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Original Study

Impaired Response Selection During Stepping Predicts Falls in Older People—A Cohort Study

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ABSTRACT

Background: Response inhibition, an important executive function, has been identified as a risk factor for falls in older people. This study investigated whether step tests that include different levels of response inhibition differ in their ability to predict falls and whether such associations are mediated by measures of attention, speed, and/or balance.
Methods: A cohort study with a 12-month follow-up was conducted in community-dwelling older people without major cognitive and mobility impairments. Participants underwent 3 step tests: (1) choice stepping reaction time (CSRT) requiring rapid decision making and step initiation; (2) inhibitory choice stepping reaction time (iCSRT) requiring additional response inhibition and response-selection (go/no-go); and (3) a Stroop Stepping Test (SST) under congruent and incongruent conditions requiring conflict resolution. Participants also completed tests of processing speed, balance, and attention as potential mediators.
Results: Ninety-three of the 212 participants (44%) fell in the follow-up period. Of the step tests, only components of the iCSRT task predicted falls in this time with the relative risk per standard deviation for the reaction time (iCSRT-RT) = 1.23 (95%CI = 1.10-1.37). Multiple mediation analysis indicated that the iCSRT-RT was independently associated with falls and not mediated through slow processing speed, poor balance, or inattention.
Conclusions: Combined stepping and response inhibition as measured in a go/no-go test stepping paradigm predicted falls in older people. This suggests that integrity of the response-selection component of a voluntary stepping response is crucial for minimizing fall risk.
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Processing speed (the general ability of the brain to quickly and efficiently process information) declines with age and especially so when tasks are more complex. For example, compared with young people, older people are disproportionately slow in complex stimulus-response mappings in a choice reaction time (RT) task,[1] a finding that also highlights the importance of attention and executive functioning (EF) for response execution in older age. Negotiating real world environments can require rapid and accurate volitional and reactive stepping to avoid losing or regaining balance—tasks that rely on input from cortical areas and circuits underpinning attention and EF.[2] Among other tasks, good EF reflects the ability to inhibit unnecessary stimuli and select an appropriate response that is an important marker of fall risk.[3,4]

Findings as to whether step initiation times in volitional choice stepping reaction times (CSRTs) differ between fallers and nonfallers are inconsistent.[5,6] Cho et al found fallers and nonfallers performed similarly in a Rapid Step Test in which participants had to choose to step with either the left or right leg following verbal step direction instructions.[5] In contrast, Lord and Fitzpatrick demonstrated that elderly fallers had slower CSRTs when instructions were provided visually,[6] suggesting the importance of visuospatial processing on fall risk. The role of inhibition during stepping in predisposing older people to falls is also unclear. It has been reported that prolonged CSRTs are due to initial motor program errors resulting from impaired inhibition,[7–9] and that the addition of a conflict resolution task increases both step errors and response times.[8,9] Melzer et al found that

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stepping RTs only discriminated between older fallers and nonfallers when participants performed a verbal color-word Stroop task,[10] but it is unclear whether this was due to impairments in inhibition or dual tasking.

In a cross-sectional study, we developed a Stroop stepping test (SST) instead of using a dual-task paradigm. This incorporated a visuospatial conflict resolution task within a CSRT test. We found this test was better at discriminating fallers from nonfallers than either a standard CSRT test, the traditional pen-and-paper Stroop test or other sensorimotor factors.[11] In contrast to the standard CSRT, which has a low inhibitory component and emphasizes rapid step initiation, the SST requires high-level cognitive processing with a subsequent lower weighting of the rapid step component. To include both rapid stepping and inhibition in one test, we developed an inhibitory choice stepping reaction time task (iCSRT). This test included a “go/no-go” component to the CSRT, requiring rapid steps for the “go” trials and withholding of steps for the “no-go” trials.

The primary aim of this study was to compare the relative predictive validity of 3 step tasks (CSRT, SST, and iCSRT) in relation to falls in a prospective cohort study of community-dwelling older people. As several known risk factors of falls in older people are an integral part of the stepping tests, a secondary aim was to determine whether the predictive ability of the step tests was direct (independent of the other measures) or mediated through physical and/or cognitive pathways, using measures of balance, processing speed, and attention.

Methods

Participants

Participants were independently living older people recruited from a volunteer database and oral presentations in Sydney, Australia. Participants were residing in private households or retirement villages. Interested persons were included if they were (1) aged 70 years or older; (2) able to step without assistance (step size 25-30 cm); and (3) ambulant with or without walking aids. People were excluded if they were cognitively impaired (Rapid Dementia Screening Test score $\leq$4),[12] were color-blind, had visual impairments that could not be corrected (>6/16 on a LogMAR visual acuity chart), or had neurodegenerative disorders or limiting lower limb pain that affected stepping performance. Written informed consent was obtained from all individuals prior to their participation in the study that was approved by the Human Research Ethics Committee at the University of New South Wales.

Falls

A fall was defined as an unexpected event in which participants came to rest on the ground, floor, or lower level.[13] Falls data were collected using monthly calendars and follow-up phone calls.[13] Participants who reported 1 or more falls during a 12-month follow-up period were classified as fallers.

Step Tests

A custom-made step mat measuring 150 $\times$ 90 cm containing 12 panels was used for administering the step tests. Step actions were registered by electrical switches when individuals lifted up their feet (step initiation) or when they stepped down on a panel (step completion). Timing was recorded by the computer clock accurate to 1 milliseconds for all tests. For the step tests, eight panels were used: 2 central stance panels, 2 front panels, the near left panel, the near right panel, and 2 back panels (Figure 1). The mat and display monitor (resolution, 1280 $\times$ 768 pixels; 60 Hz refresh rate; 58 cm diagonal distance) were connected to a computer with the display screen positioned on the floor and tilted upward 1 m in front of the participant. Presentation of visual stimuli on the screen and recording of participant step responses were controlled using custom software written in Python 2.6. Identical to the established assessment protocol for the traditional Stroop test approach, the order of the step tests (CSRT, iCSRT, SST) was the same for all participants presenting the congruent task before the incongruent ones.

During measurement of CSRT (Figure 1A),[14] participants were asked to stand on the 2 stance panels. Stance and target panels were displayed on the screen. Participants were instructed to step onto a panel as quickly as possible when the corresponding arrow on the monitor changed color from white to green. Stimulus presentation was 100 milliseconds. When a step response was made to a wrong direction, the error changed its color to gray. Participants were informed that stimulus presentation would be random and they should not try to anticipate step targets. Time between trials also was randomized, with stimuli occurring 0.5 and 1 second after the participant returned both feet to the stance panels. After 6 practice trials (1 step in each direction), a random sequence was presented, with 6 repeats per panel (overall 36 trials). The time in milliseconds for step RT (time between stimulus presentation and lift-off of either the left or right foot from the central stance panels) and movement time (MT, time between foot lift-off and touchdown on a panel) were measured. In addition, the number of step errors (wrong step direction) and omission errors (no step response) were recorded.

During the iCSRT (Figure 1B) an additional response-selection component using a go/no-go test paradigm was incorporated. The test procedure was the same as for the CSRT, except that go trials were indicated by green, and no-go trials by purple. Participants were instructed not to step and remain on the stance panels in the no-go trials. When a correct step was made, the arrow on the screen changed color to dark green to provide visual feedback of step completion. Similarly, failure to inhibit was indicated by a dark purple arrow. Steps in wrong directions (ie, to incorrect target arrows) were indicated by the color gray. After 6 practice trials (one stimulus for each target panel with 2 stimuli to be withheld), a random sequence of 36 trials was presented. In line with previous studies, we used a 2:1 go/no-go presentation rate to ensure activation of prefrontal cortex areas involved in executive control tasks.[15,16] The time in milliseconds for step RT (iCSRT-RT), MT (iCSRT-MT) during go trials, and the inhibitory cost (iCSRT minus CSRT) were measured. In addition, the number of errors (step error go trials: wrong step direction; omission error go trials: no step response; commission error no-go trials: failure to inhibit) were recorded.

The SST has been described before.[11] Briefly, during this test a green arrow was presented in the center of the screen pointing in one of 4 directions (front, back, left, and right) that matched the 4 possible step directions. A word was written in yellow inside the arrow (front, back, left, and right) indicating a direction. In the congruent version of the SST (Figure 1C), the arrow’s shape and the written word matched. In the incongruent version (Figure 1D), the word always indicated a different direction than the arrow’s shape. Participants were instructed to step as fast as possible according to the word, while inhibiting the response indicated by the arrow’s shape. We assumed that the arrow’s shape was the predominant response, and thus administered the CSRT and iCSRT tests (in which individuals were always required to step by the arrow) prior to the congruent SST and eventually the incongruent SST. If participants stepped on a wrong panel, they had to repeat the trial until it was correctly executed. The average time (milliseconds) to complete a trial (excluding those with error), the whole step sequence, the interference time (incongruent minus congruent), and the number of errors (step, omission, commission) were recorded.

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