Age Differences in Timed Accurate Stepping With Increasing Cognitive and Visual Demand: A Walking Trail Making Test

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Background. Impaired vision, cognition, and divided attention performance predict falls. Requiring both visual and cognitive input, the ability to step accurately is necessary to safely traverse challenging terrain conditions such as uneven or slippery surfaces. We compared healthy young and older adults in the time taken to step accurately under conditions of increasing cognitive and visual demand.

Methods. Healthy Young (n = 42, mean age 21) and Older (n = 37, mean age 70) participants were required to step accurately on an instrumented walkway under conditions of increasing visual and cognitive demand. Based on the paper-and-pencil neuropsychological test, the Trail Making Test (P-TMT) A and B, participants stepped on instrumented targets with increasing sequential numbers (Walking Trail Making Test A [W-TMT A]) and increasing sequential numbers and letters (Walking Trail Making Test B [W-TMT B]), under conditions of Low as well as Normal lighting.

Results. W-TMT performance time increased with increased age (Older vs Young), decreased light (Low vs Normal), and increased cognitive demand (Trails B vs Trails A). W-TMT performance time was disproportionately increased in Low light and in the Older group under the highest cognitive demand (W-TMT B) conditions. Paired W-TMT A–B differences were three times higher in the Older group than in the Young group. In the Older group, the correlation between W-TMT results and P-TMT B was particularly strong (p < .001).

Conclusions. The time to perform a stepping accuracy task, such as may be required to avoid environmental hazards, increases under reduced lighting and with increased cognitive demand, the latter disproportionately so in older adults.

All risk is increased by visual and cognitive impairment (1,2). Visual impairment also predicts hip fractures (3–6). As part of multifactorial interventions, the effect of vision screening and vision impairment management on fall reduction may be modest (7). These findings are not surprising given that visual impairment may not contribute to every fall (6). Because fall risk is increased by the presence of an environmental hazard [as in an uneven walking path, (9)], vision becomes more critical in avoiding a fall when the environment places more demand on vision. Demand is increased in a darkened area, or where there are hazards to be traversed and stepping accuracy becomes critical.

Studies have linked cognitive impairment and falls or fall-related injury (10–12). Patients with Alzheimer’s dementia were more likely to respond inappropriately to a postural challenge or contact an obstacle in their gait path (13). In experiments where cognitive demand increases, such as when participants are required to maintain balance or walk while performing a cognitive task (termed “dual task” or “divided attention”), the balance or walking performance declined, particularly in those persons with a history of falls or balance impairment (14,15). Prospective studies have shown that slowed walking while talking (performing a verbal task) predicts falls (16). Thus, cognitive demand can disrupt balance and walking and increase fall risk.

When required to avoid an obstacle, healthy older adults, as compared to young controls, are more likely to make contact with the obstacle (17), particularly under divided attention conditions (18). In these older adults, obstacle clearance performance relates to cognitive function, i.e., attention and aspects of executive function, such as problem solving and response inhibition (19). A relevant measure, the paper-and-pencil Trail Making Test (P-TMT; 20), evaluates visual scanning and mental flexibility and predicts major fall injury (21). In the P-TMT A, the participant must connect as rapidly as possible 25 randomly arranged numbered circles in ascending order (1-2-3-4 . . . , etc.). P-TMT B presents a higher cognitive demand, in that the participant must connect an alternate sequence of ascending numbers and letters (1-A-2-B-C-4 . . . , etc.).

A number of studies have examined the accuracy with which humans can step on irregularly spaced targets (22,23); to our knowledge, the effects of age have not been studied. In addition, there are no clinical tests of a patient’s ability to step accurately under conditions of increased environmental demand. Accurate stepping is required to safely traverse challenging terrain conditions such as uneven or slippery surfaces. To take accurate (and safe) steps, an older adult must maintain balance and at the same time use cognitive skills such as visual scanning, vigilance, attention,
Methods

Participants

Young adult participants (Young: n = 42, mean age 21 years, range 18–29 years; 21 females) were recruited from among university students. Older adult participants (Older: n = 37, mean age 70 years, range 60–85 years; 20 females) lived independently in the community. All participants were healthy, i.e., without significant otological, musculoskeletal, neurological, or ophthalmological abnormalities on history and examination. All participants had corrected bi-ocular visual acuity 20/50 or better. Folstein Mini-Mental State Examination (MMSE) scores were ≥25 (mean ± standard deviation [SD] 29 ± 1) in the Older group. Level of education (in years) was similar in both groups (Young 15 ± 2, Older 16 ± 3).

W-TMT Protocol

Following a methodology described (J. A. Ashton-Miller, B. Giordani, J. Kemp, N. B. Alexander, unpublished data), participants were instructed to walk 3.66 m along a 1 m-wide instrumented linoleum mat walkway, turn, and return at a comfortable pace. A strip of conductive metal tape was affixed across each shoe sole under the metatarsal heads. When this strip landed centered on a walkway stepping target, it completed the connection between the left and right halves of the conductive metal foil surrounding the target, thereby signaling a computer that the foot had been placed correctly on the target. Each stepping target consisted of a 48 mm-diameter black circular annulus encircling a one- or two-digit alphanumeric symbol in 75-point black font on a white background. A total of 33 stepping targets (17 targets in the outbound direction and 16 in the return direction) were arranged on the mat. Room light was modified to compare stepping accuracy performance in “Normal light” (84 ft candles at the walkway surface) with that in “Low light” (0.1 ft candles at the walkway surface, akin to illumination provided by a night light).

Participants were instructed to imagine that the white walkway was an icy sidewalk and the black targets were the only safe spots to step on without slipping. They were also instructed to achieve 100% accuracy and to not miss a single target, thereby simulating a real-world effect of the high risk of an error in a hazardous situation.

Participants first practiced walking while stepping on targets with increasing numbers (1, then 2, then 3, etc.) but with no other target distractors, to establish a baseline, no-distractor walking speed (“Baseline” trials). This baseline walking speed was used as a covariate for statistical analysis of the W-TMT tests. For W-TMT A and B walkways, additional letter and number targets were placed at random and in a random pattern to distract the participant and require more intensive visual scanning and processing, thereby simulating standard P-TMT A and B. Each time a target contact was made as part of the correct numerical-letter sequence, an audible tone was produced to give the participant feedback of successful contact. The following walkway conditions were used: Trails A Normal (step on sequentially increasing numbers), Trails B Normal (as in Trails A but step on sequentially increasing numbers and letters in an alternating manner, i.e., 1, then A, then 2, then B, etc.), Trails A Low (as in Trails A but in low light), and Trails B Low (as in Trails B but in low light).

Participants performed two versions of the W-TMT tests for each A and B condition: one version with the stepping targets arranged in a diagonally shaped path and the second in a chevron-shaped path. Each path version had target step lengths and widths based on a ±10% random variation of 0.5 times the mean adult step length and +0, +5%, or 10% of mean step width during comfortable gait, because both step length and gait speed are known to be reduced (and step width increased) on a potentially slippery surface (24). The purpose of using different path shapes, stepping patterns, and distractor patterns was to make it more difficult for participants to memorize a particular path sequence for each TMT condition. Three trials of each diagonally and chevron-shaped path were attempted in each A and B condition (12 trials total). Trials were presented in an order randomized both by shape, and by A versus B condition. The Normal light W-TMT was presented first (12 trials) followed by at least an 8-minute period for adaptation to the darker Low light condition, and then the Low light W-TMT (additional 12 trials). Mean timed data from only the chevron-shaped paths (three A and three B trials for Normal and then for Low, for a total of 12 trials) were used for analysis. Test–retest reliability performed 1 week apart on a subset of Young and Older showed no significant difference (J. A. Ashton-Miller, B. Giordani, J. Kemp, N. B. Alexander, unpublished data) (r = 0.90–0.99).
P-TMT B, participants connected, in alternate sequence, ascending letters and numbers (1-A-2-B-3-C . . . , etc). A stopwatch was used to time completion of the test.

**Data Analysis**

W-TMT time was compared across the four conditions by repeated-measures analysis of variance (ANOVA) using Proc Mixed (SAS, Cary, NC), covarying for Baseline walking speed and analyzing for the effect of age group, Trails condition (A vs B), Light condition (Normal vs Low) and gender. Interactions of Age * Trails condition, Age * Light condition, Trails condition * Light condition, and Age * Trails * Light conditions were also examined. Pairs of individual differences between W-TMT A and W-TMT B times (W-TMT B – W-TMT A) were compared between age groups by a two-sided, independent t test. W-TMT was also correlated with P-TMT in the Older group, using Pearson’s r.

**RESULTS**

Young and Older groups did not differ in the time to complete the Baseline walkway with sequential targets and no distractors (mean ± SD walk times: Young 37 ± 10 s; Older 40 ± 12 s). Figure 1 shows that performance time increased in Older versus Young (p < .0001), in W-TMT B versus W-TMT A (p < .0001), and in Low versus Normal light (p < .02). W-TMT B time was disproportionately longer in the Older than in the Young (Age * TMT type, p < .001) and in Low light (TMT type * Light, p < .03).

Mean P-TMT A and B times were longer in the Older than in the Young group (p for both < .0001) (See Figure 2). Correlations between W-TMT and P-TMT were significant overall when both age groups were considered (W-TMT A with P-TMT A: r = 0.51–0.52; W-TMT B with P-TMT B: r = 0.69–0.77). Examining the Older group only (See Table 1), the relationships between W-TMT B and all of the W-TMT (A and B, r = 0.59–0.83) and between W-TMT A or B and P-TMT B (r = 0.59–0.72) were particularly strong. In the Young group, the relationships between W-TMT B and all W-TMT were equally strong, ranging from 0.54 to 0.89 (all p < .0005), but weaker between P-TMT B and W-TMT A or B (0.36–0.44, all p < .03).

**DISCUSSION**

W-TMT performance time was increased in the Older compared to the Young group, and under increased visual (Low vs Normal) and cognitive demand (Trails B vs Trails A) conditions. However, the key finding in this study was that W-TMT performance time was disproportionately increased in the Older (vs Young) in the highest cognitive

**Table 1. Relationship Between Walking Trail Making Tests (Trails A and B Normal and Low Light) and Paper Trail Making Tests A and B in Old Group Only**

<table>
<thead>
<tr>
<th></th>
<th>W-TMT A</th>
<th>W-TMT A</th>
<th>W-TMT B</th>
<th>W-TMT B</th>
<th>P-TMT A</th>
<th>P-TMT B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.74*</td>
<td>0.79*</td>
<td>0.59*</td>
<td>0.32</td>
<td>0.63*</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0.62*</td>
<td>0.68*</td>
<td>0.34†</td>
<td>0.58*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.83*</td>
<td>0.33</td>
<td>0.72*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0.30</td>
<td>0.61*</td>
<td></td>
<td></td>
<td>0.40†</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Correlation coefficients are presented as Pearson’s r.*

*p < .0001.

†p < .05.

W-TMT = Walking Trail Making Test A or B under Normal or Low light; P-TMT = Paper Trail Making Test.
demand condition, Trails B. Pair-wise differences between the W-TMT cognitive levels (W-TMT B – W-TMT A) were three times higher in the Older than in the Young group.

To our knowledge, this is one of the few studies to embed a relevant fall risk-associated standard neuropsychological test with increasing cognitive load into a mobility task. Given that standard (finger) choice reaction times associate with falls, Lord and Fitzpatrick (25) found that choice stepping reaction time (CSRT), the time taken to make contact with one of two feet into one of four panels, was associated with fall risk. Other dual task (divided attention) studies do not embed the cognitive demand into the mobility task but add the cognitive task as an irrelevant distracter. During performance of simultaneous cognitive tasks such as memory or mental arithmetic tasks, standing postural stability (26) and recovery from postural instability (27) decline in older adults. Visually guided obstacle avoidance, under divided attention conditions, declines with age (18). Paralleling these findings, W-TMT performance declined with increased cognitive demand. One issue in dual task studies is how the participant prioritizes cognitive versus mobility task performance (28). By requiring a high level of stepping accuracy (as might be required to avoid a real-world hazard), stepping accuracy was prioritized over walkway completion speed. Furthermore, by using TMT-A and B paradigms, we were able to increase cognitive demand in a standardized manner using a previously validated assessment.

Which neuropsychological factors are important in mobility and fall avoidance? In the Lord and Fitzpatrick study (25), CSRT performance correlated to a number of neuropsychological tests, including spatial working memory and attention (Digit Symbol test), visuomotor processing (P-TMT A and B), and mental flexibility (Stroop test), suggesting a link between multiple cognitive factors and stepping performance. Other studies have found links between visuospatial and executive functioning (e.g., cognitive flexibility) and falls (29) and obstacle clearance ability (19). W-TMT performance may reflect sophisticated visual processing and problem solving, aspects of executive functioning, which may be necessary to deal with challenging terrain. In contrast to the CSRT task, which involves short, repetitive, stereotyped motions, W-TMT performance requires a prolonged navigational strategy, and thus may more aptly reflect cognitive load challenges found in the daily environment. In the present study, W-TMT performance correlated highly with P-TMT B performance as opposed to P-TMT A, likely because of the greater cognitive load imposed by P-TMT B versus the more simple scanning and sequencing required by P-TMT A. The relationship between W-TMT and P-TMT B also suggests a link between visuomotor processing and mobility task performance and supports the validity of W-TMT. Other studies have found a similar link between P-TMT B and functional mobility (30), increased fall risk based on a fall history or Timed Up and Go > 13.5 seconds (31), and fall injury (21). Future studies should test whether W-TMT (especially W-TMT B) performance ultimately predicts falls better than does P-TMT B, particularly in falls with an environmental hazard etiology.

The effect of reduced illumination on W-TMT performance was not surprising. Walking speed declines under decreased illumination conditions, particularly if there are obstacles present and stepping accuracy is important (32,33). The impact of the light reduction appeared to be equivalent, however, in both Young and Older groups, possibly because visual function (at least in terms of visual acuity) appeared to be intact in both groups. Perhaps even greater reductions of lighting would have a disproportionate effect in older versus young persons. However, in our pilot testing, reductions of light to more severe levels, such as to the point of threshold of distinguishing the target at one stride length, did not show any further age-related decrements. This result agrees with the finding that most eye saccades have already been made to the next stepping target footfall while that foot is still on the ground, with the remainder being completed in the next 500 ms of the ensuing swing phase (34). Our results suggest that as long as young and older adults with intact vision can see the next target, there is minimal reduction in age-related stepping accuracy performance.

Future studies should also evaluate the impact of visual and cognitive impairment, in the presence of increasing visual and cognitive demand, on W-TMT performance in older adults. Which aspects of visual impairment, such as reduction in contrast sensitivity and depth perception (both of which have been linked to falls; 35) predict W-TMT performance? In addition, which aspects of cognitive impairment (such as reduced problem solving ability and attention) ultimately predict W-TMT performance? The impact of balance and gait disorders on W-TMT performance is not known, i.e., it is unclear whether there is an additional disproportionate effect in individuals with balance and gait disorders beyond the effect already predicted by reduced baseline gait speed.

The W-TMT may be adapted as a clinical test of stepping accuracy under conditions of increased environmental demand. In a future prospective study, the W-TMT could be used to predict those persons who will fall because of an environmental hazard, i.e., those persons with a lower W-TMT score would be expected to be more at risk to fall under challenging environmental conditions. Being better able to attend to the hazard and execute a safer traversing strategy may be sufficient for some to avoid falls. Present performance-oriented measures used to predict fall risk include global measures of balance and gait (such as the Timed Up and Go) (36), with some tests focusing on static balance (37) or dynamic stepping (38). The ability to traverse obstacles is more impaired in fallers (vs nonfallers), but has not yet been used to predict falls prospectively (39). In addition to the falls assessment applications, the controlled walkway might be used to train the at-risk patients in accurate stepping. However, to date, practice in traversing an obstacle course has not been proven to reduce falls (40). Whether this training under controlled conditions will generalize to performance while traversing real environmental hazards is unclear. However, particularly in those with visual impairment, it may be possible to develop compensatory behavioral strategies to enhance vision and reduce fall and hip fracture risk (41).