. This study investigated the influence of step training on the timing characteristics of voluntary step initiation in younger and older adults.

Methods. Voluntary reaction time stepping was evaluated before and after training in 12 younger adults and 8 healthy community-dwelling older adults who performed a 3-week regimen of either twice weekly induced step training (destabilizing large waist pulls) or voluntary step practice to a somatosensory reaction stimulus cue (nondestabilizing small waist pulls).

Results. Overall, the first step initiation times were slower for the older than for the younger subjects for both the somatosensory reaction stimulus cue task and an auditory transfer cue task. Step completion time was completed earlier for the young posttraining subjects, and older subjects generally had a longer step length. Training resulted in significant reductions in step initiation timing for the old (17%) and young (15%) subjects. Across age groups, the induced training group showed greater reductions in step initiation time than the voluntary practice group for the auditory transfer cue task.

Conclusions. A 3-week period of either voluntary or waist-pull-induced step training reduced step initiation time in older and younger adults. Moreover, compared with voluntary step practice, induced step training resulted in a significantly greater improvement in reaction time stepping for an auditory transfer cue task. At least in the short term, such step training has the potential to help older adults perform more like younger adults in their step initiation timing.

FALLS related to impaired balance are among the major problems associated with aging (1–4). To reduce the risk of serious injury and to improve functional well being among older persons, there is a need to minimize the incidence of falls through the optimization of balance performance. A growing body of evidence (5–10) has indicated that stepping is a commonly executed protective strategy for maintaining balance in the everyday environment. Steps may be initiated voluntarily to guard against a fall, or induced reactively in response to external challenges to balance. In general, older individuals, especially those with a history of falls, show a greater tendency than younger adults to take protective steps to maintain their balance (5,9,11,12). Thus, there is an important need for older persons to be effective in using protective stepping strategies.

To date, there has been a lack of interventions aimed at optimizing protective stepping function. A major factor to consider in such balance training is the timing of the response. For example, a generalized slowing in voluntary reaction time (RT) (13,14), including RT stepping (15–19), is a consistent accompaniment of human aging and is among the strongest sensorimotor predictors of falls (19). Consequently, individuals who require more time to initiate and execute stepping to maintain their balance may be at a greater risk for falling (14).

It has been previously observed that the initiation timing of externally induced reflex-like stepping can be more rapid than voluntary stepping (16,20,21) and that it can be as fast for older persons as for younger adults (5,16,22). The ability of some older individuals to respond as quickly as younger adults for induced stepping raises the possibility that there may be some potential for training older individuals to improve the speed of their voluntary stepping. It is conceivable that the central nervous system processes that mediate protective stepping resemble those involved in the control of gait (23,24). If that is the case, then it is possible that perturbation-induced step training, involving the repetitive application of high-intensity sensory stimulation that evokes stepping, could affect the same central pattern-generating mechanisms that have been proposed for the control of voluntary stepping (23,24).

Task-specific practice can improve RT performance in healthy individuals and pathological populations (25–28). It can therefore be expected to improve RT in voluntary stepping. It would be informative to assess the relative training effects of perturbation-induced stepping and voluntary stepping practice.

This study investigated the influence of step training on the timing characteristics of voluntary step initiation in younger and older adults. Specifically, we sought to determine (a) the effects of waist-pull-induced stepping and voluntary stepping practice on first step initiation and completion times; (b) the effects of the type of training on step-timing characteristics; and (c) whether potential training-related changes in the speed of RT stepping to
a somatosensory stimulus cue (small waist pull) would generalize to a different reaction stimulus (auditory) cue. We hypothesized that step training would increase the speed of voluntary step initiation timing in both younger and older adults. We also expected that, as a result of the enhanced sensorimotor facilitation of perturbation-induced stepping, induced step training would have a greater and more generalized effect than voluntary step training on the speed of step-timing characteristics.

**METHODS**

**Subjects**

Twenty healthy, volunteer subjects participated in the study. Twelve adults (8 women and 4 men), recruited from among university students, comprised the young group (mean age, 24 ± 2 years). Eight adults (4 women and 4 men), recruited through an Aging Research Registry and Geriatric Evaluation Service, were included in the old group. One older male participant did not complete the training because of health reasons. The remaining 7 older subjects had a mean age of 70 ± 9 years. All subjects signed an informed consent form approved by the Institutional Review Board prior to their participation.

Individuals were excluded if they had a significant history of cardiopulmonary, musculoskeletal, neurological, or other major systemic medical problems. Subjects were also excluded if they had a history of falls or used an assistive device for walking. Subjects were also randomly assigned into one of two training groups: induced (IND) stepping, \( n = 10 \), consisting of 7 women (3 old, 4 young) and 3 men (1 old, 2 young), and voluntary (VOL) stepping, \( n = 10 \), consisting of 4 women (4 young) and 6 men (4 old, 2 young).

**Experimental Protocol**

Subjects stood on two separate force platforms (biomechanics platform; Advanced Mechanical Technology Inc., Newton, MA), using a standardized foot position that was traced onto poster board to ensure a consistent initial foot placement (18). A pressure-sensitive contact mat was positioned directly in front of the preferred stepping limb with the poster board overlaying the contact mat in order to record step length. The preferred limb was determined by asking subjects to spontaneously begin stepping. An online visual display controlled the initial postural weight-bearing conditions prior to each trial (18). For safety purposes, the subjects wore a harness, and a “spotter” was positioned nearby.

**Pretraining and Posttraining Testing**

Step-timing characteristics were measured for simple RT conditions during blocks of five trials both pretraining and postraining (within 2 days of completing training) in response to a small forward waist-pull somatosensory (SOM) cue and to an electronic beep auditory (AUD) cue. For the SOM task, subjects were connected to a stepper-motor-driven waist-pull system (22) by means of a taut flexible cable attached at one end to the puller and at the other end to a rigid connection aligned at the level of the umbilicus on a waist belt. Subjects were instructed to “take one and only one step as fast as possible in response to the waist pull.” The SOM cue (0.045 m displacement, 0.09 m/s velocity, 1.80 m/s² acceleration) was applied following a visual “ready” cue by a randomly varied delay interval of 250–1000 milliseconds. The pull was not of sufficient magnitude to force the subject to take a step and only served as a reaction stimulus cue at the waist. The subjects were asked to briefly hold their position at the end of their step in order for step length to be marked. For the AUD cue task, subjects assumed the same starting position and were instructed to “take one and only one step as fast as possible in response to the beep,” which followed a random delay interval of 250–1000 milliseconds.

**Training Period**

Each subject participated in six training sessions. The first session began immediately following the pretest. Training sessions were administered twice weekly for 3 weeks, with no less than 2 days and no more than 5 days between sessions. Each session consisted of 53 trials, with 3 of the total trials serving as catch trials to discourage premature stepping. Step length was marked during 13 of the 53 trials (trials 1–5, 20, 30, 39, and 49–53). Seated rest periods were given after every 10 trials and when needed.

For the VOL training group, the SOM cue served as the go signal to initiate voluntary stepping. Subjects were instructed in the same manner as they were during the pretest. The IND training group received large waist pulls that were of sufficient magnitude (0.135 m displacement, 0.27 m/s velocity, 5.40 m/s² acceleration) to always force stepping (22). The IND group was instructed to “remain relaxed before each pull and react naturally to the pull. Hold your position at the end of your step.” This instruction to react naturally was given for two reasons. First, pilot studies indicated that when subjects were instructed to react to the large pulls by consciously stepping “as fast as possible,” their initiation timing was slower than for the “react naturally” instruction. This was because the voluntary intention to step resulted in a postural-step sequence that initially interfered with the early phase of the perturbation-induced step. Second, our past studies indicated that subjects always step for the present perturbation magnitude (9), even when instructed to “try not to step.”

**Data Analysis**

Interactive graphical analysis programs were used to compute the first step-timing measures (Figure 1) for each trial without knowledge of subject group identification. Step initiation time (IT) was defined as the interval from the onset of the reaction stimulus cue (go signal) until the vertical ground reaction force under the stepping limb equaled zero at foot liftoff. Step completion time (CT) was defined as the time interval from foot liftoff to floor contact as registered by the instrumented contact mat. The analysis program automatically marked the events, and data were confirmed visually (18,22). These timing measures were previously shown to be moderately to highly reliable for comparable tasks (29). Step length, expressed as a percentage of the
subject’s height, was measured manually with a tape measure from the midpoint of the heel during initial stance to the heel mark made on the poster board at the completion of the first step.

**Statistical Analysis**

Mean values were calculated for the five pretraining and posttraining trials for each outcome variable. Descriptive statistics were computed and a repeated measures analysis of variance determined any significant time of testing differences for each outcome variable. The between-subjects factors were age group (young and old) and type of training (VOL and IND). The within-subjects factor was time of testing (before or after training). A significance level of $p < .05$ was used for all comparisons.

**RESULTS**

Nineteen subjects completed the study. One younger subject in the IND group had step characteristics that were statistical outliers (mean values greater than 3.5 SD from the remaining group mean values), and this individual’s results were not included in the analysis. The descriptive statistics are presented in Table 1.

**Initiation Time**

There were significant age group main effects for the SOM cue ($p < .01$) and the AUD cue step IT ($p < .001$), as shown in Figure 2. Overall, older adults were slower than the younger adults for the two stepping tasks. No significant main effect was found for the type of training for step IT. However, a marginally significant ($p < .06$) time of testing by training group interaction for the AUD cue IT (Figure 2B) revealed a greater (post hoc, $p < .06$) pretraining to posttraining improvement of 18% for the IND group compared with a 5% improvement for the VOL group. When collapsed across the age and training groups, significant pretesting to posttesting time main effect differences were obtained for both the SOM cue IT ($p < .01$) and AUD cue IT ($p < .01$) (Figure 2). Notably, the mean SOM cue step IT of the older adults after training approached that of the younger adults prior to training (Figure 2A).
**STEP TRAINING AND VOLUNTARY STEP INITIATION SPEED**

**Completion Time**

The results for step CT are presented in Figure 3. No significant main effects for age group, type of training, or time of testing were found for the step practice groups (open symbols) measured pretraining and posttraining for A, the somatosensory reaction cue (small waist-pull) condition, and B, the auditory cue condition. *Indicates a significant age group by time of testing interaction, showing a faster step completion time for the young subjects after training.

**Step Length**

Overall, the older group had a significantly longer (p < .02) height normalized first step length than the younger group for the SOM cue condition; a similar trend for the AUD cue task approached statistical significance (p < .08) (Table 1). No significant differences caused by training were found for the step length measures before and after training, showing that the improvements in step timing caused by training were not attributable to changes in step length.

**DISCUSSION**

The results of this study indicated that older individuals were generally slower than younger adults to initiate and complete voluntary RT stepping. They also took longer steps in response to either a SOM cue or an AUD cue. As hypothesized, significant reductions in initiation timing occurred regardless of age following either practice of SOM-cued voluntary stepping or perturbation-induced stepping over a 3-week training period. Moreover, as also hypothesized, compared with SOM-cued practice, induced step training was associated with greater improvement in initiation timing for the AUD transfer cue task.

The findings corroborated previous reports (15–19) indicating an age-associated increase in voluntary step IT. A generalized slowing in RT is a consistent accompaniment of human aging (13,14) and is a strong sensorimotor predictor of the risk of falls (19). This study demonstrated that, following step training, step IT can be improved significantly in older and younger adults (average of 100 milliseconds, 17%, and 65 milliseconds, 15%, respectively). As indicated by the slower pretraining timing characteristics for the older group, the elderly individuals might have been initially farther away from a performance ceiling effect than the young individuals. If so, then older subjects could have had a greater performance range over which they could improve their step IT (30). It was also notable that the SOM cue IT of the older subjects after training approached the mean IT of the younger subjects before training (see Figure 2A). Thus, such forms of training could, at least in the short term, narrow the gap in age-associated RT differences in stepping.

Similar to past studies of other voluntary movements (25–28), practice resulted in significant decreases in voluntary step IT in the younger and older groups. Although initiation timing was reduced for both training groups, perturbation-induced training tended to show greater improvements than practice alone for the AUD transfer cue task. This suggested a more effective generalized enhancement of initiation speed for the IND stepping group when subjects responded to a reaction stimulus trigger cue that was relatively unpracticed but that involved an identical movement response. Additional support for a generalized enhancement of response initiation timing caused by induced step training was obtained for the older subjects in this study, who, while participating in a different clinical assessment study, were tested with a seated finger-press RT task before and after the present training programs. For these older individuals, subjects in the induced training group significantly improved their RT performance (by 12%) compared with the subjects in the step practice group (3%).

The young, but not the old, also reduced their step CT and stepped faster than the elderly group did after training.
Furthermore, older subjects took consistently longer steps than the young, whose steps became qualitatively shorter after training (see Table 1). Thus, the training differences in step CT could have reflected the need for older subjects to maintain a relatively greater mechanical stability margin through a longer step length versus a faster and shorter step.

Startle-induced reflex-like stimuli have been used previously to affect RT performance (31) and might involve response triggering at a subcortical level that bypasses the temporally longer cortical processing level. Conceivably, the potentially startling nature of the abrupt and potent waist-pull stimuli utilized here might explain why the IND stepping group generally improved their AUD-cued RT performance more than the VOL stepping group. Alternatively, if peripherally triggered reflex-like steps share common neural circuits with voluntary command signals for stepping (23), then such repetitive application of stimuli could enhance the synaptic effectiveness of step pathways (24), or generally increase arousal or attention during RT performance (32).

Conclusions

This study was undertaken as a first effort at evaluating whether step training can improve the speed of voluntary step initiation in aging. Although we did not investigate whether the RT improvements were retained beyond immediate (i.e., within 2 days) posttraining, the results are encouraging and expose the need to determine the potential for more permanent changes in performance indicative of learning. It is also acknowledged that the study was limited by the small sample size and the lack of a control group that did not undergo step training. It would also be important to determine whether training-induced changes in stepping performance carry over to unexpected situations that require steps for balance recovery.

In summary, older adults demonstrated significantly slower ITs than younger adults in the performance of a voluntary step. This slower RT may increase their risk of falling when a quick response is needed. Our results indicated that a 3-week period of either voluntary or waist-pull-induced step training significantly reduced step IT in older and younger adults. Moreover, compared with voluntary step practice, induced step training resulted in greater improvement in RT stepping for an AUD transfer cue task. At least in the short term, such step training has the potential to enable older adults to perform more like younger adults in the speed of their step initiation timing. Step training may be a potentially effective intervention to help improve balance function and mobility, reduce the risk of falls, and enhance the quality of living among older persons.

The contributions of T. Cattaneo, S. Grimes, J. Janzewski, S. Kress, K. Fricke, R. Reiter, and M. Wyemura are gratefully acknowledged. We thank J. D. Brooke and S. Schindler-Ivens for comments on an earlier draft of the manuscript.

Address correspondence to Mark W. Rogers, PhD, PT, Department of Physical Therapy and Human Movement Sciences, The Feinberg School of Medicine, Northwestern University, 645 North Michigan Avenue, Suite 1100, Chicago, IL 60611. E-mail: m-rogers@northwestern.edu

References


Received March 18, 2002
Accepted July 12, 2002