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Effects of Age, Step Direction, and Reaction Condition on the Ability to Step Quickly

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Background. The ability to take a step quickly is important for balance maintenance during activities of daily living. The purpose of this study was to investigate the effects of age, reaction condition, and step direction on the ability to take a volitional step as fast as possible.

Methods. The performance of a voluntary step task was measured in young adult (mean age 20, *SD* 0.9 years), young-old adult (mean age 67, *SD* 3.7 years), and old adult (mean age 78, *SD* 2.3 years) healthy female participants. Each participant stepped as fast as possible in eight directions in response to a visual cue in a simple or choice reaction time condition. The effects of age, reaction condition, and step direction and their interactions on the primary outcome variables of response time, step liftoff, and step landing time were examined.

Results. The normal aging process progressively increased the response, liftoff, and landing times. The choice reaction time condition, compared to the simple, had significantly increased response, liftoff, and landing times. Step direction significantly affected the liftoff and landing times, with lateral, diagonal, and anterior and posterioir (A-P) times increasing, respectively.

Conclusions. We found substantial declines in the ability to step rapidly in healthy adults as age increased. When a decision was required regarding the step direction, the step performance also declined. Step direction also significantly affected step performance. The assessment of voluntary step performance, which may be an indicator of balance ability, should include dimensions of both direction and the choice condition.

FALLS are a major source of death and morbidity among the elderly. Stepping frequently prevents a fall (1,2) when externally perturbed and during planned movements (voluntary step). Older, compared with young, adults are slower to step in choice (step direction indicated by cue) (3,4) and simple (invariant step direction) reaction time (RT) tasks (5,6), just as they are in other choice RT tasks (7–9). As age-related cognitive slowing models predict (10), this may be due to increased complexity in choice RT.

Fall direction influences the occurrence and consequences of a fall, with lateral falls more likely to result in a hip fracture (11–16). The type of recovery response depends on response direction (17). Older adults more frequently took multiple steps in response to posterior (18) and lateral (1) perturbations. Voluntary side-stepping, compared to other directions, was faster with the greatest age-related speed decrements in forward stepping (4). Nonetheless, older adults shifted more weight to the stance leg while laterally stepping. This safer strategy could be a compensation for less postural stability.

How step direction influences age effects in simple and choice RT tasks is not known. This study investigated elderly fall prevention strategies by examining the effect of RT task condition and step direction on older and younger adults' ability to make rapid voluntary steps.

Methods

Participants

Young (YA), young-old (YOA), and old (OA) healthy, community-dwelling, regularly exercising adult women (Table 1) participated after written informed consent (institutional human subjects committee approved). A detailed health history was obtained, and a nurse, in consultation with a geriatrician, conducted physical examinations (elderly only). Participants were excluded if they had had otologic, musculoskeletal, neurologic, or cardiovascular disease or impairments; uncorrectable visual impairment; symptoms of vertigo, lightheadedness, or unsteadiness; or if they had fallen.

Tasks

Participants performed voluntary step tasks in simple and choice RT conditions in eight step directions [anterior, right and left anterior (AR, AL), posterior, right and left posterior (PR, PL), and right and left lateral (LR, LL)]. Each participant stood relaxed with feet in self-selected marked locations, arms folded across chest, and wearing a suspended harness for safety. The display board, placed 1 m in front at eye level, contained a yellow warning light surrounded by eight "go" red arrow lights pointing outward indicating step direction. The warning light illuminated randomly

Table 1. Subject Data

	Young	Young-Old	Old
Number (*n*)	16	16	8
Mean age (y)	20.0 (0.9)	67.3 (3.7)	78.0 (2.3)
Age range (y)	19–22	62–73	75–82
Mean height (cm)	165.2 (7.6)	164.7 (5.9)	164.1 (6.4)
Mean body mass (kg)	60.5 (8.1)	64.8 (10.1)	60.5 (7.6)

Notes: No significant differences between groups were found in height and mass. Standard deviations appear in parentheses.

0.5 to 3 seconds prior to arrow illumination. Instructions were to maintain equal weight on each foot, step as fast as possible with a comfortable length step, and then bring the stance foot next to stepped foot. Several practice steps in each direction were taken. Participants completed six tests in the anterior, AR, LR, posterior, and PR directions and three tests in the remaining three directions in a predetermined random order in each condition with scheduled breaks.

Data Recording and Analysis

We measured foot/support-surface reactions using a forceplate (Advanced Mechanical Technologies Inc., Watertown, MA). Switchplates surrounded a contact plate pasted onto the forceplate. Sampling frequency was 200 Hz for 3 seconds. Using MATLAB (Mathworks, Natick, MA), we digitally filtered the forceplate data using a second-order low-pass Butterworth filter (6 Hz cutoff frequency) with forward/backward reflection to minimize initial and final-time artifacts (19) and forward/backward passes to eliminate phase shift (20). We determined liftoff (LOT) and landing times (LT) using a threshold method on the contact and switchplate signals. The time history of the center of reaction location was calculated using the foot/support-surface reactions. We determined RT using a threshold method applied to the rate of change in the center of pressure location (21), which indicated the onset of active control.

Statistical Analysis

Using SPSS 9.0 (SPSS Inc., Chicago, IL), three-way analyses of variance (ANOVAs) (age × reaction condition × step direction) were conducted on the dependent variables (RT, LOT, and LT). Type I error was controlled on all post hoc pairwise comparisons using the Bonferroni test with *p* values less than .05 considered statistically significant. We tested step-side effects using three-way ANOVAs (step-side × age × task) on the dependent variables for each pair of step-side directions (AR and AL, PR and PL, and LR and LL). No step-side effects or interactions were found. Thus, we analyzed only the right side (AR, LR, PR), anterior, and posterior stepping directions. Learning effects were tested using repeated measures ANOVAs on the dependent variables over the six trials for each group, direction, and task. As no trends in learning were found, the average value for each parameter was used in all final analyses.

Results

Figures 1, 2, and 3 show means (± *SD*) for age, direction, and task, respectively.

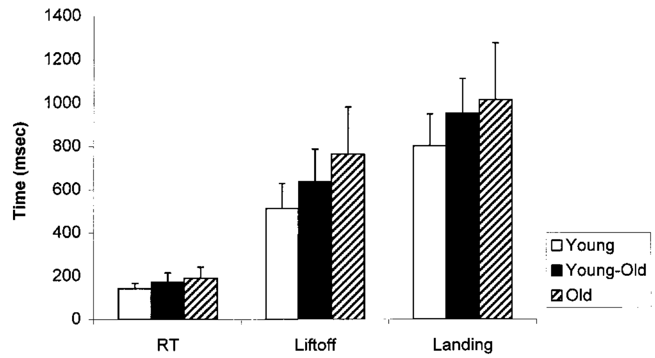

Figure 1. Mean (± *SD*) reaction time (RT), liftoff time, and landing time for the young, young-old, and old groups.

RT

RT exhibited significant age ($p < .001$) and condition ($p < .001$) effects with no significant interactions. All age follow-up tests were significant. The OAs were 10% slower than the YOAs, who were 23% slower than the YAs. Choice, compared to simple, was 13% slower.

LOT

LOT exhibited significant age ($p < .001$), condition ($p < .001$), and step direction ($p < .001$) effects with no significant interactions. All age follow-up tests were significant. The OAs were 20% slower than the YOAs, who were 24% slower than the YAs. Choice, compared to simple, was 19% slower. There were no significant differences between the anterior and posterior (A-P) directions or between the AR and PR (diagonal) directions. The diagonal, compared to lateral, had 13% longer LOTs ($p < .05$); and the A-P directions, compared to diagonal, had 16% longer LOTs ($p < .01$).

LT

LT exhibited significant age ($p < .05$), condition ($p < .001$), and step direction ($p < .001$) effects with no significant interactions. All age follow-up tests were significant. The OAs were 7% slower than the YOAs, who were 19% slower than the YAs. Choice, compared to simple, was 8%

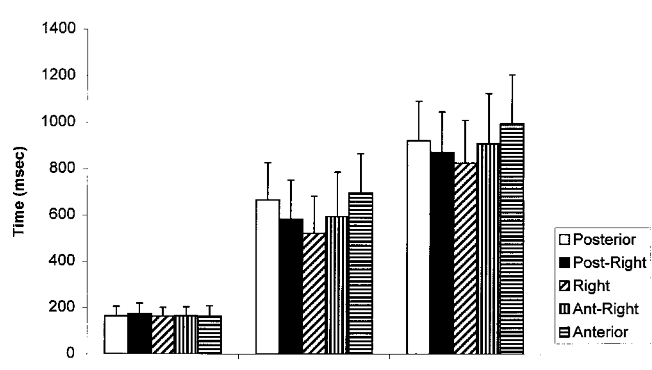

Figure 2. Mean (± *SD*) reaction time (RT), liftoff time, and landing time for the posterior, posterior-to-the-right, lateral right, anterior-to-the-right, and anterior directions.

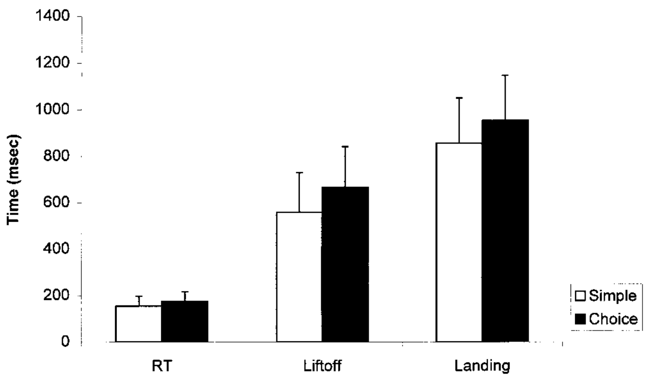

Figure 3. Mean (± *SD*) reaction time (RT), liftoff time, and landing time for the simple and choice conditions.

slower. There were no significant differences between the A-P directions or between the diagonal directions. The right had 10% shorter LTs than AR ($p < .05$) and 16% shorter than A-P ($p < .005$) directions.

Discussion

We demonstrated that rapid voluntary stepping was affected by age, step direction, and reaction condition. Age progressively increased RT, LOT, and LT. Step direction affected LOT and LT, but not RT. The choice condition, compared to simple, increased the RT, LOT, and LT. With no significant interactions among age, direction, and condition, it appears that aging does not amplify the effects of direction or condition.

Our results are consistent with previous findings that age increases total time for rapid stepping (22), due to increased RT and weight shift times (WST) (3,4). RT increases (measuring response programming) with age are predicted by cognitive slowing models (10). Similar increases in WST with age are not always seen in compensatory stepping (3), suggesting that slower weight transference by elders could represent a safer stepping strategy.

Our data are consistent with previous step direction research that also found no A-P difference in voluntary stepping (2) and WST shortest in the lateral, compared to the A-P, directions (4). This was most likely because participants shifted the least weight to the stance foot during lateral stepping. It is interesting that the elderly transferred a larger percentage of weight to the stance foot. Once again, elders seem to select a safer movement strategy.

Patla and colleagues (4) found larger age group differences in anterior steps, which we did not find. Whether the lack of concordant results is due to subtle task or participant differences is not clear.

The effect of step task condition (simple vs choice) has not previously been reported, although our findings are consistent with previous RT studies (10,23). The RTs, LOTs, and LTs were greater for the more complex choice condition, but the increased timing for the step components was equivalent across age groups. It is unlikely that our choice RT task was simpler than those commonly used. Our lack of greater slowing in the choice RT task in the OAs may instead be due to the nature of our elders, who were healthy, regular exercisers. Participation in regular exercise can reverse or slow age-related motor skill declines (24). With greater age group differences in physical fitness, elders may be slower in choice RT tasks.

Our data suggest differences in the ability of elders to step rapidly and that the speed of step initiation depends on step direction and prior knowledge of step direction. The ability to step quickly underlies many daily activities, during many of which the steps take place in a predictable environment. More difficult step initiation may occur when step direction is unpredictable due to environmental variability, such as when ambulating in the presence of young children or pets. Our data suggest that stepping laterally under conditions of response certainty is easiest, although, even here, older adults alter their task approach to reflect a safer movement strategy.

Our studies suggest that both compensatory and voluntary stepping should be measured during clinical balance assessment as the two are not necessarily related. We suggest the importance of examining the ability to step rapidly in various directions. Stepping in an anterior/posterior direction may identify individuals with subtle balance impairments. However, those who demonstrate difficulty with lateral stepping may represent a greater future fall risk. Maki and colleagues suggest that the most sensitive tests discriminating fallers from nonfallers measure lateral stability (25).

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