Multitasking: Association Between Poorer Performance and a History of Recurrent Falls

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OBJECTIVES: To examine the association between poorer performance on concurrent walking and reaction time and recurrent falls.

DESIGN: Cross-sectional analysis.

SETTING: Community.

PARTICIPANTS: Three hundred seventy-seven older community-dwelling adults (mean age $\pm$ standard deviation 78 ± 3).

MEASUREMENTS: Reaction times on push-button and visual-spatial decision tasks were assessed while seated and while walking a 20-m course (straight walk) and a 20-m course with a turn at 10 m (turn walk). Walking times were recorded while walking only and while performing a reaction-time response. Dual-task performance was calculated as the percentage change in task times when done in dual-task versus single-task conditions. A history of recurrent falls (≥ 2 vs ≤ 1 falls) in the prior 12 months was self-reported. Multivariate logistic regression models were used to predict the standardized odds ratios (ORs) of recurrent falls history. The standardized unit for dual-task performance ORs was interquartile range/2.

RESULTS: On the push-button task during the turn walk, poorer reaction time response (slower) was associated with 28% lower ($P = .04$) odds of recurrent fall history. On the visual-spatial task, poorer walking-time response (slower) was associated with 34% ($P = .02$) and 42% ($P = .01$) higher odds of recurrent falls history on the straight and turn walks, respectively.

CONCLUSION: These findings suggest that walking more slowly in response to a visual-spatial decision task may identify individuals at risk for multiple falls. Prospective studies are needed to confirm the prognostic value of poor walking responses in a dual-task setting for multiple falls.
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Key words: attention; multitasking; dual task; visual-spatial; reaction time; cognition

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Poor multitasking is commonly assessed using a dual-task paradigm. According to this paradigm, poor multitask performance is presumed to be an indicator of age-related changes in attentional capacities[1] or of two concurrent tasks competing for shared processing domains.[2] One form of multitasking, impaired ability to maintain normal gait while performing other cognitive tasks, may predispose individuals to postural instability while walking and to falls by reducing obstacle avoidance[3] and ability to recover from a postural perturbation[4] independent of neuromuscular function. Older adults who walk more slowly in response to performing a concurrent cognitive task tend to be older and weaker and to be slower walkers.[5] In young and older adults, balance[6–10] and walking speed[11] declines when cognitive tasks are introduced, with older adults experiencing more degradation than younger adults.[10]

Few studies have examined multitask performance in relation to clinically relevant outcomes in older adults. Some[12,13] but not all studies[14] have reported an association between dual-task performance and greater fall risk. Poorer ability to perform a timed basic mobility task while carrying a cup of water[12] and the cessation of walking when engaged in conversation[13] were both associated with a four times greater fall risk. Furthermore, performance on tests of dynamic balance involving platform perturbations during a simultaneous cognitive task was a better predictor of fall risk than were tests of dynamic balance alone.[15]

Prior studies assessing the relationship between poorer multitask performance and clinically relevant adverse out-

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comes have included small sample sizes (N = 42–60)[12,13,15] or have focused only on frailer and institutionalized individuals.[14] To address these limitations, a cross-sectional study of 377 older community-dwelling adults was performed to examine the relationship between multitask performance using concurrent reaction time and timed walking tests and a recent history of recurrent falls in the previous year. It was hypothesized that poorer ability to multitask would be associated with a history of recurrent falls (vs a history of 0 or 1 fall).

METHODS

Population

Study participants included a subset of the 3,075 older adults enrolled in the Health, Aging and Body Composition (Health ABC) Study. Details of recruitment and enrollment for the Health ABC Study have been described previously.[16] Of the 426 subjects attending their sixth annual examination between December 2002 and May 2003 at the Pittsburgh, Pennsylvania, clinic, two refused to participate, and 33 were excluded, because they were unable to understand instructions or walk without significant pain or injury risk (staff-determined). Fourteen subjects did not participate because of study time constraints. The analysis sample consisted of 377 subjects (88.5%) with a mean age±standard deviation of 78 ± 3; 277 subjects (65.0%) completed all four dual-task experiments because of partial exclusions for safety concerns (n = 11) or technical problems and study time constraints (n = 89). All subjects provided written informed consent. The University of Pittsburgh institutional review board approved the protocol.

Experimental Measures

Reaction time consisted of a simple push-button task and a verbal response to a visual-spatial decision task. Push-button reaction time involved pushing, as quickly as possible, a handheld button in response to an auditory tone (1,000 Hz). The visual-spatial decision task was adapted from a previous study[17] and involved listening for "time of day" prompts and determining whether the two hands of a clock face were on the same or different sides of a clock with a vertical line through the 12 and 6. Participants were instructed to visualize the time and say aloud, as quickly as possible, "same" or "different." Visual-spatial response accuracy (yes/no) was recorded. Reaction times were averaged initially for each trial and subsequently for each experiment.

Walking tasks included a straight 20-m walk down a corridor (straight walk) and an approximately 20-m walk with a turn at 10 m (turn walk). Walking times on both walks were recorded from the time that the first toe crossed the start and finish lines marked by tape on the floor. Whether subjects used a cane was recorded.

Protocol

Reaction time tests were performed under three postural test conditions: seated, straight walk, and turn walk. Walking tests were performed under three cognitive test conditions: no reaction time test, push-button reaction time, and visual-spatial decision reaction time. Single-task refers to the control condition under which reaction time or walking-time is assessed in isolation and dual-task to experimental conditions under which cognitive and walking tests are performed simultaneously. Reaction-time tasks were initially practiced while seated. Walking tests were not practiced. With the exception of the two single-task walking tests, which were always performed before the dual-task tests, experiments were performed in one of two possible orders: easy or hard. Because of random assignment, approximately half of subjects performed the most difficult trial conditions first (e.g., walking, turn walk, and visual-spatial reaction time). Remaining subjects performed the easier set of conditions first. All trials were repeated twice. If staff were concerned for a participant's safety before testing, only the visual-spatial walks were performed; otherwise, testing could be stopped after the push-button walks.

Instrumentation

Participants wore headphones, a lapel microphone, and while walking, a 4.5-pound pack around their waist. The pack held a Mini DAT wireless electronic device (ViaStat, Carlsbad, CA) that relayed computer-generated auditory prompts to the headphones and transferred data from the microphone and push-button back to the computer using sampling rates of 5,000 Hz (voice data) and 1,000 Hz (button data). All prompts were delivered at random intervals spanning 1.5 to 4.5 seconds (tones) and 2.25 to 2.75 seconds (time-of-day prompts).

Dual-Task Performance

Ability to perform dual tasks was assessed as the relative change in reaction time and walking time between dual and single task. Reaction-time response was calculated as the percentage change in the dual-task versus single-task condition: 100 × (RT dual-task − RT single-task)/RT single-task. Similarly, walking-time response was calculated as the percentage change in dual-task versus single-task condition: 100 × (WT dual-task − WT single-task)/WT single-task. Reaction-time and walking-time responses were calculated separately for each of the four dual-task conditions: straight walk and push-button reaction time, straight walk and visual-spatial reaction time, turn walk and push-button reaction time, and turn walk and visual-spatial reaction time. A higher dual-task response indicates slower dual-task performance relative to single-task performance and therefore a poorer response.

Recurrent Falls

Participants were interviewed and asked whether they had fallen and landed on the floor or ground in the previous 12 months and, if so, how many times. Recurrent falls were defined as two or more falls (vs 1 or 0 falls). Recurrent falls were identified as opposed to single falls, because multiple falls are associated with an intrinsic predisposition to falling, and isolated falls are not.

Participant Characteristics

The following characteristics were assessed during participant interviews: race, age, sex, educational attainment, alcohol consumption, smoking status, leg pain in the previous 30 days, and self-rated health. Routine walking, defined as walking for exercise; walking to work, store, or church; or walking the dog in the previous week and at least 10 times in the previous 12 months, was ascertained using the Leisure Time Physical Activity Questionnaire.[18]

Characteristics measured during clinical examinations were height, weight, visual acuity (with near-distance correction scored as the total correct),[19] visual depth perception using disparity,[20] and visual contrast sensitivity[20] (defined as poor if the log score is <1.55). Hearing loss was defined as pure tone average greater than 25 db at low frequencies (500, 1,000, and 2,000 Hz) in the worse ear[21] and depression as a score greater than 15 on the Center for Epidemiologic Studies Depression Scale.[22] Medications were assessed through a comprehensive medication inventory, and number of prescriptions and use of antidepressants were recorded.

Cognitive function was ascertained using the Modified Mini-Mental State Examination (3MS),[23] the Digit Symbol Substitution Test,[24] and a clock-drawing and scoring procedure to assess visual-spatial function.[25] Knee-extension and ankle strength (dorsiflexion) was assessed using a Kin-Com 125 AP Isokinetic Dynamometer (Kin-Com, Chattanooga, TN). Slow rapid-walking speed (<1.20 m/s) was determined from walking as fast as possible over 20 m. Finger-tapping score was assessed as the number of taps on a computer mouse in 15 seconds.[26]

Analysis

All analyses were performed using Stata (Stata Corp., College Station, TX). Potential confounders were identified using a conservative $P<.10$. Using chi-square, Fisher exact, and Mann–Whitney tests, general sample characteristics (e.g., age, race, sex, and cane use) were compared in groups of participants who completed only the visual-spatial walk, only the push-button walk, or both walks. On the visual-spatial task, a kappa statistic was used to examine whether response accuracy varied across the three postural test conditions and logistic regression to examine a possible relationship between response accuracy and single-task reaction times and dual-task responses.

Logistic regression was used to determine whether walking-time and reaction-time responses were associated with having a history of recurrent falls. Three hierarchical multivariate logistic models were implemented. Model 1 adjusted for potential experimental confounders, including randomized task order, cane use, and response accuracy (visual-spatial task only). Model 2 adjusted for the confounders in Model 1 plus the general sample characteristics that differed with respect to participation in a given experiment that could bias results. Model 3 adjusted for the confounders in Model 2 plus all subject characteristics associated with recurrent falls. To minimize collinearity, a subset of subject characteristics that were associated with recurrent falls was identified using logistic regression with a forward-selection procedure within each major category. Criteria for forward-selection included $P<.10$ to enter the model and $P<.15$ to remain.

RESULTS

One hundred five (29%) participants reported having at least one fall during the prior 12 months, and 37 (10%) reported at least two falls. The median age of participants was 78 (range 74–85), and only 10 participants showed signs of cognitive impairment, defined as a 3MS score less than 80.[27] The subject characteristics that were associated with recurrent falls were absence of routine walking, poorer general health, depression, leg pain, use of four or more prescription medications, antidepressant use, weaker knee-extension and ankle strength, poorer Digit Symbol Substitution score, and slower finger tapping ($P=.10$ for all) (Table 1).

Subjects' characteristics differed between subgroups performing only the visual-spatial tasks (n = 86), only the push-button tasks (n = 14), or both tasks (n = 277). The sample performing only the visual-spatial task was older (78.9 vs 78.4 and 77.2), more likely to perform the set of harder tasks first (59.3% vs 47.8% and 14.3%), and more likely to use a cane (7.1% vs 1.6% and 0.0%) than the samples who performed both tasks and only the push-button tasks, respectively ($P<.10$ for all). The sample performing only the push-button task was more likely to be black than those performing both tasks or only the push-button tasks (50.0% vs 25.0% and 39.4%, respectively ($P=.01$ for both)). There were no differences identified with respect to sex ($P=.86$).

The median single-task walking times (seconds) on the straight and turn courses were 17.01 (interquartile range (IQR) = 15.03–19.15) and 19.15 (IQR = 16.70–21.79), respectively. The median (IQR) single-task reaction times (ms) on the push-button and visual-spatial tasks were 473 (IQR = 398–475) and 952 (IQR = 631–1,441), respectively. Median walking-time responses on straight and turn courses with the addition of the push-button task were –5.6% (IQR = –9.8–2.2%) and –5.5% (IQR = –9.4–1.5%), respectively, and those with the addition of the visual-spatial task were 0.9% (IQR = –4.3–5.5%) and 1.9% (IQR = –2.2–7.8%), respectively. On the straight and turn courses, median (IQR) push-button reaction-time responses were 19.6% (IQR = 5.4–34.7) and 19.3% (IQR = 9.0–33.8%) and median (IQR) visual-spatial reaction-time responses were 7.2% (IQR = –17.0–38.4%) and 15.0% (IQR = –22.6–68.1%), respectively.

Approximately three of every four subjects responded accurately to visual-spatial prompts while seated, and the accuracy of responses was similar across the three postural conditions (kappa = 0.495, $P<.001$). Accuracy was associated with longer reaction times (slower) in all experimental conditions (z-score <-5.20, $P<.10$) and shorter walking-time responses (faster) on the straight and turn walks ($P=.001$ for both), suggesting that visual-spatial accuracy may be an important confounder of the association between walking-time response and recurrent falling.

In Model 1, adjusting for corresponding reaction time or walking time responses and visual-spatial response accuracy (visual-spatial task only), there was no evidence of an association between history of recurrent falls and poorer reaction time responses on any of the four dual-task experiments ($P>.10$ for all), although there were trends toward poorer walking-time response and higher odds of recurrent fall history ($P<.10$) identified during the push-button and visual-spatial turns walks (Table 2).

In Model 2, adjusted for Model 1 covariates plus randomized task order and cane use, the trend of poorer walk-

Table 1. Comparison of Subject Characteristics According to History of Recurrent Falling (N = 370)

Characteristic	≥2 Falls (n = 37)	0 (n = 265) or 1 (n = 68) Fall
Demographics and anthropometrics		
Age, mean±SD	78±3	78±3
Female, %	58	51
White, %	66	72
BMI, kg/m^2, mean±SD	29±5	28±5
Height, cm, mean±SD	164±79	164±91
<High school education, %	16	12
Health behavior, %		
Smoke	0	5
Moderate alcohol consumption	34	21
Walks routinely	21	49‡
Impairment		
Fair/poor self-rated health, %	29	13‡
Hearing loss, %	51	59
Depression, %	18	10*
Leg pain, %	53	40*
Visual acuity, total correct, mean±SD	57±5	56±5
Disparity in depth perception, mean±SD	178±215	160±209
Poor contrast sensitivity, %	21	16
Medication, %		
≥4 medications	73	54†
Antidepressants	21	10†
Neuromuscular function§		
Knee-extensor strength, Nm, mean±SD	68±20	76±27†
Ankle dorsi-flexor strength, Nm, mean±SD	30±10	38±25†
Rapid walking speed <1.2 m/s, %	23	17
Finger tapping score, mean±SD	60±8	63±10*
Cognitive function, mean±SD		
Teng modified Mini-Mental State Examination score	93±6	94±6
Digit Symbol Substitution score	37±11	40±11*
Clock drawing test score	11±2	11±2

$P\leq$*.10, †.05, ‡.01. § Models adjust for sex, height, and body mass index (BMI). SD = standard deviation.

ing-time response and higher odds of recurrent falls history on both turn walks remained ($P<.10$), and an association between poorer walking-time response and higher odds of recurrent fall history on the visual-spatial straight walk emerged ($P=.01$). In addition, an association between poorer reaction-time response and lower odds of recurrent fall history on the push-button turn walk emerged ($P=.03$).

In Model 3, Model 2 covariates were adjusted for, plus age, race, and the risk factors identified from forward-selection procedures, including absence of routine walking, poorer general health, use of four or more prescription medications, weaker ankle strength, and lower Digit Symbol Substitution score. The additional covariate adjustment in Model 3 did not explain any of the trends or associations between dual-task response and history of recurrent falls identified using Model 2.

The strength of the associations between dual-task performance and odds of recurrent falls history were based on standardized regression coefficients for dual-task responses (unit = IQR/2). On the visual-spatial task, higher walking time response (e.g., poorer) were associated with 34% and 42% higher odds of recurrent falls history on the straight ($P=.02$) and turn walks ($P=.01$), respectively. On the push-button task, there was a trend toward higher walking time response (e.g., poorer) and 24% higher odds of recurrent falls history on the turn walk ($P=.08$). During this same experiment, there was an association between poorer reaction-time response and 27% lower odds of recurrent falls history ($P=.04$).

In post hoc analyses, because cognitive impairment may influence dual-task performance, multivariate regression models of dual-task performance were rerun after excluding the 10 individuals with cognitive impairment (3MS score<80); nearly identical results were found (data not shown).

DISCUSSION

A cross-sectional study of 377 community-dwelling older adults examined the relationship between dual-task performance involving concurrent reaction time and timed walking tests and recent history of recurrent falls. Poorer walking-time responses due to a timed visual-spatial decision task, but not a push-button reaction time task, were associated with higher odds of recurrent falls history. With the exception of the push-button reaction time experiment involving a turn walk, poorer reaction-time responses were not associated with a history of recurrent falls. On the push-button reaction-time task, an increase in reaction time due to walking at one's usual pace on a 20-m course with a turn at 10 m was associated with *lower* odds of recurrent falls history. The association between poorer walking-time responses due to the speeded visual-spatial decision task and odds of recurrent falls history was slightly higher (42% vs 34%) while walking on the course with a turn than the straight course.

How walking is affected in a dual-task setting is presumably an indicator of attentional resources or capacity for cognitive loading while walking.[28] The finding that poorer walking-time response due to performing a concurrent visual-spatial task, but not a push-button task, is associated with a history of recurrent falling is consistent with this theory. The finding that visual-spatial decision reaction times were more than two times as long as the push-button reaction times is evidence of higher cognitive loading while walking with the visual-spatial decision task than with the push-button reaction-time task. As such, any association between history of recurrent falls and poorer walking time response would be expected to be higher on the visual-spatial decision task than the push-button reaction-time task. The same logic would be applicable to the type of walking

Table 2. Association Between Poorer Dual-Task Performance and Standardized* Odds of Recurrent Falls History

Dual-Task Response According to Experiment	Model 1†	Model 2‡	Model 3§
	OR (95% Confidence Interval) *P*-value		
Push-button task			
Reaction-time response, straight walk	1.14 (0.90–1.43) .27	1.09 (0.85–1.39) .51	1.09 (0.82–1.45) .53
Reaction-time response, turn walk	0.84 (0.65–1.08) .17	0.73 (0.56–0.96) .03	0.72 (0.53–0.99) .04
Walking-time response, straight walk	1.17 (0.95–1.45) .14	1.12 (0.87–1.44) .37	1.11 (0.85–1.47) .42
Walking-time response, turn walk	1.23 (0.98–1.53) .07	1.21 (0.97–1.51) .10	1.24 (0.97–1.59) .08
Visual-spatial task adjusted for visual-spatial accuracy			
Reaction-time response, straight walk	0.87 (0.68–1.12) .30	0.95 (0.73–1.23) .71	1.03 (0.76–1.39) .86
Reaction-time response, turn walk	0.91 (0.70–1.19) .51	1.06 (0.74–1.50) .75	1.13 (0.76–1.68) .54
Walking-time response, straight walk	1.16 (0.94–1.42) .16	1.34 (1.06–1.69) .01	1.34 (1.04–1.74) .02
Walking-time response, turn walk	1.21 (0.99–1.48) .06	1.23 (0.99–1.51) .06	1.42 (1.08–1.85) .01

* Odds ratios (ORs) are standardized to half of the interquartile range.
† Adjusted for walking-time or reaction-time response and visual-spatial accuracy (visual-spatial task only).
‡ Adjusted for Model 1 plus randomized task order and cane use.
§ Adjusted for Model 2 plus race, age, walks for exercise/other, poorer general health, use of ≥4 prescription medications, weaker ankle strength, and lower Digit Symbol Substitution score.

course performed, such that it would be expected that any association between history of recurrent falls and poorer walking-time response would be higher on the walking course with the turn, because the turn poses an additional balance challenge to that of the straight walking course.

There are other theories suggesting that the type of cognitive loading matters. In a study of 16 older adults classified as transitionally frail,[29] stride time variability increased when participants walked and performed an arithmetic task but not a verbal fluency task. The push-button reaction-time task, which is a simple perceptual-motor process, includes neuromuscular coordination but little to no decision process, whereas the visual-spatial decision task requires spatial-to-verbal mental conversion, including a spatial decision and a verbal response. Thus, it is also plausible that the interaction between cognition and walking performance with a history of recurrent falling may be related more to cognitive resources involving spatial memory or higher-level decision-making than to simpler perceptual-motor skills in community-dwelling adults who are relatively mobile and cognitively intact, a finding that is consistent with prior balance studies.[1,30,31]

With the exception of the push-button turn walk, no associations were found between reaction time responses and recurrent falls history. On the turn walk, poorer push-button reaction-time responses were associated with lower odds of recurrent falls history. It is likely that this unexpected finding is a marker for being more attentive to one's environment under a complex setting of coordinated motor tasks and postural threat. Median usual-paced walking times were consistently faster (5–6%) on both walks when a push-button task was introduced. The coordination of the two motor tasks may have imposed faster walking and individual walking times. Indeed, push-button reaction times under dual-task conditions on the straight (correlation coefficient $(r) = 0.22$, $P < .001$) and turn walks ($r = 0.27$, $P < .001$) were correlated. Similar results of shorter stride times (e.g., faster walking) due to the introduction of a fast finger-tapping task while walking on a 10-m pathway have been reported in younger adults.[32] This faster walking may be due to the tendency for biological oscillators to attract each other,[33] and it has been speculated that the imposed modulated walking (implied faster) may occur because of the potential for structural interference between shared neurobiological networks in two different rhythmic motor tasks.[32]

Poorer reaction time responses in a setting of postural threat (e.g., turn walk) in addition to presumably imposed faster walking may be a marker of being more attentive to one's environment. After adjusting the push-button reaction-time responses for walking-time responses, randomized task order, cane use, age, race, absence of routine walking, poorer general health, use of four or more prescription medications, weaker ankle strength, and lower Digit Symbol Substitution score, recurrent fallers tended toward lower median reaction time responses on the turn walk (23%, IQR = 16–28%) than the straight walk (25%, IQR = 20–31%). Single fallers and nonfallers tended toward higher median reaction time responses on the turn walk (24%, IQR = 18–31%) than the straight walk (21%, IQR = 17–26%). Together, these data support the hypothesis that poorer reaction-time responses and lower odds of recurrent falls history may be a marker for being more careful during conditions that threaten posture, thus reducing one's risk of recurrent falls.

These findings suggesting that poorer walking-time response on a visual-spatial task is associated with greater odds of recurrent fall history are consistent with prior research. One study reported that subjects with poorer responses on a timed get up and go test due to carrying a glass of water[13] and subjects who stopped walking when engaged in conversation[12] were four times as likely to fall over 6 months. Relevant elements of the visual-spatial decision task used in the current study were likely involved in carrying a full glass of water and when being engaged in conversation. Visual-spatial resources were likely involved with holding a cup of water level while gathering information about the object in space as well as the mental conversion of largely unpredictable auditory stimuli (e.g., time-of-day prompt) in terms of the specific contents of conversation. In a study of older adults, performance on dynamic tests of balance involving platform perturbations during a simultaneous test of counting backwards by threes was a better predictor of greater risk for falls than were the tests of dynamic balance alone.[15] However, in the Leiden 85-Plus study of adults aged 85 and older, shorter walking times during a verbal fluency task were not associated with fall risk.[14] Adults in the latter study include the oldest-old, with the majority (52%) having a history of falling, so results may not generalize to the current study.

This study had limitations and strengths. Subjects self-reported their falls over a 12-month period; however, falls recalled over a 1-year period have been shown to be as reliable as falls recalled over 6 months.[34] The current study data are cross-sectional, so relationships do not imply causality. Furthermore, although it is possible that poorer attentional resources reflected by poorer walking-time responses may contribute to recurrent fall risk through reduced obstacle avoidance or an inability to regain stability after a postural perturbation, it is also plausible because of the cross-sectional nature of the data that a history of recurrent falls contributes to poorer dual-task performance. It is also possible that recurrent fallers, who may receive fall interventions, such as balance training, would be more likely to walk more slowly when multitasking than during undistracted walking. Still, this study included a large sample of well-characterized older community-dwelling adults.

This study found a recent history of recurrent falls in older community-dwelling adults to be associated with poorer ability to maintain usual-paced walking time while simultaneously making decisions that draw on memory and visual-spatial resources. Dual-task experiments involving usual walking and visual-spatial decision tasks may be useful for targeting individuals at risk for recurrent falls during their everyday activities. In daily life, individuals are faced with unexpected hazards in which multitasking or, more specifically, attention-related restrictions may impair one's ability to detect and avoid hazards and effectively implement postural stabilizing compensatory strategies. Future studies are warranted to examine whether declining ability to maintain usual-pace walking time during a visual-spatial decision task predicts incident falls and possibly fractures, because poorer multitasking may also affect one's ability to break one's fall after a fall occurs.

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