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ORIGINAL RESEARCH

Risk Assessment of Falls Among Older Adults Based on Probe Reaction Time During Water-Carrying Walking

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Purpose: Falls are a significant factor affecting the health of older adults and are closely related to cognitive function. Adopting an effective method to evaluate the risk of falls in older adults is essential for improving their healthcare. This study combined cognitive and motor functions to determine a reliable probe reaction time during water-carrying walking.

Patients and Methods: We divided 100 community-dwelling older adults (aged 65 years and over) into two groups according to their fall history: the fall group and no-fall group. All subjects were tested on fall tasks using the timed up-and-go (TUG) test, 10-m walk timing test, trail marking test part-A (TMT-A), and water-carrying walking probe reaction time (P-RT).

Results: The fall group showed slower walking speeds and longer TUG, TMT-A, and P-RT times than the no-fall group. In the logistic regression analysis with falls as the dependent variable, water-carrying walking P-RT was identified as a useful factor, and the cut-off value of the water-carrying walking P-RT was 454 ms, which was evaluated using the receiver operating characteristic curve.

Conclusion: The P-RT of the water-carrying walking test was found to be credible and useful for evaluating the fall risk in older adults. Therefore, it is recommended that the P-RT-based dual-task be used as a predictive indicator of future falls in the older population.

Keywords: falls, probe reaction time, older adults, dual task

Introduction

Falls are a significant problem affecting the daily lives of older adults.[1] Falls can result in a series of problems such as injury, hospitalization, and loss of autonomous motor ability,[2,3] which threaten the health and quality of life of older people and incur high costs for public health and social services.[4,5] Accurate identification of the individual fall risk is critical for effective intervention to reduce apraxia and subsequent injuries.

Many falls in older adults occur while walking,[6] especially when performing tasks that simultaneously require high attention, which makes it more difficult to maintain stability, thereby increasing the risk of falls.[7] Therefore, it is necessary to consider not only personal factors but also environmental and behavior-related factors when assessing the risk of falls.[8] Most previous studies have focused more on muscle strength,[9] reaction time,[10] balance ability, and walking ability.[11] In recent years, research assessing the fall risk in older adults has encompassed the evaluation of both physical motor and cognitive functions. However, most studies have considered only a single factor. Given these limitations, researchers worldwide have begun to focus on the risk of falls in older adults with impaired cognitive behavior.

The main manifestation of cognitive impairment is related to damage to memory-related brain regions, such as attention, memory, processing speed, and executive function, which can further cause a decline in balance and gait stability, resulting in an

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increased risk of falls. Research has indicated that reaction time affects balance ability,[12] and a long reaction time reflects impaired responsiveness to the environment. Simultaneously, the overall cognitive level of older adults declines with age. Olsson et al[13] reported that some older adults stopped walking while talking because an additional cognitive task could significantly distract them from walking.

A dual-task walking assessment could be a predictor of falls in older adults,[14] and can be used to assess the interaction between mobility and cognitive ability.[15] Many scholars have integrated walking with various cognitive behaviors to assess the fall risk. In one experiment, the subjects recited letters alphabetically while walking regularly and then recited them alternately.[16] The results showed that older adults with longer completion times experienced more falls within the next 12 months, indicating that walking tasks integrated with cognitive tests could effectively predict falls in older adults. Olsson et al examined the effect of the second task on balance and gait in daily life by asking the subjects to hold a glass with 50 mL of water while performing the timed up-and-go (TUG) test, and further calculated the difference in time to complete the TUG test alone and the TUG test while holding a glass of water.[17] The results showed that the older adults with longer time differences and lower functional scores were more likely to fall. Therefore, evaluating additional movements during walking can be a useful tool for predicting falls. More scholars have used dual-task tests to assess the fall risk of older adults. Bloem et al[6] showed that gait changes caused by dual tasks were mainly attributable to the competitive demand for attention in gait and oral tasks. Furthermore, Beauchet et al examined changes in oral task performance while walking by asking subjects to count backward from 50.[18,19] The results showed that the counting speed of older adults who were prone to falls increased when walking. These results indicate that walking tasks integrated with cognitive tests can effectively predict falls in older adults.

The evaluation of additional movements while walking may be a useful tool for predicting falls. Carrying a glass of water while walking was used as a cognitive task in the dual-task test to assess the fall risk of older adults.[20] Research has shown that when performing a water-carrying task, the test time of the subjects increased, and the time of the non-fall group was shorter than that of the fall group.[15,17,21,22] This indicates that carrying a glass of water while walking can serve as a cognitive task in the dual-task.

Recently, the probe reaction time (P-RT) has become a reliable method for evaluating the risk of falls among older adults. When a moving task is executed, other tasks are executed simultaneously. If the main task is relatively simple, adults can assign more attention to the second task, which can be performed quickly. Therefore, if a relatively short second task is required during the execution of a motion task, then the main task is automatically executed. This time is known as the P-RT. Huo et al evaluated the fall risk in older adults by calculating the P-RT as a dual-task.[23,24] The study asked the subjects to answer "Pa" after hearing the sound "Pi" while walking. The time difference between the two sounds was calculated as the P-RT. When measuring the P-RT during walking, the reaction time of older adults with a history of falls was longer than that of those without falls; the cutoff value of the receiver operating characteristic (ROC) curve was 406 ms.[23,24] Therefore, P-RT can be used to assess the risk of falls.

Carrying a cup of water while walking is a motor task used in daily life. Conducting P-RT while carrying a cup of water can be used to explore the impact of cognitive tasks on falls while simulating daily walking. The motor and cognitive tasks serve as dual tasks, with a combination of walking and water-carrying as the motor tasks and P-RT as the cognitive task. Therefore, this study aimed to investigate the ability of the water-carrying walking P-RT to predict future fall risk in older adults in the community.

Materials and Methods

Subjects

The participants were 100 community residents aged 65 years and older who were recruited by posting recruitment posters and contacting community service centers. The two selected communities are both large communities in the Laishan District of Yantai, which include community service centers and senior centers. All the participants signed an informed consent form. All testing projects were conducted outdoors in the neighborhood to simulate daily walking activities in real daily living environments. All participants were tested separately and randomly assigned in sequence. Participants were recruited between October 2022 and February 2023. All participants provided prior written informed consent. None of them had participated in any relevant tests or dual-task training before this study.

Table 1 presents the subject characteristics. Before the study, all the participants were screened using a medical history questionnaire. The study complied with the ethical rules for human experimentation stated in the Declaration of

Table 1 Subject Characteristics[a]

	No-Fall Group (n = 78)	Fall Group (n = 22)	Overall (n = 100)	p
Age (y)	71.28±5.68	73.00±5.71	71.66±5.70	p>0.05
Height (cm)	163.15±6.65	160.86±9.07	162.65±7.24	p>0.05
Weight (kg)	67.12±9.51	66.11±11.60	66.9±9.95	p>0.05

Notes: Values are mean ± standard deviation. [a]Fall group = older people who had experienced at least one fall in the previous 12 months. No-fall group = older people with no history of falls. No significant differences between groups at 0.05 alpha level.

Helsinki, including the approval of the institutional review board. Written consent was obtained from the Ethics Review Committee of Binzhou Medical University. Ethics No: 2022-262.

The exclusion criteria were a history of cardiopulmonary, musculoskeletal, somatosensory, or neurological disorders or serious loss of visual and vestibular function. All participants lived independently in the community and complied with the following inclusion criteria: (1) could complete daily life independently, (2) walked with or without aid, (3) followed simple instructions, (4) held a cup, and (5) did not need help from others.

All participants completed a fall questionnaire survey to determine whether they had fallen within a year. According to the fall history questionnaire, the participants were divided into two groups: the fall group, who had fallen at least once in the past 12 months and filled in the questionnaire as "yes", and the no-fall group, who had never fallen before and filled in the questionnaire as "no". The questionnaire survey included the time, location, and injury status of the falls. Falls are defined as "a person's body accidentally stopping on the ground or another lower level, not owing to a major internal event or great danger".[25] The subjects filled in the fall questionnaire on the day of the test and were grouped. All assessments were performed in both groups by assessors blinded to the group allocation.

The calculation of sample size was carried out using G * Power 3.1.9.7 software. We adopted the method of "sample size estimation for comparison of two sample means by completely random design". The sample size of this study was calculated under the following conditions: $\alpha=0.05$, inspection efficiency $1-\beta=0.8$. Referring to the literature[26] and combined with the previous case analysis,[27] when the significance level was 0.05 on both sides and the confidence level was set to 80%, the effect was set to 0.8, and considering a 10% dropout rate, each group required 21 participants, with a minimum total sample size of 42. As the proportion of falls among older adults is 20–30%, the overall sample size was expected to be 100. The final fall group consisted of 22 participants and the no-fall group consisted of 78 participants.

Procedures

All participants underwent mobility and balance, processing speed, and dual-task tests performed separately. We conducted tests in the order of completing the questionnaire. The mobility and balance tests included: 1) The TUG test;[28] subjects were asked to sit on an armchair (the chair seat was approximately 45 cm high and the armrests were approximately 20 cm high) with their bodies on the back of the chair and their hands on the armrests. When the examiner gave the "start" command, the subject stood up from the armchair. After standing steadily, the subjects walked 3 m forward according to the usual walking gait, passed the marker, turned around, walked back to the chair, turned around, sat down, and leaned back on the chair. No physical help was provided during the test. 2) The 10-m walk timing test;[29] the time required for the subjects to walk for 10 m, marked at 2 m and 12 m to allow for acceleration and deceleration, was measured.

The processing speed test was assessed with the trail making test part-A (TMT-A).[30] The TMT-A is widely used in clinical medicine as a testing method for attention and executive dysfunction, such as brain function damage and cognitive impairment. By comparing the completion time of the test, we assessed the overall attention ability and whether the subjects had cognitive impairment. The TMT-A consists of 25 circles distributed over a sheet of paper. The circles were numbered 1–25, and the participants were asked to draw lines connecting the numbers in ascending order. Participants were instructed to connect the circles as quickly as possible without lifting the pen or pencil from the paper. The participant was allowed to correct errors if any were made during the test. The errors affected the participants` scores only in that the time for correcting errors was included in the completion time for the task. It was unnecessary to continue the test if the participants had not completed both parts after 5 min had elapsed.

The dual-task reaction time test consisted of a digital audio player and recorder. A sound stimulus document was compiled using the personal computer overtone opinion processing software DigionSound5 (Digion), which included 16 preparatory signals "sets" and the sound stimulus signal "Pi" (3000 Hz, 50 ms). The MP3 was connected to the recorder and the headset at the same time, and the prepared signal sets were played; the time difference between the sound stimulus signal "Pi" and the "Pa" answered by the subjects was recorded. In this study, the interval between the warning and stimulus signals was adjusted to between 2 and 3 s using an Excel random number table.

The reaction time tests included: 1) The quiet standing probe reaction time (QSP-RT). Using the above equipment, the subjects responded to the auditory prompts while standing in place by saying the word "Pa" loudly as soon as possible. The difference in reaction time was calculated. 2) The water-carrying standing probe reaction time (WCSP-RT). A quiet standing single reaction time test was conducted while carrying 50 mL of water, and the time difference in response to sound stimulation was recorded. 3) The water-carrying walking probe reaction time (WCWP-RT). Using the above equipment, the subjects were required to grasp a glass cup containing 50 mL of water on a table (70 cm high) and walk, with the liquid surface 5 cm away from the top edge of the cup. After the subjects walked with a glass of water for 1 min, the digital player was started, and the P-RT was evaluated at the maximum walking speed. The DigitSound5 sound processing software was used for data analysis. The WCWP-RT was measured as the interval between the auditory prompt and the "Pa" sound when walking with a glass of water.

Outcomes

All subjects performed each mobility and balance test three times. The average value of the tests was then calculated. The time required for all participants to complete the TMT-A was calculated. Each P-RT test was recorded ten consecutive times, and the total response time of each participant for the ten responses was calculated.

Data Analysis

The Kolmogorov–Smirnov test was used to test whether the data conformed to the normal distribution. Regarding the differences between the fall and no-fall groups, a non-parametric test was used for data conforming to the non-normal distribution, and an independent sample *T*-test was used for data conforming to the normal distribution. The Pearson's correlation coefficient was used to determine the correlation between each item. To determine the reliability of measurement values, the intraclass correlation coefficient (ICC) was calculated, and logistic regression analysis with falls as the status variable along with ROC curves were used to determine the relationship between falls and each factor. SPSS, version 19.0 (IBM, Armonk, NY, USA) was used for data processing and statistical analysis, and statistical significance was set at $p < 0.05$.

Results

Table 2 presents the differences between the test items for each group. The TMT-A time, TUG time, 10-m walking speed, and P-RT of the water-carrying walking test were significantly longer in the fall group than in the no-fall group ($p<0.05$). The QSP-RT and WCSP-RT scores did not differ significantly between the two groups.

Table 3 shows the correlations among the items. There was a strong correlation between WCWP-RT, QSP-RT, and WCSP-RT. Moderate correlations were found among the other items.

Table 2 Results of Mobility and Balance, Processing Speed, and Reaction Time in the Fall Group and No-Fall Group

		No-Fall Group (n = 78)	Fall Group (n = 22)
Mobility and balance	Timed up and go test (s)	7.81±1.15	10.01±1.71**
	10 m walking velocity (m/min)	84.95±12.51	69.48±8.45**
Processing speed	Trail making test part- A (s)	52.23±18.43	75.86±21.88**
Reaction Time (ms)	Quiet standing probe reaction time (ms)	290.11±92.78	363.07±123.96
	Water-carrying standing probe reaction time (ms)	303.09±93.37	390.64±117.40
	Water-carrying walking probe reaction time (ms)	360.84±99.01	563.92±289.31**

Notes: Values are mean ± standard deviation. **p<0.01.

Table 3 Pearson Correlation Coefficients Between Measures[a]

	QSP-RT (ms)	WCSP-RT (ms)	WCWP-RT (ms)	TMT-A	TUG	Walking Velocity
QSP-RT (ms)	1.00					
WCSP-RT (ms)	0.86**	1.00				
WCWP-RT (ms)	0.60**	0.70**	1.00			
TMT-A	0.09	0.10	0.12	1.00		
TUG	0.23*	0.28**	0.28**	0.24**	1.00	
Walking velocity	−0.22*	−0.29**	−0.30**	−0.14	−0.64**	1.00

Notes: *p<0.05. **p<0.01.
Abbreviations: [a]QSP-RT, Quiet standing probe reaction time; WCSP-RT, Water carrying standing probe reaction time; WCWP-RT, Water carrying walking probe reaction time; TMT-A, Trail Making Test Part-A; TUG, Time "Up and Go" Test; Walking velocity, 10 m walking velocity.

As shown in Table 4, the ICC value of the WCWP-RT was 0.98, indicating high test–retest reliability, which was higher than the ICC values of the QSP-RT and WCSP-RT.

Table 5 shows the logistic regression analysis, taking falls as the dependent variable for the WCWP-RT and TMT-A. To prevent multicollinearity, we determined only two related factors: WCWP-RT and TMT-A. Using the statistical results of the Hosmer and Lemeshow test, χ^2=6.62 (p=0.579). The odds ratio (OR) was obtained, and only WCWP-RT was a significant independent factor for the risk of falls.

Using falls as a state variable, we calculated the area under the ROC curve (AUC) of the P-RT (AUC = 83%) (Figure 1). The cutoff value of the ROC curve was 454 ms, the sensitivity was 68%, and the specificity was 85%.

Discussion

This study aimed to investigate the ability of the PR-T, based on dual tasks, to predict the future fall risk of older adults in the community. The results indicated a significant relationship between the QSP-RT, WCSP-RT, WCWP-RT, TUG, and 10m walking speed. Therefore, physical and cognitive abilities can be reliably measured. The QSP-RT, WCSP-RT, WCWP-RT, TMT-A, and TUG times of the fall group were longer than those of the non-fall group, and their walking speed was slower at 10 m. Therefore, older people at risk for falls showed lower physical ability and poorer cognitive function.

Falls usually occur while walking, which requires attention and is a movement that must be coordinated by integrating information from multiple senses. Participants with inconsistent sensory integration over a long walk move more slowly.[31,32] Changes in physical performance during dual tasks can be attributed to competition between the attention required to complete both tasks.[33] Older adults must pay more attention to walking than younger adults because

Table 4 Measurement and ICC (1, 2) of Two Measurements

	First Measurement	Second Measurement	ICC (1, 2)
QSP-RT (ms)	306.16±103.77	304.44±101.66	0.97**
WCSP-RT (ms)	322.35±104.51	329.82±105.00	0.97**
WCWP-RT (ms)	405.52±179.45	406.81±179.08	0.98**

Note: **p<0.01.

Table 5 Results of Logistic Regression Analysis with Falls as the Dependent Variable

ITEM	Odds Ratio	95% CI	p
Water-carrying walking probe reaction time	1.014	1.007–1.022	0.000
Trail making test part- A	1.020	0.994–1.047	0.130
The Hosmer- Lemeshow Test	χ^2 = 6.68		p = 0.572

Note: Stepwise Way.
Abbreviation: CI, Confidence Interval.

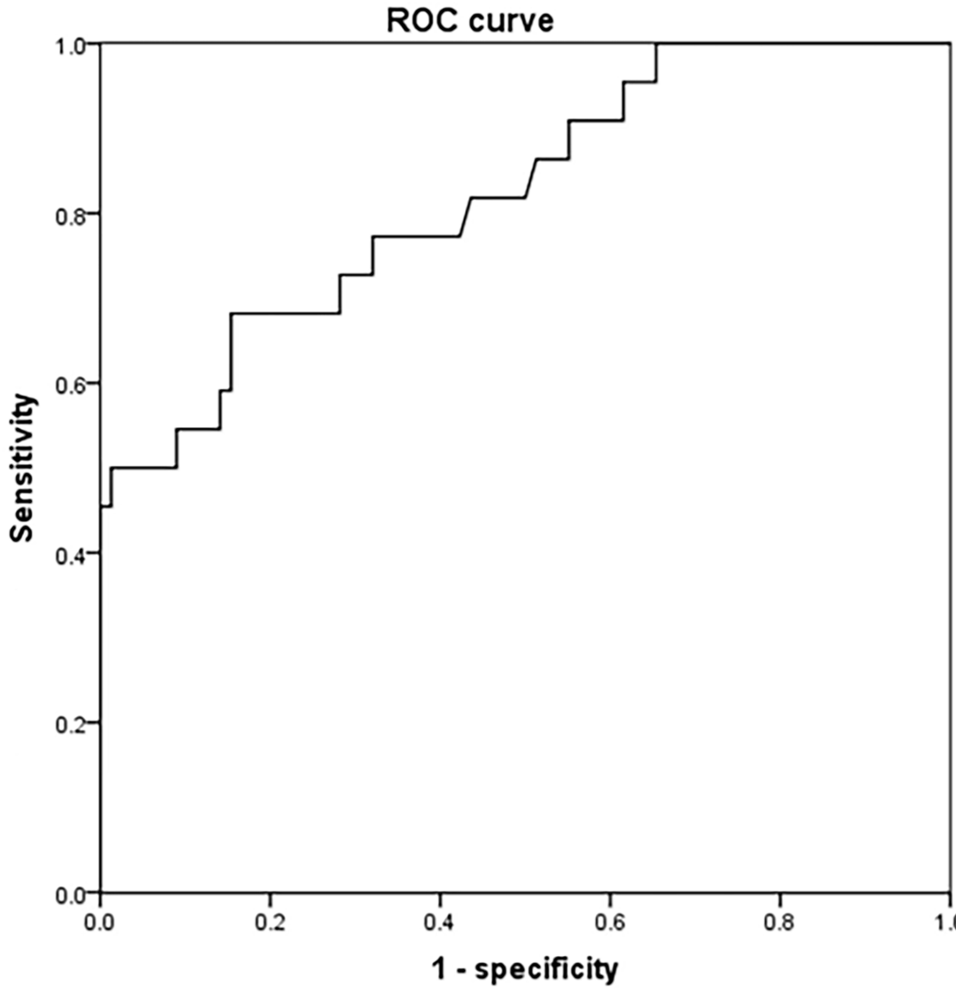

Figure 1 The Receiver-Operating-Characteristic (ROC) curve of the probe reaction time.

their cognitive and motor functions gradually decrease with age. The P-RT during walking was measured in this study, and the results of the fall group showed that their reaction time was slower than that of the no-fall group. The longer P-RT is attributed to the increased attentional demand for walking, which affects the degree of distracted attention in the brain. Distracted attention plays an important role in walking while multitasking and changing conditions, and the assessment of fall risk is clinically significant.[1] Some studies have shown that dual-task execution slows the gait. Although changes in gait were not included in the present results, the extension of the response time indicates that older adults pay more attention to maintaining gait stability, which increases the response time.

In dual tasks, carrying water while walking is a motor task that must be completed, whereas listening to sound stimulation and responding are conscious cognitive tasks in which the brain participates in thinking. During walking, the attention of older people is expected to increase significantly to prevent falls. To complete the two tasks, patients need to readjust their attentional resources and allocate part of the attentional resources originally used for cognitive tasks to the walking task, resulting in less effective attentional resources being allocated to cognitive tasks, further affecting their reaction ability, and prolonging their reaction time. The dual-task is not only an assessment of the risk of falls, but also an effective intervention to reduce the risk of falls in older adults. Norouzi et al[34] conducted a dual-task training test on older individuals, and the results showed that dual-task intervention could improve balance function. Park et al[35] and Philom et al[36] also showed that compared to single-task training, dual-task training can effectively reduce the risk of falls and improve cognitive function in older people in the community. Furthermore, Santos et al[37] proposed that dual tasks can improve both walking and cognitive abilities in older individuals. Exercise ability plays an important role in walking and daily life; therefore, compared with previous studies, the addition of motor tasks can better assess the risk of falls. Therefore, WCWP-RT, as a fast and convenient assessment method, can effectively predict the risk of falls in older people in the community. In future research, this method is expected to be an intervention measure for hospitals, communities, and nursing homes. This evaluation method can be transformed into an intervention measure to improve the ability of older adults to handle dual tasks, improve exercise ability by increasing motor tasks, prevent cognitive decline, and reduce the occurrence of falls in older adults through dual-task training. This study provides meaningful clinical information for the care and rehabilitation of older adults.

Although we did our best to collect data as precisely as possible, this study has several limitations. First, there was a certain subjectivity in the measurement of response time, which required researchers to independently choose the time difference between the stimulus sound and the subject's response, resulting in a certain deviation in time. Second, individual differences and environmental factors may have resulted in deviations in the TMT-A test results. Some subjects' vision declines with age but does not reach the level of visual impairment, and poor light may also have affected the results of the TMT-A. All these factors lead to the conclusion that TMT-A was not correlated with reaction time. Third, because the reaction time was measured in a public place, the subject's attention was affected by objective factors. However, from a practical perspective, we chose to test this in public places. Assessing the risk of falls using data obtained in a real state indicates that the more realistic the environment, the better the ability of older adults to handle dual tasks in their daily lives. The resulting data and conclusions were closer to real-life situations. Fourth, the gait changes during walking were not assessed.

Conclusion

In summary, changes in walking ability and cognitive function during dual-task conditions are associated with the future fall risk under environmental factors, and this association is stronger than that observed under single-task conditions. The WCWP-RT can identify the risk of falls in older people based on their physical function and the effect of environmental factors on walking ability. Therefore, it is recommended that the P-RT-based dual-task be used as a predictive indicator of future falls in the older population.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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