

ORIGINAL ARTICLE

Older Fallers With Poor Working Memory Overestimate Their Postural Limits

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ABSTRACT. Liu-Ambrose T, Ahamed Y, Graf P, Feldman F, Robinovitch SN. Older fallers with poor working memory overestimate their postural limits. *Arch Phys Med Rehabil* 2008;89:1335-40.

Objective: To compare the accuracy of perceived postural limits between older fallers with good working memory and those with poor working memory.

Design: Cross-sectional study.

Setting: Research laboratory.

Participants: Thirty-three community-dwelling older adults with a history of falls.

Interventions: Not applicable.

Main Outcome Measures: We measured the accuracy of perceived postural limits by using the perceived reach test in 33 fallers. The difference between the verbal digits forward test score and the verbal digits backward test score was used to provide an index of the central executive component of working memory. Participants were then allocated into 2 groups: (1) good working memory or (2) poor working memory. Comparisons of group characteristics and scores were undertaken by using Student independent-sample *t* tests for differences in means between those with good working memory and those with poor memory. One hierarchical linear regression model was constructed to determine the independent association of the central executive component of working memory with the accuracy of older fallers' perceived reach capacity.

Results: There was a significant difference in the mean percentage error in perceived reach between older fallers with good working memory and those with poor working memory ($P=.01$). The verbal digit span difference score was independently associated with the percentage error in perceived reach. The verbal digit span difference score resulted in an R^2 change of 18.2% and significantly improved the regression model ($F_{1,26}$ change, 7.45; $P=.01$).

Conclusions: Our novel results suggest that impaired executive functioning may increase falls risk by impairing older adults' judgment in motor planning for daily activities. How-

ever, future studies with larger sample sizes are needed to confirm our current results.

Key Words: Accidental falls; Memory; Rehabilitation.

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FALLS ARE A MAJOR HEALTH care problem for older people. Falls are the third cause of chronic disability worldwide,¹ and about 30% of community-dwellers over the age of 65 experience 1 or more falls every year.² In Canada alone, the annual direct medical expenditure related to falls exceeds Can \$2.4 billion.³

Falls are associated with cognitive dysfunction.² Approximately 60% of older people with cognitive impairment fall annually; this incidence is approximately twice that of cognitively intact peers.^{2,4} The cognitively impaired older faller is also at increased risk of major injury such as fracture and head trauma.⁴ After an examination of risk factors for falling in community-dwelling seniors, Tinetti et al² reported an odds ratio of 5 for cognitive impairment; this compares with an odds ratio of 3.8 and 1.9 for disability in the lower extremities and impaired balance and gait, respectively. A critical domain of cognitive function is executive functions, the higher-order cognitive processes that control and integrate other cognitive abilities,⁵ such as, but not limited to, attention and perception. One of the most critical aspects of executive functions is working memory,⁶ a system that is required for complex attention, strategy formation, and interference control. Working memory consists of 3 main components: the phonologic loop, the visuospatial sketch pad, and the central executive. The phonologic loop and visuospatial sketch pad are recruited for the storage and manipulation of verbal and nonverbal information, respectively.⁷ The central executive system is a limited-capacity attentional system that selects goal-relevant behavior by focusing and switching attention.⁷

Among older adults, impaired executive functions have been shown to be associated with falls.⁸⁻¹¹ Specifically, impaired executive function is associated with an increased risk of a major fall-related injury,¹² impaired balance,^{13,14} impaired gait,¹⁵⁻¹⁸ impaired balance recovery,¹⁹ and reduced obstacle avoidance ability^{20,21} in older adults. The successful performance of a challenging or complex locomotor task depends on the structural integrity and functionality of the neurologic structures that subservise the central executive.²²

To date, studies of central executive functioning and falls have largely focused on dual-tasking, the ability to focus in-

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List of Abbreviations

ABC	Activities-specific Balance Confidence
BDI	Beck Depression Inventory
MMSE	Mini-Mental State Examination
TUG	Timed Up & Go

multaneously on several relevant stimuli. Specifically, these studies examined older adults' ability to simultaneously perform cognitive and motor operations, such as walking while carrying on a conversation.^{11,23} Impaired ability to talk while walking has been shown to predict falls in community-dwelling nondemented seniors.²⁴

However, impaired executive functioning may also increase falls risk by impairing older adults' judgment in motor planning for daily activities (eg, walking, reaching). Rappoport et al⁹ showed that poor performance on standard neuropsychologic tests sensitive to response inhibition, a key process of executive functioning, accounted for unique variance in falls. Thus, we conducted a cross-sectional study to compare the accuracy of perceived postural limits between older fallers with good working memory and older fallers with poor working memory. We hypothesized that older fallers with poor working memory have the tendency to overestimate the limits of their postural stability.

METHODS

Participants

The sample consisted of 33 men and women recruited from the community. We included those who (1) were aged 65 years and older, (2) reported 1 or more nonsyncopal falls in the last 12 months, (3) were living independently in their own home, (4) were able to stand unassisted for 10 minutes, and (5) obtained a score 24 or higher on the MMSE.²⁵ We excluded those who (1) had a diagnosed neurodegenerative disease (eg, Alzheimer's disease) and stroke, (2) were taking psychotropic drugs, or (3) did not speak and understand English. We restricted our study sample to older adults with a history of falls to reduce the number of potential confounding variables that may influence one's ability to accurately determine his/her reach capacity (eg, fear of falling). A fall was defined as an unexpected event in which the participant comes to rest on the ground, floor, or lower level. The study was approved by the relevant ethics boards, and all participants provided written informed consent.

Sample Size

Based on previous work by Robinovitch and Cronin,²⁶ we assumed that there would be a 5% difference in the percentage error of perceived reach between older adults with good working memory and older adults with poor working memory. We also assumed a common SD of 5%. Based on these assumptions, a sample of 13 persons per group would provide a power of .80 at an α level of .05.

Descriptive Variables

Standing height was measured twice as stretch stature to the nearest 0.1cm by using standard protocol. Weight was measured twice to the nearest 0.1kg on a calibrated digital scale. Mean values were used for analysis.

Global cognitive state was assessed by using the MMSE.²⁵ We used the BDI²⁷ to screen for depression. BDI scores range from 0 (no depression) to 63 (severe depression).²⁷ The occurrence of falls in the last 12 months was ascertained by means of an interview.

Falls-related self-efficacy was assessed with the 16-item ABC scale.²⁸ Each scale item is rated from 0% (no confidence) to 100% (complete confidence). Functional mobility was assessed by the TUG test.²⁹ Participants were instructed to rise from a standard chair with arms (seat height, 45cm; arm height, 62cm), walk a distance of 3m, turn, walk back to the chair, and

sit down again. A stopwatch was used to record times, and the mean of 2 trials was calculated and used for statistical analysis.

Accuracy of Perceived Postural Limits: Perceived Reach Test

We measured the accuracy of perceived postural limits by using the perceived reach test.^{26,30} To ensure that the participants had a clear understanding of the task, the assessors first showed the task, and participants were then required to verbally describe the specific movements involved to the assessors. Participants were required to first estimate their reach capacity and then execute maximum-distance forward reaches. Specifically, participants stood with their feet shoulder-width apart and right shoulder 3cm from the wall. The back of their heels were aligned along a clearly marked line on the floor. A blank tape measure was mounted on the wall, starting from the point corresponding to the marked line on the floor and extending horizontally at the height of the participant's acromion. Each participant's arm length was measured as the distance from the participant's heels to the tip of his/her longest finger while they held their arm at 90° of forward flexion. The participant was then asked to visually estimate his/her maximum forward reach, defined as the distance from the participant's heels to the tip of his/her longest finger, when reaching forwards as far as possible while maintaining the fingertip at the height of the shoulders and without lifting his/her heels. To acquire estimated reach values, the assessor would slowly slide a yellow cylindrical pointer of 1cm in diameter and 15cm in length, held perpendicular to the wall, along the blank measuring tape away from the participant. Participants were instructed to say the word stop when it reached their estimated maximum forward reach. The participant was then asked to confirm his/her satisfaction with the estimate and given the opportunity to revise it. The estimates of forward reach were marked discretely by the assessors on the blank measuring tape and measured in centimeters after the tape was removed from the wall. Three trials of estimated forward reach were performed, and the mean was used for statistical analysis.

The digit span tests (see Working Memory: Verbal Digit Span Tests section) were administered between the estimation trials and the actual performance trials. We acquired 3 trials of actual forward reach by using the protocol described in the previous paragraph. Three trials of actual forward reach were performed, and the mean was used for statistical analysis. We calculated the percentage error in perceived reach as: $(\text{mean actual reach} - \text{mean estimated reach}) / (\text{mean actual reach}) \times 100$.

Positive percentage error scores indicate underestimation, whereas negative percentage error scores indicate overestimation of forward reach. We also calculated the reach excursion for each participant as actual reach minus arm length.

The reliability of both the estimated and actual reach performance of the perceived reach test is high (intraclass correlation coefficient $> .90$).^{26,30} Of specific relevance to falls risk, Robinovitch and Cronin²⁶ found that among older adults those with impaired balance tended to overestimate their maximum forward reach.

Working Memory: Verbal Digit Span Tests

We used the verbal digits forward and verbal digits backward tests to index the central executive component of working memory.³¹ Both tests consist of 7 pairs of random number sequences that the assessor reads aloud at the rate of 1 per second. The sequence begins with 3 digits and increases by one at a time up to a length of 9 digits. The test includes 2

sequences of each length, and testing ceases when the participant fails to recollect any 2 with the same length. The score recorded, ranging from 0 to 14, is the number of successful sequences. For the verbal digits forward test, the participant's task is to repeat each sequence exactly as it is given. For the verbal digits backward test, the participant's task is to repeat each sequence in the reversed order. Higher scores indicate better performance.

Both verbal digit span tests represent a measure of the capacity of the phonologic loop. Successful performance on the verbal digits span backward test represents a measure of central executive function because of the additional requirement of manipulation of information within temporary storage.⁷ Thus, we calculated the difference between the verbal digits forward test score and the verbal digits backward test score to provide an index of the central executive component of working memory. Participants were then allocated into 2 groups based on their verbal digit span difference score: (1) good working memory or (2) poor working memory. Hester et al³² recommend a cutoff difference score of greater than 4 to indicate poor working memory. Thus, in this study, participants who had a difference score of greater than 4 were classified as having poor working memory.

Data Analyses

Data were analyzed by using SPSS^a for Windows. Descriptive data are reported for variables of interest. Comparisons of group characteristics and scores were undertaken by using Student independent-sample *t* tests for differences in means between those with good working memory and those with poor memory. Also, single-sample *t* tests were used to assess

whether, in those with good working memory and those with poor working memory, the mean percentage error in perceived reach significantly differed from zero.

The level of association between the percentage error of perceived reach and variables of interest was examined by using the Pearson product-moment coefficient of correlation. Alpha was set at *P* less than or equal to .05.

One hierarchical linear regression model was constructed to determine the independent association of the central executive component of working memory with the accuracy of older fallers' perceived reach capacity. In this model, the dependent variable was the percentage error in perceived reach. Age and BDI score were statistically controlled by forcing these 2 independent variables into the regression model first. The verbal digit span difference score was then entered into the regression model. The independent variables were determined from the results of the Pearson product-moment coefficient of correlation analyses (ie, BDI score) and based on biologic relevance (ie, age).

RESULTS

Characteristics of the Participants

Table 1 reports descriptive statistics for relevant descriptor variables and the outcome measures of interest. All results are mean \pm SD unless noted otherwise.

Overall, our cohort of older fallers overestimated their reach capacity by 8%. The participants also performed below age-normative values for both the verbal digits span forward test and the verbal digits span backward test. Based on the mean TUG test time, those with poor working memory were at a

Table 1: Descriptive Statistics for Descriptors and Measures of Interest

Variable	Entire Cohort (N=33)	Poor Working Memory (n=16)	Good Working Memory (n=17)
Age (y)	79 \pm 7	81 \pm 6	76 \pm 7
Height (cm)	155.7 \pm 24.9	155.6 \pm 27.2	155.7 \pm 23.4
Weight (kg)	74.5 \pm 28.5	72.8 \pm 29.5	76.0 \pm 28.4
MMSE score (max, 30 points)	28 \pm 2	28 \pm 2	28 \pm 2
BDI score (max, 63 points)	5 \pm 4	5 \pm 4	5 \pm 5
Education*			
High school certificate or diploma	7 (21)	2 (12)	5 (31)
Trades/professional certificate or diploma	10 (30)	7 (41)	3 (19)
University certificate or diploma	2 (6)	1 (6)	1 (6)
University degree	6 (18)	3 (18)	3 (19)
Female*	27 (82)	12 (71)	15 (94)
TUG test (s)	12.8 \pm 3.3	13.6 \pm 3.2	12.0 \pm 3.3
Verbal digits span			
Forward test (max, 14 points)	7 \pm 2	8 \pm 2	6 \pm 2 [†]
Backward test (max, 14 points)	4 \pm 2	3 \pm 2	5 \pm 2 [†]
Difference score	4 \pm 2	6 \pm 1	2 \pm 2 [†]
Perceived reach (cm)	102.4 \pm 14.7	104.6 \pm 11.9	100.6 \pm 16.8
Actual reach (cm)	95.5 \pm 11.9	91.4 \pm 13.2	98.6 \pm 10.4
Arm length (cm)	64.5 \pm 7.4	66.3 \pm 8.1	63.2 \pm 6.9
Reach excursion (cm)	31.2 \pm 11.7	25.6 \pm 12.7	35.3 \pm 9.1 [†]
Percentage error in perceived reach	-8.0 \pm 14.7	-16.0 \pm 15.7	-1.9 \pm 10.6 [†]

NOTE. Values are mean \pm SD. MMSE scores from 24 to 30 equate to cognitive impairment, 18 to 23 equate to mild cognitive impairment, and 0 to 17 equate to severe cognitive impairment.²⁹ BDI scores from 0 to 9 equate to no depression, 10 to 18 equate to mild depression, 19 to 29 equate to moderate depression, and 30 to 63 equate to severe depression.^{12,30} A TUG test time of 13.5 seconds or more indicates a high risk of falling.¹⁸ Age-normative values (ie, 75-79y) for verbal digits span forward score equals 9 and for verbal digits span backward equals 6.¹⁷ Verbal digit span difference score = verbal digits span forward test score - verbal digits span backward test score. The age-normative value (ie, 75-79y) for the verbal digit span difference score equals 3.¹⁷ Reach excursion = actual reach - arm length. The percentage error in perceived reach = (mean actual reach - mean perceived reach)/mean actual reach.

*The number of yes cases within each group with the percentage of yes cases within each group.

[†]The significant difference between the 2 groups at *P* \leq .02.

Table 2: Pearson Product-Moment Coefficient Matrix Between Age, Global Cognition (MMSE Score), Depression (BDI Score), Falls-Related Self-Efficacy (ABC Scale Score), Functional Mobility (TUG Test), the Central Executive Component of Working Memory (Verbal Digit Span Difference Score), and the Percentage Error in Perceived Reach (N=33)

Variable*	Percentage Error in Perceived Reach
Age (y)	.07
MMSE score	-.18
BDI score	.41 [†]
ABC score	-.15
TUG test (s)	.11
Verbal digit span difference score*	-.39 [‡]

*Verbal digit span difference score = verbal digits span forward test score – verbal digits span backward test score.

[†] $P < .01$.

[‡] $P < .05$.

relatively higher risk of falling.³³ Older adults with good working memory had obtained significantly greater reach excursion than those with poor working memory ($P = .02$).

Percentage Error in Perceived Reach

There was a significant difference in the mean percentage error in perceived reach between older fallers with good working memory and those with poor working memory ($P = .01$). Specifically, older fallers with poor working memory overestimated their reach capacity by 16% compared with 2% by older fallers with good working memory. The mean percentage error in perceived reach differed significantly from zero ($P < .01$) in those with poor working memory but not in those with good working memory ($P = .48$).

Correlation Coefficients

Both the BDI score and the verbal digit span difference score were significantly associated with the percentage error in perceived reach (table 2). The remaining variables were not significantly associated with the percentage error in perceived reach.

Hierarchical Linear Regression Model

The verbal digit span difference score, an index of the central executive component of working memory, and BDI score were independently associated with the percentage error in perceived reach in the final model (table 3). Age and BDI score together accounted for 18.3% of the total variance. Adding the verbal digit span difference score resulted in an R^2 change of 18.2% and significantly improved the model

($F_{1,26}$ change, 7.45; $P = .01$). The total variance accounted for by the final model was 36.5%.

DISCUSSION

We found that the central executive component of working memory was independently associated with the accuracy of older fallers' perceived reach capacity. To our knowledge, this is the first study that has examined the independent association of executive function (ie, working memory) to older fallers' perception of postural limits. The postural limit is the horizontal displacement of the body's center of gravity with respect to the base of support provided by the feet, beyond which stepping is required to prevent a fall.³⁴ This study's results suggest that impaired executive functioning may increase falls risk by impairing older adults' judgement in motor planning for daily activities, such as reaching. Our results also highlight that impaired executive functions exists in older fallers who show intact global cognitive function.

There is increasing evidence of an association between impaired cognition and falls in older adults,^{35,36} but there is scant knowledge relating to the underlying mechanisms. We hypothesized that impaired executive functions may increase falls risk in older adults, not only via decreased dual-tasking ability as shown by previous studies^{11,24} but also via impaired judgment in motor planning. A previous study of 1571 persons showed that older fallers believed their own risk-taking behavior was a more common cause of falling than their health or environmental factors.³⁷ To plan successful movements depends on operating within one's neuromuscular constraints. For this to occur, an accurate awareness of these constraints is necessary. Older adults with inaccurate awareness of their neuromuscular constraints may increase their risk of falling by (1) planning and executing movements that create loss of balance (ie, overestimation of ability) or (2) remaining physically inactive to avoid opportunities for the loss of balance and thus reducing physiologic function (ie, underestimation of one's ability).

Given that our sample consisted entirely of older fallers, we expected that the participants would underestimate their reach capacity at least in part because of reduced falls-related self-efficacy. Instead, we observed a mean overestimation of 8% and found that falls-related self-efficacy was not significantly associated with the percentage error of perceived reach. Specifically, older fallers with poor working memory (ie, verbal digit span difference score ≥ 4) significantly overestimated their reach capacity by 16%, whereas those with good working memory did not. However, older adults with good working memory had significantly greater reach excursions than those with poor working memory. One rationale for this interesting difference may be that those with good short-term memory performed better on the perceived reach test simply because

Table 3: Hierarchical Linear Regression Model Summary for the Percentage Error in Perceived Reach in Older Fallers (N=33)

Independent Variable [†]	Percentage Error in Perceived Reach*				
	R^2	R^2 Change	Unstandardized B (SE)	Standardized β	P
Model 1	.183	.183			.07
Age			.003 (.004)	.124	.49
BDI score			.013 (.006)	.425	.02
Model 2	.365	.182			.01
Age			.006 (.004)	.297	.09
BDI score			.013 (.005)	.396	.02
Verbal digit span difference score			-.027 (.010)	-.462	.01

*Percentage error in perceived reach = (mean actual reach – mean perceived reach)/mean actual reach.

[†]Verbal digit span difference score = verbal digits span forward test score – verbal digits span backward test score.

they remembered their estimated reach distance and consciously aimed for this distance when performing the actual reach. However, we made efforts to minimize this effect by (1) using a new blank tape measure for each assessment of perceived reach and actual reach and (2) incorporating a 20-minute break between the perceived reach trials and the actual reach trials; the verbal digit span tests were administered during this 20-minute interval. Also, older adults with poor working memory performed better on verbal digits span forward, a measure of short-term memory. We note that depressive symptoms (ie, BDI score) were associated with an underestimation of reach capacity among our participants; it may be that those with depressive symptoms were generally less motivated or interested. In addition, people with depressive symptoms may also suffer from low levels of confidence in many different areas of life. Thus, the possibility exists that those with depressive symptoms underestimated their reach capacity because of low levels of confidence.

Current evidence supports our finding that impaired executive functions can exist concurrently with intact global cognitive function.³⁸ Impaired executive functions may, in many cases, be caused by underlying structural changes in subcortical and periventricular white matter of the brain,^{15,39} such as volume reduction, neuronal atrophy, synapse loss, change in neurochemistry, senile plaques, infarcts, and lesions.^{15,39} These changes have been shown to correlate with declines in gait and impaired balance.⁴⁰ Specifically, Whitman et al⁴⁰ showed that the development of gait and balance dysfunction in older adults was associated with a gradual onset of cerebral white-matter lesions. Thus, although many of the structural changes associated with impaired executive functions are clinically silent, they are prevalent⁴¹ and may result in an increased falls risk.

Our results significantly add to the current literature on the relationship between impaired executive functions and falls. The majority of research to date has focused solely on the contribution of impaired dual-tasking to falls,^{11,24} and, thus, our findings generate novel hypotheses. The need for falls research to include cognitive function measures has been highlighted.³⁶

Given the observed relationship between executive functioning and the ability to determine one's limits of stability, effective falls-prevention strategies should not only target physiologic impairments (eg, muscle weakness) and environmental hazards but also executive functions in older adults. Current evidence suggests that exercise, specifically aerobic training, has robust but selective benefits for cognition, with the largest benefits occurring for executive functions in older adults aged 55 years and older.⁴² More research is needed to ascertain whether exercise, such as aerobic training, may ameliorate executive functions in older adults with a history of falls.

Study Limitations

We acknowledge several limitations in the current study. First, behavioral factors, such as one's level of motivation and competitiveness, have potential effect on our measures of maximum forward reach. However, we minimized such effects by encouraging participants in these measures to reach a little further until imbalance was observed. To motivate participants to obtain their maximum forward reach, we suggest that future studies use verbal instructions that would create visual imageries of common everyday activities, such as passing a glass of wine over a sofa without spilling it. A second limitation is that we measured the older fallers' judgment in motor planning for daily activities in a single, but common, scenario. Also, our participants were all older adults with a history of falls in the last year, and, thus, our results may not apply to older adults

without a history of falls. Finally, our small study sample limited the number of independent variables that we could enter into the regression model.

CONCLUSIONS

The central executive component of working memory was independently associated with the accuracy of older fallers' perceived reach capacity. Our novel results suggest that impaired executive functioning may increase falls risk by impairing older adults' judgment in motor planning for daily activities. However, future studies with larger sample sizes are needed to confirm our current results.

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- Supplier**
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