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Falls in older adults: Prevention and risk evaluation

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Tzvi Dwolatzky

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Falls in older adults: Prevention and risk evaluation

Topic editor

Tzvi Dwolatzky — Technion Israel Institute of Technology, Israel

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A Postural Assessment Utilizing Machine Learning Prospectively Identifies Older Adults at a High Risk of Falling

*Katharine E. Forth[1], Kelly L. Wirfel[2], Sasha D. Adams[3], Nahid J. Rianon[4,5], Erez Lieberman Aiden[1] and Stefan I. Madansingh[1]**

[1] Zibrio, Inc. Houston, TX, United States, [2] Department of Internal Medicine, Division of Diabetes, Endocrinology and Metabolism, McGovern Medical School, University of Texas Health Science Center at Houston, Houston, TX, United States, [3] Department of Surgery, McGovern Medical School, University of Texas Health Science Center at Houston, Houston, TX, United States, [4] Department of Family and Community Medicine, McGovern Medical School, University of Texas Health Science Center at Houston, Houston, TX, United States, [5] Department of Internal Medicine, Division of Geriatric and Palliative Medicine, McGovern Medical School, University of Texas Health Science Center at Houston, Houston, TX, United States

Introduction: Falls are the leading cause of accidental death in older adults. Each year, 28.7% of US adults over 65 years experience a fall resulting in over 300,000 hip fractures and $50 billion in medical costs. Annual fall risk assessments have become part of the standard care plan for older adults. However, the effectiveness of these assessments in identifying at-risk individuals remains limited. This study characterizes the performance of a commercially available, automated method, for assessing fall risk using machine learning.

Methods: Participants (N = 209) were recruited from eight senior living facilities and from adults living in the community (five local community centers in Houston, TX) to participate in a 12-month retrospective and a 12-month prospective cohort study. Upon enrollment, each participant stood for 60 s, with eyes open, on a commercial balance measurement platform which uses force-plate technology to capture center-of-pressure (60 Hz frequency). Linear and non-linear components of the center-of-pressure were analyzed using a machine-learning algorithm resulting in a postural stability (PS) score (range 1–10). A higher PS score indicated greater stability. Participants were contacted monthly for a year to track fall events and determine fall circumstances. Reliability among repeated trials, past and future fall prediction, as well as survival analyses, were assessed.

Results: Measurement reliability was found to be high (ICC(2,1) [95% CI]=0.78 [0.76–0.81]). Individuals in the high-risk range (1-3) were three times more likely to fall within a year than those in low-risk (7–10). They were also an order of magnitude more likely (12/104 vs. 1/105) to suffer a spontaneous fall i.e., a fall where no cause was self-reported. Survival analyses suggests a fall event within 9 months (median) for high risk individuals.

Conclusions: We demonstrate that an easy-to-use, automated method for assessing fall risk can reliably predict falls a year in advance. Objective identification of at-risk patients will aid clinicians in providing individualized fall prevention care.

Keywords: balance, stability, postural stability, fall risk, aging, fall prediction, machine learning

Edited by:
Tzvi Dwolatzky, Technion Israel Institute of Technology, Israel

Reviewed by:
Juan José Solano-Jaurrieta, Servicio de Salud del Principado de Asturias (SESPA), Spain
Liang-Yu Chen, Taipei Veterans General Hospital, Taiwan

****Correspondence:***
Stefan I. Madansingh
stefan@zibrio.com

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INTRODUCTION

Falls are the leading cause of trauma death and trauma admissions (1) in large hospital systems across the US, and the leading cause of accidental death in older adults (2). Each year, 28.7% of older adults fall in the US (3), which results in ∼300,000 hip fractures, and over $50 billion dollars in medical costs (4). Yet, despite the dramatic impact falls have on health, fall risk assessments and management were infrequently utilized in primary care (5) until 2011 when the Centers for Medicare & Medicaid Services required fall risk assessments for all Medicare annual exams (6). Despite this requirement, there is no clear gold standard in clinical assessments for fall risk (7).

The challenge for creating a gold standard fall risk assessment is the many contributing risk factors, including cognitive impairment, balance and gait abnormalities, disabilities of the lower limbs, foot problems (8), vision impairment (9), fall history (10), and fear of falling (11). Of these risk factors, fall history is considered the best predictor of falls (10) and forms the basis for the recommended clinical practice guidelines for fall prevention (12). Unfortunately, less than half of patients will actually report falls to their physicians (13). One approach to improving fall risk assessment is to quantify an individual's intrinsic stability control mechanisms using posturography.

Posturography characterizes the sway of an individual's center-of-mass (COM) over time using measures of position, velocity, acceleration and jerk. To date, the resulting measurements have been shown to have modest fall prediction capabilities (14–18), although these have been limited by the difficulties associated with tracking falls in an aging population, resulting in limitations on sample sizes and on the length and quality of follow-up. Other limitations to date include: choices about which fall types are studied [e.g., multiple falls (18), indoor falls (14)], use of complex protocols, use of expensive equipment, and requirements of testing under multiple conditions (18). Characterizing COM as a system which dynamically shifts through non-linear stability states of equilibria may provide deeper insight into balance control and yield greater predictive capability as it will reveal intrinsic postural control failures (19, 20).

In this study, we assessed the validity and reliability of an eyes open, 60 s standing balance test, performed on a commercially available balance platform that automatically calculated a postural stability (PS) score using linear and non-linear stability states, as an indication of fall risk for older adults. Prospective fall risk data were collected in a large, heterogeneous population of older adults to assess overall predictive fall risk performance.

METHODS

Participant Recruitment

In order to assess the accuracy of fall risk assessments based on a PS score, we recruited 209 community dwelling adults to participate in a yearlong prospective study. These individuals were drawn from eight different independent senior living facilities (tested on site) and five local community centers (tested at the Texas Medical Center Innovation Institute). This prospective cohort was part of a larger clinical trial wherein a total of 412 adults were enrolled. The remaining 203 participants were recruited from physical therapy clinics, geriatric medicine outpatient clinics and a hospital rehabilitation ward in the greater Houston area participated in a cross-sectional study only and were not tracked longitudinally. Individuals who were unable to stand for 60 seconds unassisted, those who self-reported severe vestibular problems (e.g., Meniere's disease) or musculoskeletal issues related to balance control, and those who self-reported a history of dementia and were considered unable to provide accurate fall history due to cognitive deficits were also considered exclusion criteria. Only one person was excluded in the study. The experimental protocol was approved by the Westerns IRB (#20171926 and #20172324), and the University of Texas Health Science IRB HSC-MS-16-0019), and informed consent was obtained prior to testing.

Data Collection

Upon enrollment, participants were instructed to stand still for 60 s, silently, with their arms to their sides, their feet comfortably shoulder-width apart and their eyes looking forward, on a commercially available SmartScale (Zibrio, Houston, TX, USA), see **Figure 1**. Participants were asked to wear their standard footwear during testing. This low-cost force plate was validated to accurately measure center-of-pressure (COP) over time with a frequency of 60 Hz (21). Using the collected COP data, linear quantifications of postural sway, including: path length, velocity, acceleration and jerk, in both anterior-posterior and medial-lateral directions, as well as non-linear measures of postural stability characterized using a Hidden Markov Model (19, 20) were utilized as factors (22) to calculate the PS score. The PS score is scored ranging from 1 to 10, where larger scores indicate higher stability. The parameters of the Hidden Markov Model were determined using COP data previously on a laboratory-grade force plate and no algorithmic refinement occurred during this study. No PS scores or balance feedback were provided to the participants. The above trial was immediately repeated. If technical and timing constraints did not interfere, a third test was also performed (in 322 cases). This allowed us to examine PS score reproducibility and participants were offered the opportunity to sit and rest between trials.

During an accompanying interview, participants reported age, medical condition status, and asked if they had experienced a fall in the past 6 months, a near fall in the past 6 months, a fall in the past 12 months, and a near fall in the past 12 months. These four ordered questions focused attention on a shorter time period first to optimize recall accuracy, while still extracting valuable longer period information (23). A fall event was counted if the participant confirmed that they had "unintentionally reached the ground or a lower level" (8), unless the event was due to self-reported orthostatic intolerance or syncope. Only one fall event from the initial interview was excluded, due to self-reported fainting.

For participants in the prospective study, monthly follow-up was performed via telephone, e-mail, or text-message for a year after initial testing, in order to document any changes in

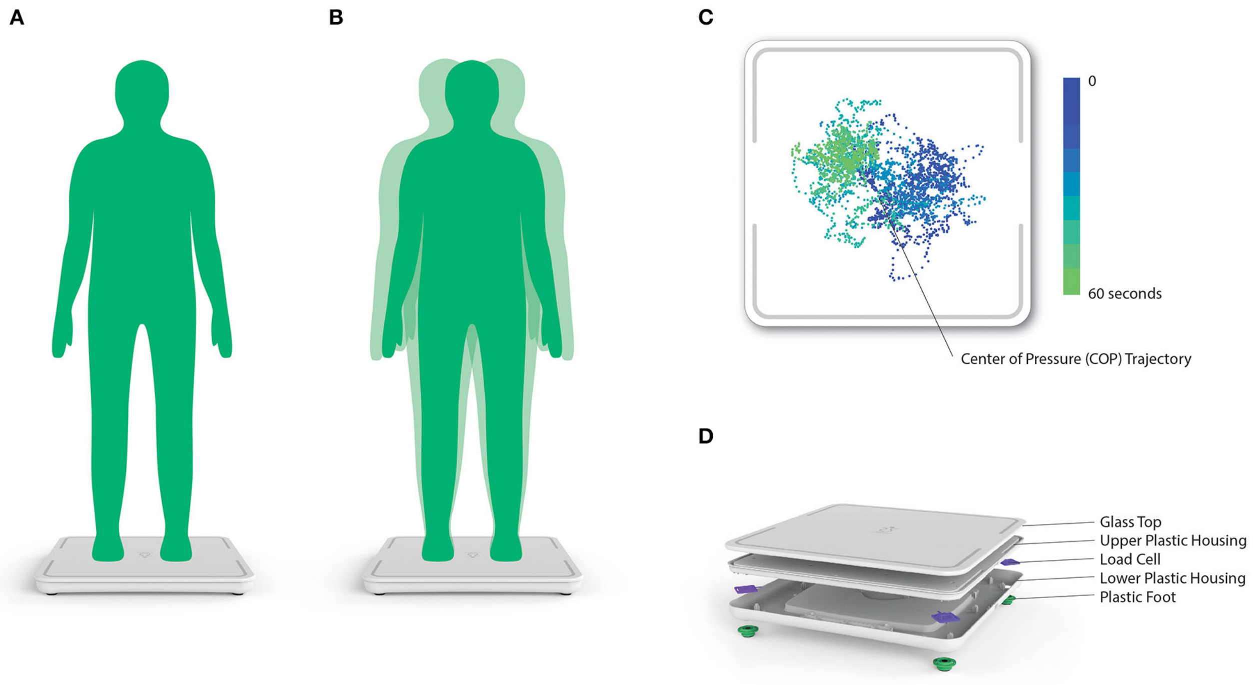

FIGURE 1 | (A,B) Postural stability (PS) score testing setup, procedure and instructions. **(C)** Representative 2D center-of-pressure (COP) trace collected from the Zibrio SmartScale. The color gradient denotes the change in the COP trace over time throughout the 60 second standing balance test. **(D)** A 3D rendering of the components and assembly of the Zibrio SmartScale.

medical state and to collect reliable self-reports of fall or near-fall events (24). Participants were asked if they had experienced a fall in past month (or time since last communication), and then, if they had experienced a near fall in the past month (or time since last communication). Falls were classified as: (1) a slip or trip; (2) associated with a recent change in medical status (e.g., new medication, or a recent surgical procedure); (3) associated with a challenging movement or environment, i.e., "hiking while looking at a bird's nest"; or (4) a spontaneous fall, where no mitigating explanation could be provided. See **Supplementary Table 1** for examples.

Follow-up efforts were uniform for all participants and continued throughout the 12-month period after enrollment. Occasionally an individual could not be reached, however, contact was attempted again the following month. Thirty individuals were considered lost-to-follow-up when contact could not be made after 3 months or the subject opted to withdraw from the study; in these censored cases the total enrolled duration will be <12 months (25). The PS score of participants lost-to-follow-up were distributed across PS scores 1–6, see **Supplementary Table 2**.

Data Analyses

Postural Stability (PS) Score Test-Retest Reliability

We examined PS scores collected from all enrolled subjects ($n = 412$), including the 3-test series for 322 patients and the test pairs from 90 participants. Bivariate density plots were generated to highlight within-subject agreement across different trials and Pearson's correlations were calculated for these comparisons. We also calculated a single-measurement, absolute-agreement, 2-way random effects intra-class correlation [ICC(2,1)] (26) which included participants who completed at least two measurements ($n = 380$). Analyses of reliability were performed in R(v.3.6.1) (27).

Retrospective Fall Risk Analyses

We plotted cumulative PS score frequency distributions for subjects who reported falling in the 12 months prior to enrollment, as well as subjects who did not report falling in the 12 months prior to enrollment to explore the difference in PS score distributions between past-fallers and non-fallers. To further assess the relationship between PS score and fall history, we generated receiver-operating characteristic (ROC) curves and calculated the area under the curve (AUC). The slope of the retrospective ROC curve was observed to inform categorization of the PS scores into "high," "moderate," and "low" risk categories based on estimated likelihood ratios (LR) (28). Chi-squared analyses were performed to test for differences between "fallers" and "non-fallers" among each risk categorization.

Prospective Fall Risk Analyses

We plotted cumulative PS score frequency distributions for patients who fell during the 12-month follow-up period, as well as patients who did not fall during the 12-month follow-up period to explore the difference PS score distribution between prospective fallers and non-fallers. We also generated receiver-operating characteristic (ROC) curves and calculated the area under the curve (AUC). Chi-squared tests comparing PS scores for the three defined PS score risk categorizations were performed.

After subdividing the participants into three fall risk categories, fall-free survival analysis was performed using Log Rank and Cox proportional-hazard regression tests, including censored cases. Finally, the proportion of each fall cause, based on self-report during monthly follow-up, was calculated for each PS score risk category. Chi-squared analyses were performed to test for differences between risk categories.

RESULTS

Participant Demographics

The community recruited participants enrolled in the study were typically younger, used fewer assistive devices and pharmaceuticals, and were less likely to have a positive fall history in the 12 months prior to enrollment relative to participants from independent senior living facilities, see **Table 1**. Participant demographics for the larger clinical trial cohort can be found in **Supplementary Table 3**.

Reliability of the Postural Stability (PS) Score

High correlations were observed among Trials 1-2 (r[95% CI] = 0.78 [0.74–0.82], $p < 0.01$), Trials 1-3 (r[95% CI] = 0.75 [0.70–0.79], $p < 0.01$) and Trials 2-3 (r[95% CI] = 0.82 [0.78–0.86], $p < 0.01$) implying good reliability among repeated measures. Bivariate density plots, highlighting the density and distribution of agreement between trials, are demonstrated in **Figure 2**. In general, the data exhibited a high level of test-retest reliability (ICC(2,1)[95% CI] = 0.78 [0.76–0.81]) (26) among the repeated measures taken at enrollment ($n = 380$).

Retrospective Fall Risk Assessment

Individuals with a history of falling exhibited systematically lower PS scores than those without a history of falling, see **Figure 3A**. PS scores of 1-3 had LRs (LR 3.3 to 1.7) to experience a past fall twice that of PS scores 4-6 (LR 0.7 to 0.5). LR halved again after PS scores of 7-10 (LR 0.3 to 0.0) which served to define the "high risk," "medium risk," and "low risk" categories, respectively. Individuals who were identified as "high risk" (PS score: 1-3) were significantly more likely to have experienced a fall in the past 12 months than those identified as either "low risk" ($\chi^2 = 15.11$, $p < 0.01$) or "moderate risk" ($\chi^2 = 13.56$, $p < 0.01$). Individuals identified as "moderate risk" were not found to be more likely to have experienced a fall in the past 12 months when compared with those identified as "low risk" ($\chi^2 = 1.51$). Classification as "high risk" by the PS score identified those with a positive fall history with 73.6% sensitivity, 62.8% specificity, see **Figure 3C**. The area under the ROC curve was 0.66.

Prospective Fall Risk Assessment

Similar to the retrospective data, individuals who fell during the 12-month follow-up period exhibited systematically lower PS scores upon initial enrollment than those that did not fall, see **Figure 3B**. Individuals who were identified as "high risk" (PS score: 1-3) upon initial enrollment were 3.0 [1.4–6.3] (95% CI, $p < 0.01$) times more likely to fall during the 12-month follow-up period than those who identified as "low risk" (PS score: 7-10) ($\chi^2 = 5.75, p < 0.01$), and 2.2 [1.3–3.7] ($p < 0.01$) times more likely to fall than those identified as "moderate risk" ($\chi^2 = 4.12, p < 0.01$). Classification of "high risk" predicted that an individual would fall during the 12-month follow-up period with 64.2% sensitivity and 59.8% specificity. Area under the ROC curve was 0.64, see

TABLE 1 | Participant demographics for community dwellers included in the retrospective and prospective fall risk study.

		All community dwellers (% Total)	Community recruited (% CR)	Independent senior living residents (% iSLF)
Total participants		**209**	**99**	**110**
Sex	Male	58 (27.8%)	37 (37.4%)	21 (19.1%)
	Female	151 (72.3%)	62 (62.6%)	89 (80.9%)
Age (years)		77.6 ± 0.8	67.8 ± 0.8	86.2 ± 0.6
BMI		25.49 ± 5.2	25.7 ± 5.1	25.3 ± 5.2
Assistive devices	None	169	96 (97.0%)	73 (66.4%)
	Walker	31 (14.8%)	1 (1%)	30 (27.3%)
	Cane	9 (4.3%)	2 (2%)	7 (6.4%)
4+ Medications	No	129 (61.7%)	80 (80.8%)	49 (44.5%)
	Yes	80 (38.3%)	19 (19.2%)	61 (55.5%)
Retrospective fallers	Non-fallers	136 (65.1%)	81 (81.8%)	55 (50%)
	Fallers	73 (34.9%)	18 (18.1%)	55 (50%)
Duration of follow-up		330 ± 5.2 days	303 ± 8.7 days	360 ± 3.4 days
Prospective fallers	Non-fallers	127 (61.2%)	65 (65.7%)	63 (57.3%)
	Fallers	81 (38.8%)	34 (34.3%)	47 (42.7%)
	New fallers	44 of 81	25 of 34	19 of 47
Postural Stability (PS) score		4.0 ± 0.14	5.1 ± 0.19	3.1 ± 0.17

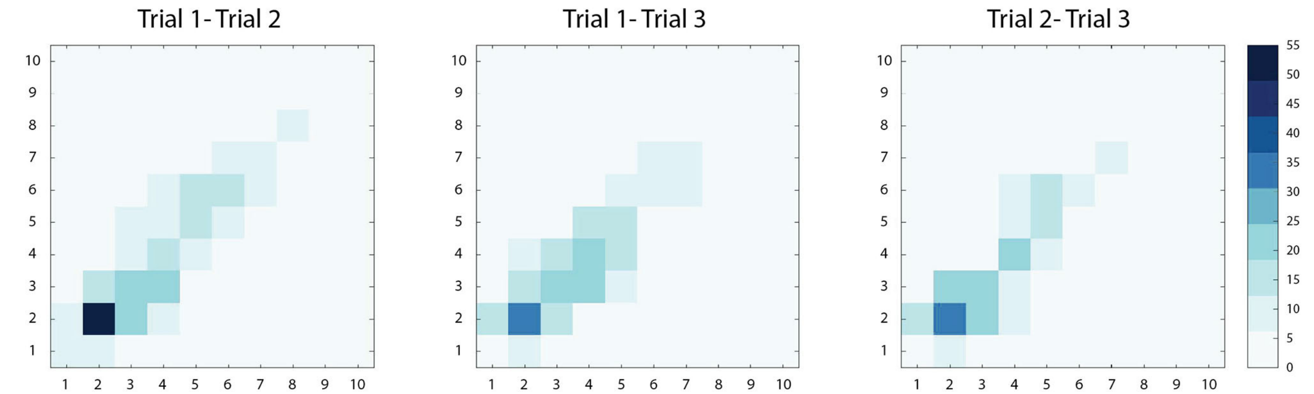

FIGURE 2 | Bivariate density plots demonstrating within-subject agreement between two PS score measurements (scored 1–10). Increased agreement between two measures is demonstrated with increasing color intensity. Among the three comparisons, Trial 1-2, Trial 1-3, and Trial 2-3, the majority of paired observations lie along the diagonal, suggesting strong agreement. Across the diagonal, the greatest intensity is observed in the lower scores (PS score<5), where the majority of scores were observed in this study.

Figure 3D. Survival analysis revealed that the median time before an individual identified as "high risk" experienced a fall was 9.2 months, see **Figure 3E**. Individuals identified as "moderate risk" (PS score: 4–6) were not found to be more likely to fall during the follow-up period when compared with those identified as "low risk" ($\chi^2 = 0.59$).

Strikingly, we observed a significant difference not only in the rate of falls among "high risk" individuals, but also in the kind of falls they suffered, see **Figure 4A**. Individuals classified as "high risk" were also an order-of-magnitude more likely (12 of 104 (11.5%) vs. 1 in 105 (1.0%), ~10× more likely) to suffer a spontaneous fall (i.e., one where no mitigating cause was identified, suggesting neither the environment nor changes in medical condition/medications were contributing factors).

By contrast, both individuals with (FH+) and without (FH-) a history of prior falls exhibited the same rate of spontaneous falling, see **Figure 4B**, suggesting fall history status provided no discrimination. Detailed results can be found in the **Supplementary Table 4**. In general, "low risk" fallers were most likely to fall due to trips/slips (72%), and "moderate risk" fallers were the most vulnerable to a fall while navigating a challenging environment (29%).

Age Based Percentiles

We examined the relationship between age and PS scores within the sampled population, see **Figure 5**. Age bins were included if >10 participants were represented, resulting in a range of 50–95 yrs. Some individuals elected to not share age upon enrollment ($n = 16$), therefore the percentiles represent $n = 396$ of the enrolled individuals. Across all participants aged >50, the mean PS score declined with age across all percentiles, dropping ~1 point per decade. The 25th percentile crosses into the "high risk" category in the 60th decade, and the 50th percentile crosses into the "high risk" category in the 80th decade. The upper 25th percentile in the 90th decade ($n = 36$) exhibits a deviation from the deteriorating trend.

DISCUSSION

The study suggests that the postural stability (PS) score, generated with a machine learning method from a simple 60 sec., eyes-open, standing balance test is a reliable and valid method for identifying fall risk in aging adults, and predicts falls up to 12 months. Throughout the 12 months following enrollment, individuals categorized as "high risk" (PS score: 1–3) were 3.0 times more likely to fall than "low risk" individuals (PS score: 7–10) and 2.2 times more likely to fall than "moderate risk" individuals (PS score: 4–6). The predictive capability of the PS score is better than commonly used clinical tools as the prospective sensitivity for identifying a future "faller" from a "high risk" categorization is 64%, compared with 46% for fall history in this study, and 31% for TUG (29) and 15% for STEADI (30) from the literature. However, one third of fallers are not identified by PS score high risk categorization, and this suggests there is further opportunity for prediction improvement.

The PS score was especially strong at predicting spontaneous falls. Individuals identified as "high risk" (PS score: 1–3) had a 10× higher chance of experiencing a spontaneous fall. In this population, 92.3% of spontaneous fallers were identified as "high risk." This dramatic effect indicates the use of the PS score could be an effective way to stratify individuals at risk of a fall for fall prevention counseling, insofar as the types of falls suffered by each group differ from one another. It is interesting, in this respect, to contrast PS scores with fall history, which is also known to be an indicator of future fall risk. Nevertheless, fall history did not predict whether an individual would have a spontaneous fall—there was no significant difference in the rate of spontaneous falling among those who did or did not have a history of falls. Taken together, our data is consistent with a model where spontaneous falls reflect intrinsic losses of stability, rather than falls caused by exogenous influences such as medication or the particular environment. If so, the advantage of a fall risk test that is sensitive to spontaneous falls is the capacity to identify patients with intrinsic balance instability issues that ought to

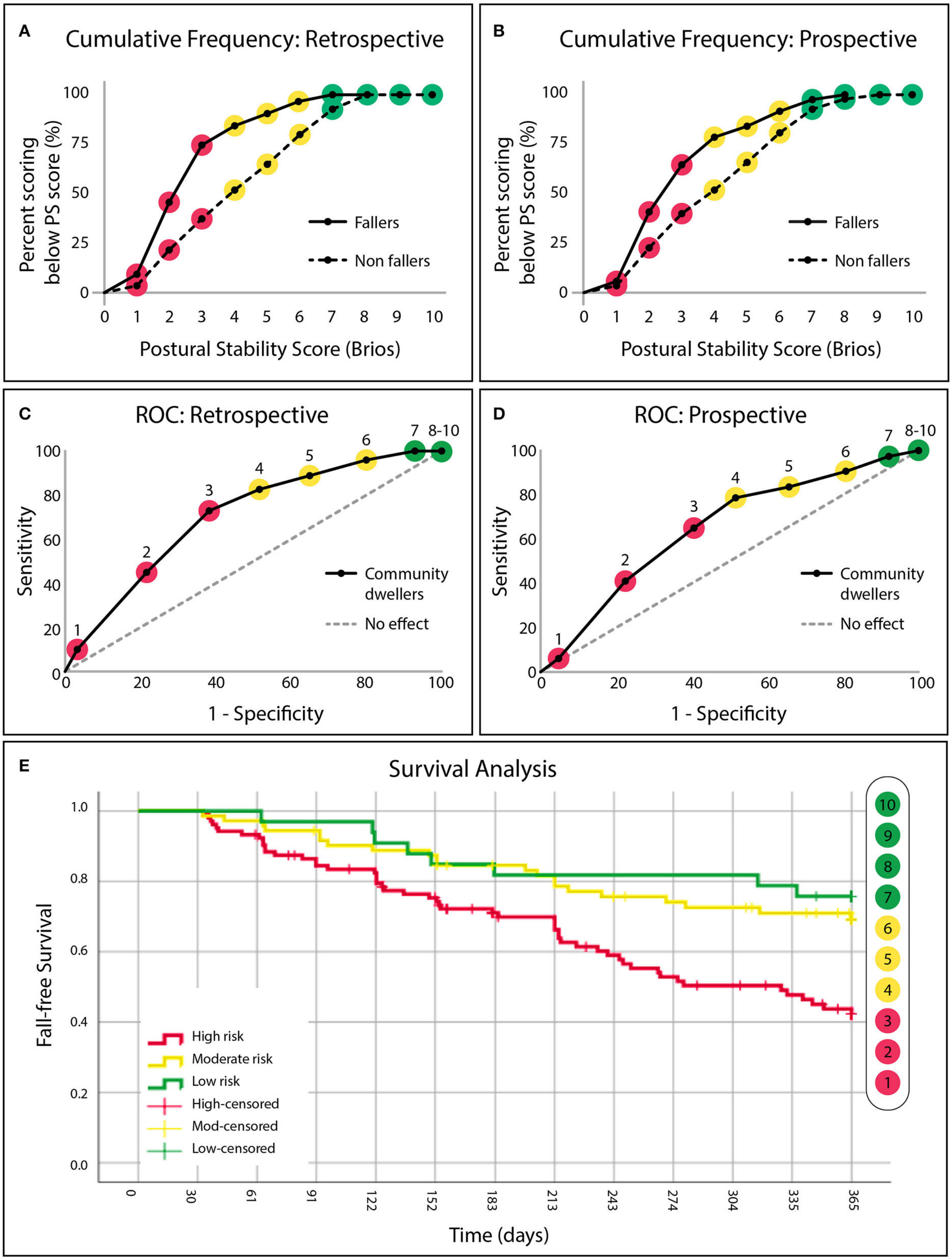

FIGURE 3 | (A) The cumulative frequency distributions of the postural stability (PS) score for "fallers" and "non-fallers" identified from retrospective fall history and **(B)** prospective fall data. **(C)** Fall risk categories defined by receiver operating characteristic curves demonstrating the sensitivity and specificity of the PS score to identify community dwellers (independent senior-living residents or community recruited individuals) with a retrospective fall history. "High risk" (red, PS score: 1–3), "moderate risk" (yellow, PS score: 4–6), and "low risk" (green, PS score: 7–10) categories are defined by a change in slope. **(D)** Retrospectively defined risk categories applied to future falls observed in the same population after 12 months of longitudinal follow-up. **(E)** Cumulative survival curves denoting avoidance of a fall for all three risk categories ("'high" in red, "moderate" in yellow and "low" in green), across 365 days (12 months).

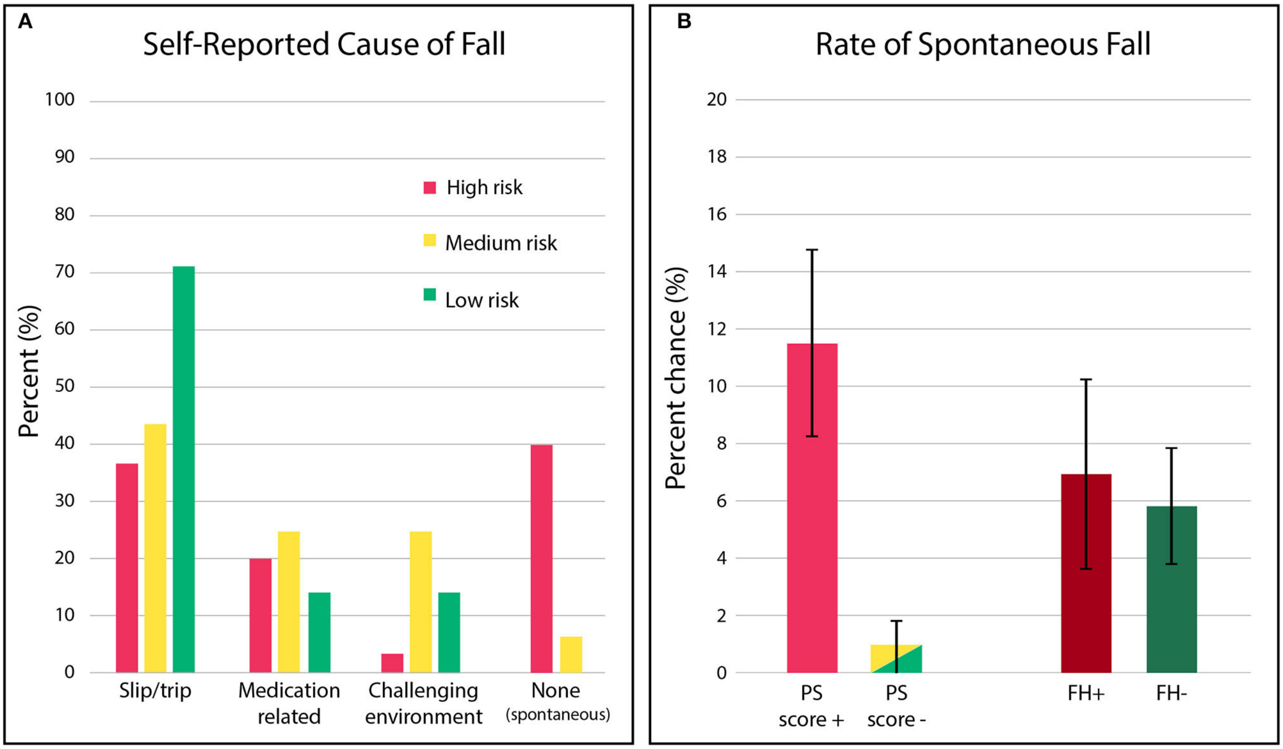

FIGURE 4 | (A) Distribution of the fall causes observed in the prospective cohort, stratified by PS score risk categories. Red denotes "high risk," yellow denotes "moderate risk," and green denotes "low risk". **(B)** The percent chance that individuals identified as "high risk," based on postural stability (PS) score or fall risk (PS score+: 1-3 or FH+: history of falling), will experience a spontaneous fall (i.e., fall event where no mitigating cause was specifically reported) relative to individuals identified as "low" / "moderate risk" (PS score-: 4–10 or FH-: no history of a fall).

be addressed clinically. Consequently, this test may facilitate precision fall prevention care for those whose underlying issues might otherwise go unnoticed.

We attribute the predictive advantages of the PS score to its ability to detect dynamic patterns of stability and instability (i.e., control failures) and reflect the capability of an individual's postural control system to minimize periods of instability. These measures are beyond the typical linear assessments of posturography and leverage new insights from machine learning and control systems theory (19, 20). As time-varying COP is readily available from any laboratory-grade force plate (21), this implementation of machine learning, which combines linear factors with the detection of primary control failures, can be applied to multiple populations at risk of postural control failure. This, in turn, enables risk to be determined before a fall history has been established and before deficits in functional performance are observed.

Although the classic Romberg standing balance test, utilizing both eyes-open and eyes-closed conditions is clinically used to seek out gross postural control deficits (31, 32), the sensitivity of the machine learning approach utilized in the present study makes the fall risk of eyes-closed standing balance unnecessary in at-risk populations. The same benefit vs. risk trade-off applies to other balance challenge tests such as the Clinical Test of Sensory Integration for Balance (CTSIB) which utilizes an unstable standing surface and requires an operator (33). By focusing on an innocuous condition of standing balance, this test is able to reduce operator burden and increase user safety, making it more accessible for fall risk management.

In general, the PS score was observed to decline with age, suggesting reduced postural stability control and increased fall risk with age. These data are in line with the U.S. national statistics that 1 in 4 over 65 years and 1 in 2 over 80 fall every year (2, 3). The corresponding 25th and 50th percentiles enter the PS score "high risk" categories at similar ages. In the ninetieth decade of age, there is a small upward trend in PS scores. This could be the result of those with poor balancing dying before reaching the ninetieth decade. Identifying a patient's PS score percentile in their age cohort can help patients to understand that a range of PS scores and fall risk exist at every age, and therefore, change is possible and improvements are attainable. The PS score percentile graph also illustrates the patient's fall risk trajectory. This means patient counseling can include future fall risk trajectories beyond the 12-month prediction window of their current fall risk categorization.

A common challenge for patient fall prevention counseling is patient denial or under-estimation of their own fall risk (34, 35), especially as a patient's own perception does not predict a fall (36). Thus, a simple, safe, objective, 60 sec. test with an easy to understand score, in the context of the patient's age cohort which

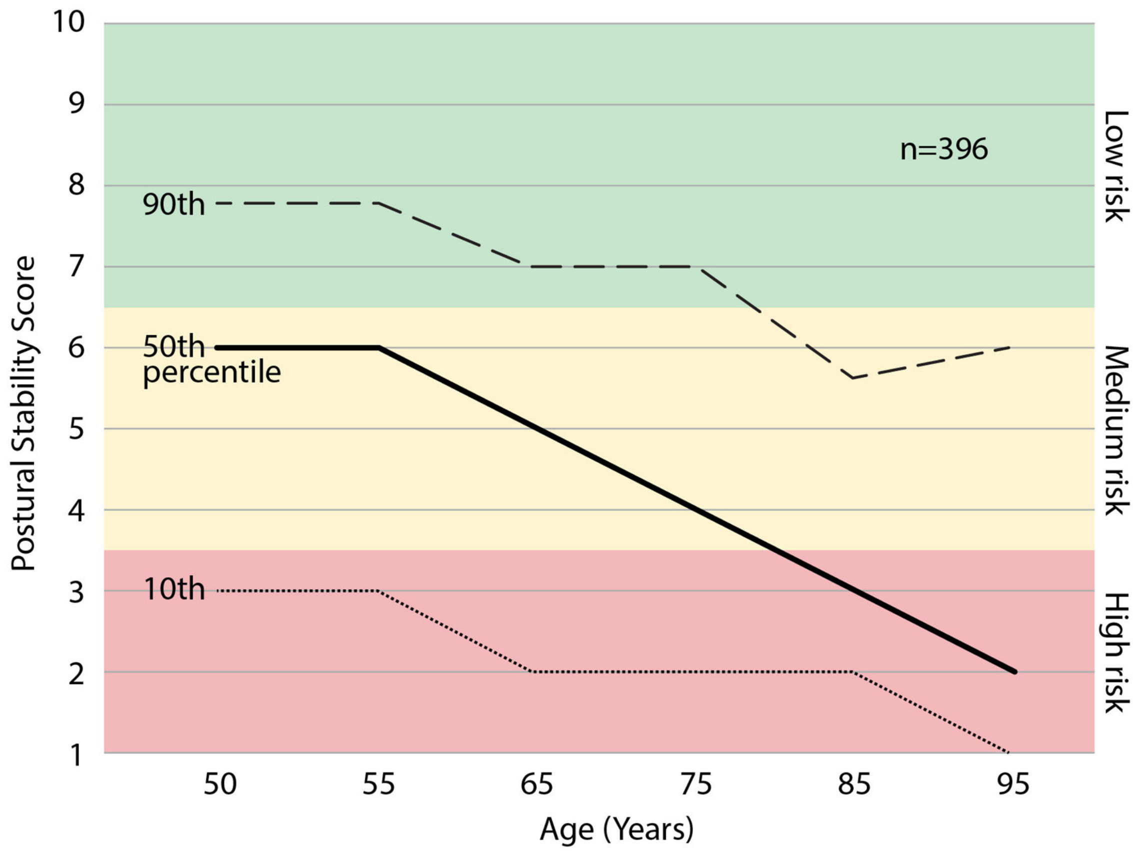

FIGURE 5 | The percentiles of postural stability (PS) score with age. Those scoring in the 25th percentile may expect to enter the "high risk" category at ∼65 yrs. and those 50th percentile may expect to enter the "high risk" category at ∼80 yrs. of age.

identifies fall risk and future risk trajectory, may provide an easy way to remove barriers to enable effective patient counseling.

Falls have traditionally been considered unavoidable accidents. Yet our data suggests that, like routine patient discussions about hypertension, fall prevention counseling encompasses measurement, risk stratification, prevention by losing weight and exercise, and, when present, effective treatment. Different fall causes for each risk category indicate that the occurrence of a fall is the combination of a person's physical capability *and* his or her opportunity for falling. For example, a "high risk" person with poor stability control can sit in a chair all day and never fall, whereas a "low risk," physically capable person may hike a treacherous trail while looking up at birds' nests and trip over a root (both of these scenarios occurred in the present study). Indeed, PS score "high risk" individuals fell spontaneously from being less physically capable (i.e., loss of stability), while PS score "moderate risk" individuals fell in more challenging environments.

As a result, some of the individuals identified as false positive may in fact be true positives with little opportunity to fall. Conversely, some false negatives may be higher performing individuals who engage in more risky behaviors. Both scenarios may explain why current clinical tools have such low predictive power for falls and why the PS score, despite having good predictive accuracy, also mis-categorized some individuals. To increase the PS score's predictive capability for all falls, future work can focus on enhancing prediction by accounting for individuals' opportunity to fall as a predictive factor. The independent senior living residents in the present study were, on average, older than the community recruited individuals and a higher percentage subsequently fell, 43 vs. 34%, respectively. These fall rates are in line with documented fall rates that increase with age (3, 8, 37). It is important, however, to acknowledge that different opportunities to fall may have existed for these two settings. A likely scenario is that fall rates were muted in the more protective environment of senior living as it is expected to have less opportunity to fall. Consequently, in this setting more false-positives would be anticipated, thus future work enhancing prediction by accounting for opportunity to fall should also consider age as a factor.

Given that opportunities to fall vary between individuals, the high PS score sensitivity to spontaneous falls provides confidence that a meaningful fall risk metric is being measured and can facilitate more personalized patient counseling. In practice, focus is typically placed upon "high risk" individuals, however risk identification can be just as important for "moderate" and "low risk" patients to get ahead of functional decline and achieve both fall prevention and a healthier population.

A limitation of this study is the lack of generalizability to people who were unable to stand unassisted for 60 s as well as individuals who self-reported a history of dementia, vestibular disorders (e.g., Meniere's disease), as they were excluded from the study. We suspect the risk for patients with Meniere's disease and vestibular disorders will be underestimated due to the protocol requirement of maintaining a still head. Future studies can look into the addition of controlled head movements to expose vestibular sensory weaknesses (38). People with dementia were excluded due to participant requirements of fall event recall in the study. If a dementia patient could adhere to the testing protocol, the results of this study may be applicable. Future work to confirm validity with dementia patients can include fall event confirmation from caregiver reporting. A further limitation to the generalizability of these results is the dependency of this assessment upon a commercial product, the Zibrio SmartScale, which may not be financially accessible to all clinical environments.

Self-reporting of falls has well-documented limitations and often results in underreported falls (24). While the present study aimed to reduce this limitation by optimizing event recall using short, monthly communications (23, 24), underreporting is still to be expected. Fortunately, injurious falls, the most relevant type of fall for public health, are most likely to be reported (24). Thus, despite reporting limitations, the findings from this study have significant relevance for public health and injury prevention. Emerging wearable technology that identifies fall events may be useful for addressing this limitation in future fall research.

The influence of participant demographics were not explored in detail in this study, therefore future work must strive to identify differences in PS scores among fall risk covariates such as sex (39, 40) and ethnicity (41). Given the insights from the present study, future work can also focus on different machine learning techniques to cluster force plate COP data for further resolution and prediction. A representative PS score is dependent on the user complying with the protocol of standing still without talking, moving their head, or fidgeting.

CONCLUSIONS

The lack of a clear gold standard for clinical fall risk assessment (7), despite clinical guidelines (6), leaves aging and older patients underserved due to misleading and incomplete fall risk assessments. Misidentification of fall risk can lead to dramatic swings in clinical decisions, costs, and savings as the impact of falling is considerable. The present study demonstrates that a postural stability score, collected on a force plate and automatically generated from a 60 s, eyes open, standing balance test using machine learning techniques, can provide a reliable and valid method for identifying aging adults at-risk of falling.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Westerns IRB (#20171926 and #20172324) and University of Texas Health Science IRB (HSC-MS-16-0019). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EL and SM were completely blinded to the data collection and only permitted to perform data analyses upon a deidentified, completed, dataset. KF aided by Kristin Bartlett, Andrea Case-Rogers, Jasmine Chigbu and Steven Wilberts collected all data in the assisted living, community dwelling, and physical therapy populations and was completely blinded to analyses until results were generated and compiled. A series of a priori analyses were performed to minimize investigator bias, as described in **Supplementary Material 5**. KW, SA, and NR from the University of Texas McGovern Medical School collected all data from hospital and clinical care facilities, and served as academic advisors in this study to ensure rigorous standards and manage conflicts of interest. All authors participated in the drafting and critical review of the manuscript prior to submission.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2020.591517/full#supplementary-material

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Conflict of Interest: KF, EL, and SM are employed by Zibrio Inc. KW developed a conflict of interest ∼12 months after completing testing due to her spouse becoming a private investor in Zibrio, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SYSTEMATIC REVIEW
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Pilates Reducing Falls Risk Factors in Healthy Older Adults: A Systematic Review and Meta-Analysis

Larissa Donatoni da Silva[1]*, *Agnes Shiel*[2] *and Caroline McIntosh*[3]

[1] School of Health Sciences, National University of Ireland Galway, Galway, Ireland, [2] Department of Occupational Therapy, School of Health Sciences, National University of Ireland Galway, Galway, Ireland, [3] Department of Podiatry, School of Health Sciences, National University of Ireland Galway, Galway, Ireland

Background: The main theme of this systematic review and meta-analysis is to synthesize the evidence of randomized controlled trial of evidence of Pilates intervention, in comparison to control groups and other forms of exercise, for falls prevention in healthy older adults.

Methods: The following electronic databases were searched up to October 2020; EMBASE, Scopus, Google Scholar, MEDLINE (Ovid), Science Direct, Cochrane, and CINAHL. The recommendations of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses were followed. A PICOS approach was adopted as a framework to formulate the research question and set the inclusion and exclusion criteria. Participants were healthy older adults, defined as older adults who have maintained functional ability, including participants of both genders, those with a falls history, non-fallers, and individuals who were considered to be sedentary or active. Randomized controlled trials studies, written in the English language, from the decade, were included if they focused on specific outcome measures to decrease falls risk; functional mobility, mobility, fear of falling, gait, and postural stability. The PEDro scale was used to assess risk of bias.

Results: There were included 12 studies. In total, 702 healthy older adults' participants were included. Pilates showed an effect in mediolateral directions in comparison to control groups (MD = −1.77, 95% CI, −2.84 to −0.70, $p = 0.001$, heterogeneity: $I^2 = 3\%$), mobility (MD = 9.23, 95% CI, 5.74 to 12.73, $p < 0.00001$, heterogeneity: $I^2 = 75\%$) and fear of falling (MD = −8.61, 95% CI, −10.16 to −7.07, $p < 0.00001$, heterogeneity: $I^2 = 88\%$). In relation to other exercises group, Pilates showed positive effects in functional mobility (MD = −1.21, 95% CI, −2.30 to −0.11, $p = 0.03$, heterogeneity: $I^2 = 80\%$), mobility (MD = 3.25, 95% CI, 1.46 to 5.04, $p < 0.0004$, heterogeneity: $I^2 = 0\%$). No evidence of an improvement was found between the groups for dynamic gait index (MD = 2.26, 95% CI, −0.05 to 4.56, $p = 0.06$, heterogeneity: $I^2 = 86\%$), anteroposterior directions of balance (MD = −1.58, 95% CI, −3.74 to −0.59, $p = 0.15$, heterogeneity: $I^2 = 51\%$) and functional mobility when compared to control groups (no exercise) (MD = −1.24, 95% CI, −2.48 to −0.00, $p = 0.05$, heterogeneity: $I^2 = 87\%$).

Discussion: Pilates may be effective in decreasing the risk of falls in older adults. Pilates intervention was found to improve functional mobility, mobility, gait, fear of falling and

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Yan Press,
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Aline Nogueira Haas,
Federal University of Rio Grande Do Sul, Brazil
Lisa Robinson,
Newcastle Upon Tyne Hospitals NHS Foundation Trust, United Kingdom

Correspondence:
Larissa Donatoni da Silva
laridonatoni@gmail.com

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postural stability and therefore there is some evidence to suggest that Pilates reduces certain risk factors for falls in healthy older adults. However, there is an absence of high-quality evidence in regards to the impact of Pilates on reducing falls and further robust RCTs are needed.

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Keywords: falls prevention, Pilates, balance, gait, functional mobility

INTRODUCTION

A fall is "an unexpected event in which the participant comes to rest on the ground, floor, or lower level" [(1), p. 1618–22]. Falls are a leading cause of morbidity, mortality, functional deterioration, hospitalization, institutionalization, and pose a significant financial burden to health and social care services across the globe (2). It is estimated that, of the 646,000 deaths following falls each year, more that 80% occur in low and middle-income countries (3). The occurrence of falls is known to increase with advancing age; from 18% in young adults to 21% in middle age and 35% in older adults (4). The middle-aged population has been shown to have the highest percentage of injuries (70.5%) particularly in the knees, while older adults most frequently incur injuries from the head to the knee (4). In relation to gender, evidence suggests that women (20.1%) are more likely to fall than men (18.2%) (5). Thus, women have the highest frequency of injuries across all age groups (4).

The aging process is associated with decreased walking ability and walking speed. In individuals between the ages of 25 and 75 years, it is known that muscle power declines by 49% and muscle strength declines by 33% in this period (6). In older adults, the number of steps taken daily and walking speed were reduced by 75% between the ages of 60 and 85 and the falls per number of steps taken per day increases by 800% (6).

The Pilates method was developed in the 1920's by Joseph Hubertus Pilates and based on "Contrology" which aimed to coordinate the balance of the body, mind and spirit. The Pilates method also focused on concentration, strength and mobility (7). Pilates has been shown to improve lower limb muscle strength, static and dynamic postural balance and functional mobility after completion of a 12-week programme (8). Pilates intervention has also been shown to decrease the fear of falling in post-menopause women (9, 10), older adults (11), and in participants with low back pain (12). Other techniques such as Yoga and Tai Chi exercises have also been suggested to improve balance and prevent falls (13).

Several previous systematic reviews (14–18) have reported on the effectiveness of Pilates. The practice improves health status, balance, muscle strength, flexibility, functional autonomy, muscle endurance, body composition and aerobic endurance (16), functional capacity to perform daily living activities (14), and quality of life (8, 14, 18). A previous meta-analysis of Pilates included 10 studies with different subjects, such as healthy participants, those with a stable but chronic disease and Parkinson's disease. The analysis showed improvements in muscle strength and static and dynamic balance in older adults (14). Previous systematic reviews have investigated the improvement in balance after Pilates (14, 15, 18) and the prevention of falls in older adults (18, 19). However, specific task training has been shown to improve balance more than Pilates-only groups (18).

A recent meta-analysis of Pilates found improvement in postural stability in older adults (15, 20). The authors included randomized controlled trials (RCTs), quasi-experimental and crossover designs studies and found that only four out of 15 studies measured static balance. The author suggested that mat-based Pilates exercises should be performed for 40 min, three times per week for 5 weeks, or two or three times per week, to improve balance (15). However, Engers et al. (17) argued that Pilates studies must also be of good quality, feature control groups and follow-up and make use of the more rigorous randomized controlled trial methodology. Bueno et al. (21) suggest that more evidence is needed to judge the effects of mat Pilates on other physical functional measures in older adults.

The systematic reviews and meta-analyses are important because they summarize the empirical evidence and analyse the results of Pilates intervention studies. They summarize information with regard to the effectiveness of Pilates RCTs for health care professionals which, might help to inform them and their clinical practice of the benefits of Pilates interventions for older adults. However, previous meta-analyses on the effectiveness of Pilates in falls prevention have shown that studies are still lacking and there is no definitive evidence on Pilates interventions in reducing/ preventing falls. Furthermore, it is still unclear whether postural balance and gait can be improved with Pilates intervention. Regarding gait, there is a distinct lack of data concerning the potential impact of Pilates intervention on the spatiotemporal parameters of gait in healthy participants, and there is a dearth of evidence from RCTs and systematic reviews. Relating to balance, a previous meta-analysis did not separate the measures of postural balance for fall risk, such as mediolateral and anteroposterior parameters and fear of falling, in healthy participants. It is important to address and clarify these fall factors to reduce any knowledge gaps for future researchers.

Further improvements in the clinical practice of Pilates for specific age groups and guidelines are needed in the context of Pilates, since broader falls prevention guidelines are available. Therefore, it is necessary to include the following in meta-analyses: randomized clinical trials (RCTs) in evidence-based Pilates practice; falls protocol for longer follow-up; and recording falls during the intervention (to measure any reduction in the incidence of falls during the intervention group program). The research question asked whether Pilates training reduces the risk of falls in healthy older adults, defined as older adults who have maintained functional ability, including participants of both genders, those with and without a fall history and those considered sedentary or active.

The main theme of this systematic review and meta-analysis is to synthesize the evidence of RCTs of Pilates intervention in comparison to control group (no exercise) and to other exercises focuses on reducing the risk of falls by improving falls risk factors for the following outcome measures; mobility, functional mobility, fear of falling, gait, postural stability and falls recorded during the Pilates intervention.

METHODS

This systematic review and meta-analysis followed the general guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The protocol for this systematic review registered in the International Prospective Register of Systematic Reviews (PROSPERO) number CRD42021206134.

Eligibility Criteria

The studies selected met the following inclusion criteria using PICOS:

- Population (P): Healthy older adults 60 years of age and older (male and female).
- Intervention (I): All Pilates interventions, including mats, accessories and equipment.
- Comparators (C): A comparison of Pilates training with parallel groups, including a control group with no intervention and a control group with other exercises.
- Outcomes (O): Pre- and post-tests with regard to fear of falling, mobility, functional mobility, gait and postural stability by platform.
- Study design (S): RCTs and peer-reviewed publications written in the English language and dated between 2010 and 2020.

Not all studies included were necessarily aimed at evaluating the effects of Pilates in preventing falls in older adults. This was due to a lack of studies that investigate the effect of Pilates on falls prevention specifically.

The exclusion criteria were: participants with neurological impairment or orthopedic conditions such as lower back pain; the use of dynamic balance to evaluate balance and with no platform used for postural stability and non-RCT studies, such as semi- or quasi-experimental studies.

Search Strategy

Electronic databases EMBASE, Scopus, Google Scholar, MEDLINE (Ovid), Science Direct, Cochrane and the Cumulative Index to Nursing and Allied Health Literature (CINAHL), were searched until 30th of October 2020.

The following search terms were used: Pilates AND healthy older adults, OR elderly OR aged, fall prevention OR risk of fall, fear of falling, postural balance OR balance, functional mobility, gait OR spatiotemporal parameters of gait AND randomized controlled trial.

Study Selection

The Covidence systematic review component of Cochrane 1.0 extraction was used for importing citations, managing screening and data extraction by the reviewers (www.covidence.org).

The citations were imported into the Covidence systematic review software where any duplicate papers were excluded. Titles and abstracts were screened by two independent reviewers (LD and CM). Any disagreements between the reviewers were mutually resolved to reach a consensus. Potentially eligible articles were then reviewed in full text by two authors (LD and CM) and any disagreements were mutually resolved to reach a consensus.

Data Extraction

Data were extracted independently by two reviewers (LD and CM) in Covidence. Consensus was reached at a later meeting between the two authors. Data extracted included participant demographics (age and sample size), study details (author, year, country), study design, setting or recruitment, aim, intervention groups and inclusion criteria. Pilates intervention description (material, duration and times per week of intervention), participants analyzed, findings and recommendations.

Outcome Measures

The primary and secondary outcomes selected are associated with a decreased fall risk in older adults. Functional mobility: The TUG test is a sensitive and specific tool to identify community-dwelling adults who are at risk of falling, including older adults who have balance impairments and who live independently within a community. Older adults who scored $\geq$ 13.5 s to perform the TUG were classified as fallers with an overall accurate prediction rate of 90% (22).

The parameters of postural stability: The anteroposterior parameter was associated with a history of falls for the conditions of eyes opened and eyes closed on a firm surface (23). Impaired balance in the lateral direction was related to a risk of falls (24), while the mediolateral displacement of the center of pressure was associated with future falls (25).

Tasks related to gait changes have been identified as fall predictors (26) among older adults with FOF without normal gait (27). Gait speed is a simple and fast variable for measuring fall risk (28) and functional capacity for health outcomes in community-dwelling older adults (29).

Primary outcomes included functional mobility (the Timed-Up-and-Go-TUG task), mobility as the functional reach test (FRT), fear of falling (the 16-item Falls Efficacy Scale-FES, questionnaire) and postural stability by force platform using COP displacement to evaluate the parameters in mediolateral (ML) and anteroposterior (AP) directions under both eyes open and closed conditions.

Secondary outcomes included falls in the past year (within 12 months), the number of falls recorded during the study, gait (the 10-min walk test- 10 MWT and the 6-min walk test- 6 MWT) and the Dynamic Gait Index (DGI). In case of incomplete or missing data for spatiotemporal parameters of gait for RCTs in healthy subjects.

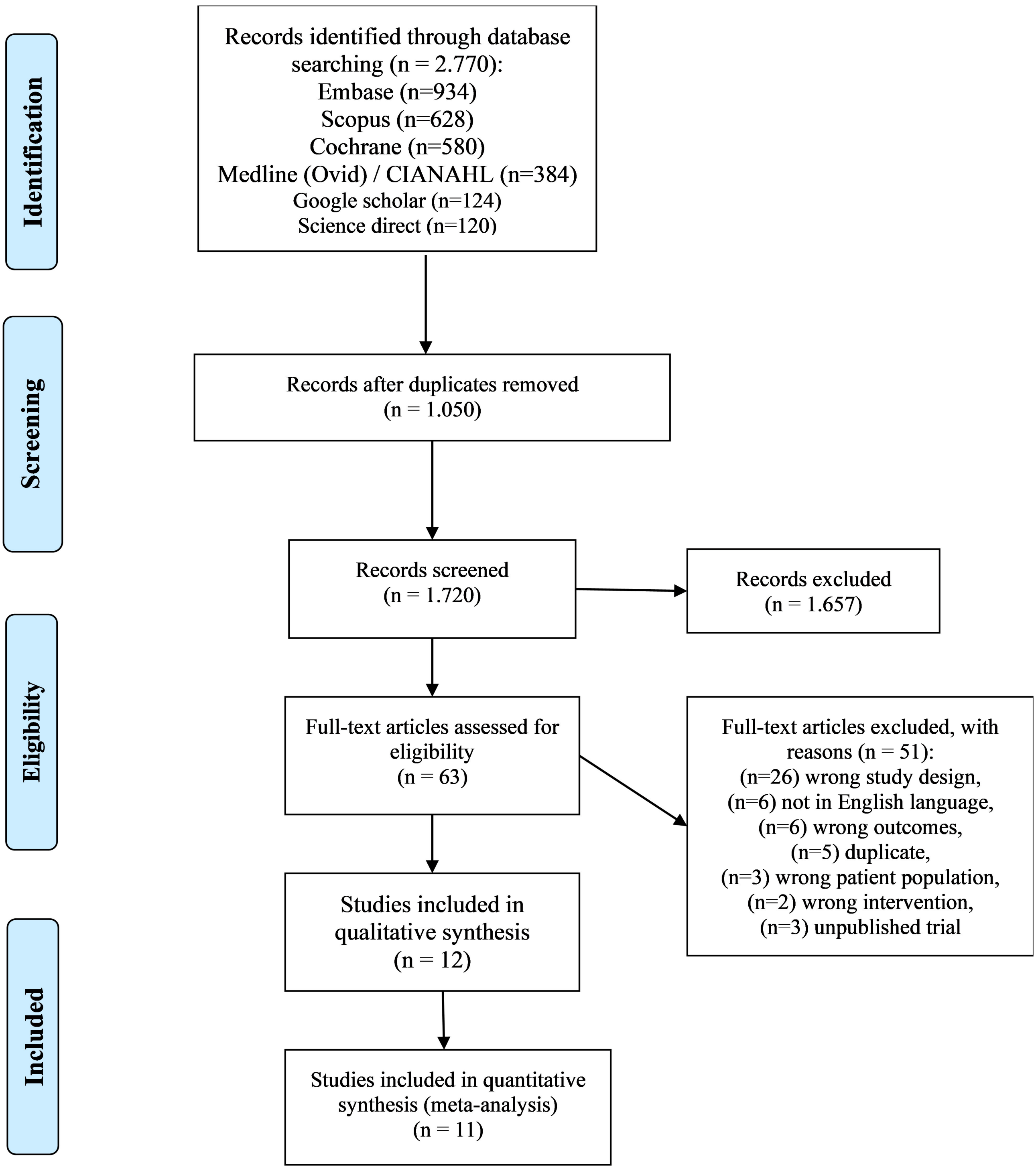


FIGURE 1 | Studies included.

Quality Assessment

The risk of bias in assessing the quality of the included studies was evaluated by two independent reviewers (LD and CM). Consensus was reached at a later meeting between the two authors.

The inclusion criteria were evaluated using the Database of Physiotherapy Evidence (PEDro) scale (http://www.pedro.org.au/english/downloads/pedro-scale) for RCTs, which contained 10 questions to assess the study quality. A study score of 6–10 is considered moderate to high quality and a score <5 is considered lower quality according to their guidelines (http://www.pedro.org.au/english/downloads/pedro-statistics/). Consensus was reached by the two independent graders and there was no requirement for a third reviewer to resolve disagreements.

Data Analysis

Statistical analyses were performed using the software package Statistic 10.0 and Cochrane Review Manager Software (RevMan 5.4, Cochrane Collaboration). A value of $\alpha = 0.05$ was considered statistically significant.

Data were entered in the software as mean and standard deviation (SD) and the total number of participants in each study allocated into groups. The author considered whether the studies reported on whether or not intention- to- treat analysis was used.

Data reported as standard errors or confidence intervals (CIs) were converted to SD using https://training.cochrane.org/handbook/current/chapter-06#section-6-5-2. If the extracted data were incomplete, the author was contacted by email for more details.

Continuous data outcomes were reported as the mean difference (MD) were reported with 95% CIs. Postural stability included two subgroups to evaluate the estimating effects for the variables for mediolateral directions (MLEO; MLEC) and for anteroposterior directions (APEO; APEC). Assuming pooled effects, a fixed-effects model with heterogeneity $I^2 \leq 50\%$ and a random-effects model with $I^2 \geq 50\%$ were used. Forest plots presented the comparison between the Pilates intervention group and the control group with no exercise. The variables TUG and FRT were also analyzed for Pilates vs. other exercise groups. Dichotomous data for the number of falls in participants during the previous year and the number of falls during the intervention were reported as exploratory due to the lower reporting of data during the intervention programme.

RESULTS

Study Selection

A total of 1,720 records were screened and 1,657 were excluded. A total of 63 studies were assessed for full-text eligibility and 51 were excluded. Twelve RCT studies were identified after the selection process for systematic review and meta-analysis; one study was excluded as the authors included path length variable as opposed to ML and AP variables of balance (30) (see **Figure 1**). The studies were conducted between 2012 and 2019.

Participants

In total, 702 participants were included, with 308 allocated to Pilates group (PG), 316 to Control group, (CG) and 78 to the three-arm exercise group.

Nine studies included both men and women (11, 30–37), while three (8, 10, 38) included only women.

Participants were healthy older adults, defined as older adults who have maintained functional ability (WHO). Six studies included healthy participants (10, 11, 30, 31, 34, 36). Other studies have inclusion criteria with restrictions such as sedentary women (8, 38) and fallers were included (32, 33, 35, 37).

At baseline, six studies (10, 11, 33–35, 37) reported participants who fell in the past year ($n = 338$ participants), shared between the Pilates group ($n = 168$) and control group ($n = 170$).

Five studies (10, 11, 33–35) reported the number of fallers ($n = 283$ participants) in the previous year at baseline before being allocated to the intervention programme. In the Pilates group ($n = 141$ participants), the number of fallers was 49 and in the control group ($n = 142$ participants), the number of fallers was 43. One study reported no events (falls) in the control group (34). Only two studies (33, 35) reported the number of falls during the intervention programme.

Two studies (35, 37) used TUG test scores ≥ 13.5 s to screen participants with a history of falls. Josephs et al. (35) also used Advanced Balance Scale (FAB) > 25 and Activities-Specific Balance Confidence Scale (ABC). Surbala et al. (32) used a FES-16 item score > 23 to screen participants.

The criteria for participants included a risk of sustaining a fall injury (33), having two or more falls or one injurious fall in the previous year (37), having at least one fall in the previous year (32), having a fall in the past year or cut-off points for TUG or FAB, or able to complete the questionnaires without assistance (35).

Study Characteristics

Of the 12 studies, six compared Pilates intervention to a control group with no exercise (10, 11, 31, 33, 36, 37). One crossover study (31) was included (see **Table 1**).

Five studies compared Pilates intervention to other interventions, such as static stretching (8) and traditional strength and balance (35). Three three-arm studies were included to compare Pilates intervention to the following: conventional balance training and control (exercise) (32); Pilates neuro-proprioceptive facilitation group (PNFG) and no intervention (daily activities) (38); and multimodal balance training and no intervention (daily activities) (30).

One study aimed to prevent falls (33), one looked at alternatives to prevent falls (38), and one aimed to reduce falls (35).

Risk of Bias Within Studies

Of all the RCTs, only one included the highest quality score (10). Seven studies were of moderate to high quality of 6–10 scores (8, 30–34, 38); four studies scored lower (11, 35–37).

Five studies did not have concealed allocation (11, 30, 35, 37, 38). Three studies were not similar at the baseline (11, 34, 35). Only one study was blinded from subjects (10). Two studies were blinded from therapists (10, 30). Four studies were unblinded to the assessors (8, 11, 30, 36). Three studies did not have appropriate follow-up (31, 34, 36). Seven studies used intention to treat analyses (8, 10, 11, 31–33, 37). Only one study did not compare between group analysis (32) (see **Table 2**).

Interventions

This study focused on the PICO method. The intervention included all types of Pilates methods, but the variables "intensity,"

TABLE 1 | Study and participants characteristics.

References/Country	Design	Setting or recruitment	Aims	Inclusion criteria	Total sample size (n), and between intervention groups	Age: Mean (SD) between groups
Aibar-Almazán et al. (10) Spain	RCT	Community-dwelling postmenopausal women	To analyse the effects that an exercise programme based on the Pilates method would have on women aged 60 years and older concerning their postural control, FOF, and balance confidence when performing daily activities.	Women, aged 60 years and over and with at least 12 months since their final menstrual period, not involved in a Pilates exercise programme in the last year; and physically independent enough to perform basic daily activities (39)	*Total, (n = 110)* PILATES, PG *(n = 55)* / NO INTERVENTION, CG *(n = 55)*	PG = 69.98 (7.83) CG = 66.79 (10.14)
Barker et al. (33) Australia	RCT	Advertisements in local general practitioner (GP), imaging and physiotherapy clinics; university newsletters; local community centers and newspapers.	To conduct a pilot, single blinded RCT to assess the feasibility of a Pilates exercise program that incorporates best practice guideline recommendations for falls prevention exercise and obtain a preliminary estimate of effect of the program on falls, fall injuries and fall risk factor outcomes to inform the design of a larger clinical trial.	aged $\geq$ 60 years; at risk of sustaining a fall injury based on a telephone screen developed by the research team (Box 1, available online); and able to negotiate a set of 10 stairs independently without a gait aid.	*Total, (n = 53)* PILATES PG *(n = 22)* / NO INTERVENTIONCG, *(n = 31)*	PG = 69.25 (6.74) CG = 69.41 (5z.76)
Bird et al. (31) Australia	RCT (crossover)	Local community groups in an urban area using radio and print media	To conduct a randomized controlled trial to investigate the effects of a Pilates intervention on the variables of static and dynamic balance and leg strength in a group of community-dwelling adults older than 60 years.	Participants did not currently have or had not recently had an acute medical condition. Volunteers who had controlled chronic conditions such as arthritis or stable chronic cardiovascular or metabolic conditions (e.g., hypertension, diabetes mellitus) were included in the study.	*Total, (n = 32)* PILATES, PG *(n = 17)* / NO INTERVENTION, CG *(n = 15),* at crossover PG *(n = 14)* CG *(n = 13)* (daily activity monitored by (CHAMPS) questionnaire)	No mentioned
Oliveira et al. (8) Brazil	RCT	Community-dwelling older adults in the city of Jacarezinho State of Paraná, Brazil	To determine the isokinetic torque of the knee extensors and flexors, static and dynamic balance, functional mobility, and quality of life of community-dwelling older adults who performed a Pilates exercise protocol.	Age 60–65 years; female; the ability to perform basic and instrumental activities of daily living without assistance; a body mass index (BMI) within the ideal range for the age group (22–27 kg/m^2); a statement from a physician indicating sufficient fitness for the practice of physical exercises; not having practiced any type of physical exercise in the previous 6 months; and agreement not to participate in any other type of physical exercise during the study	*Total, (n = 32)* PILATES, PG *(n = 16)* / STATIC STRETCHING, CG *(n = 16)*	PG = 63.6 (1.0) CG = 64.2 (0.8)

(Continued)

TABLE 1 | Continued

References/Country	Design	Setting or recruitment	Aims	Inclusion criteria	Total sample size (n), and between intervention groups	Age: Mean (SD) between groups
Donath et al. (30) Switzerland	RCT 3 arms	Community-dwelling seniors	Investigating whether the neuromuscular training effects are in favor of a traditional balance training program (BAL) or a mat-based Pilates training (PIL) in a group of healthy community-dwelling seniors	healthy seniors (75% women) without artificial joints, neurological and internal diseases, osteoporosis, acute and chronic back pain as well as trauma and balance or strength training experience within the last 6 months	*Total, (n = 59)* PILATES, PG *(n = 20)* / MULTIMODAL BALANCE TRAINING, BAL *(n = 20)* / NO INTERVENTION, CG *(n = 19)*. (daily activities)	PG =70.8 (6.5) BAL = 69.1 (5.8) CG = 69.2 (6.1)
Gabizon et al. (34) Israel	RCT	Mail Community-dwelling, independent older adults were recruited from Lehavim, a community with a high social-economic ranking near Beer-Sheva, in southern Israel	To assess whether a Pilates-training program that includes classical Pilates exercises and exercises using Thera-Band elastic resistance bands and Swiss balls would improve balance control parameters associated with an increased risk of falling.	65 years of age or older, could ambulate independently (i.e., use of a cane was acceptable, but not a walker), did not have severe focal muscle weakness or visual impairment, did not have known neurological disorders (including stroke or Parkinson's disease), did not have metastatic cancer, and did not take medications that impair balance or strength. All subjects provided a medical waiver, signed by their primary care physician, clearing them to participate in moderate physical exercise.	*Total, (n = 88)* PILATES with balance, PG *(n = 44)* / NO INTERVENTION, CG *(n = 44)*	PG =70.3 (3.8) CG =72.1 (4.60)
Josephs et al. (35) USA	RCT	Local physicians in the area, seniors' groups at churches and community centers, word of mouth and notices posted in the local libraries	To investigate the effectiveness of Pilates group exercise vs. traditional strength and balance group exercise for improving balance, reducing falls and improving balance confidence in community dwelling older adults with fall risk	65 years of age or older living in the community; impaired balance as defined by at least one of the following: a fall in the past year, TUG > 13.5 s or FAB ≤ 25; and ability to follow instructions as assessed by the ability to complete the questionnaires without assistance. Subjects were not screened for ability, such as use of assistive device for walking, but only that they met the inclusion criteria of history of fall or meeting the cut off for balance compromise with the TUG or FAB.	*Total, (n = 31)* PILATES / TRADITIONAL STRENGHT AND BALANCE No mentioned	PG = 75.6 (6.2) TG = 74.5(6.9)
Mesquita et al. (38) Brazil	RCT 3 arms	Older women belonging to a church project	To conduct a randomized controlled trial to investigate and compare the effect of both exercise methods on the static and dynamic postural balance variables in elderly women, thus identifying alternatives to prevent falls and promoting functional independency	Women who were sedentary as evaluated using the International Physical Activity Questionnaire and aged 60–80 years were included in the sample	*Total, (n = 63)* PILATES, PG *(n = 21)* / PNFG *(n =* 21) / NO INTERVENTION, CG (*n* = 21) (daily activity)	PG = 67.3 (4.9) PNFG = 68.5 (5.4) CG = 71.5 (6.2)

(Continued)

TABLE 1 | Continued

References/Country	Design	Setting or recruitment	Aims	Inclusion criteria	Total sample size (n), and between intervention groups	Age: Mean (SD) between groups
Roller et al. (37) California	RCT	Core Conditioning in Studio City advertisements in newspapers and at senior centers, and by word of mouth, and were screened *via* a telephone	To investigate whether Pilates Reformer exercises would improve balance, reduce fall risk, improve functional mobility, and improve balance confidence in adults age 65 and older at risk for falls.	Aged 65 years or older, self-reported history of two or more falls or one injurious fall in the past year, TUG test score of 13.5 s suggesting risk for falling and physician approval to participate in the study.	*Total, (n = 59)* PILATES, PG *(n = 27)* / NO INTERVENTION, CG *(n = 28)*	PG = 78.52 (7.57) CG = 76.68 (6.79)
Surbala et al. (32) India	RCT 3 arms	Ambulatory geriatric subjects were recruited from four different old age homes (OAH) in Surendranagar area	The study aims in determining and comparing the effectiveness of PI and CBT specially designed for the elderly population in improving functional balance and QOL.	Age between 65 and 74 years both males and females; able to walk at least 30 feet with or without an assistive device; not participating in any sports or physical therapy sessions; willingness to do physical exercise thrice a week with regular attendance; have fallen at least once within previous year; fear of fall scoring >23 in 16 items falls efficacy scale international questionnaire; Mini-Mental Status Examination score of 24; and no affirmative responses to the PAR-Q instrument for inactive older adults	*Total, (n = 51)* PILATES PG *(n =* 17) / CONVENTIONAL BALANCE TRAINING, CBT *(n = 17)* / CONTROL, CG *(n = 17).* (exercise)	PG = 70.7 (2.7) CBT =70.3 (2.9) CG = 69.35 (3.0)
Vieira et al. (36) Brazil	RCT	Community dwelling seniors	To investigate the effects of a 12-week Pilates-inspired exercise program on functional performance among community-dwelling older women	Each subject had been instructed to avoid caffeinated and alcoholic beverages and to not perform moderate or heavy exercise the day before and the day of the application of the protocols. Before beginning the test, subjects were interviewed and examined to confirm their good health and whether they had a normal night's sleep	*Total, (n = 52)* PILATES, PG *(n = 26)* / NO INTERVENTION, CG *(n = 26)* (daily activity)	PG = 66.0 (1.35) CG = 63.3 (0.91)
Badiei et al. (11) Iran	RCT	Elderly women who were referred to the day care center of Kahrizak sanatorium (Alborz Province) *via* the convenient sampling method.	To determine the effect of Pilates exercise on Fear of Falling (FOF) among elderly women	Age between 60 and 80 years, willingness to join the study and signing the consent form, having medical approval that certifies the person's ability to participate in physical activity and exercise routines, no history of hospitalization in the past 3 months as well as ability and availability to attend at least 80% of the Pilates exercise sessions.	*Total, (n = 44)* PILATES, PG *(n = 22)* /NO INTERVENTION, CG *(n = 22)* (daily activity - (stretching training) as usual.	PG = 68 (5.9) CG =71 (4.1)

RCT, Randomized Controlled Trial; PG, Pilates group; CG, control group; CBT, Conventional Balance Training; PNFG, Proprioceptive neuromuscular facilitation group; PI, principal investigator; OAH, old age homes; TUG, Time Up and Go; FAB, Frontal assessment battery; TG, Traditional strength; BAL, traditional balance training program; PIL, Pilates training; BMI, Body mass index; GP, general practitioner; FOF, Fear of falling; QOL, Quality of life; PAR-Q, Physical Activity Readiness Questionnaire.

TABLE 2 | Quality of assessments of include studies.

References	Random allocation	Concealed allocation	Similar at baseline	Blinding of subjects	Blinding of therapists	Blinding of assessors	Follow-up	Intention to treat analysis	Comparison between groups	Point measures variability	Score
Aibar-Almazán et al. (10)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/10
Barker et al. (33)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Bird et al. (31)	Y	Y	Y	N	N	Y	N	Y	Y	Y	7/10
Oliveira et al. (8)	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10
Donath et al. (30)	Y	N	Y	N	Y	N	Y	N	Y	Y	6/10
Gabizon et al. (34)	Y	Y	N	N	N	Y	N	N	Y	Y	6/10
Josephs et al. (35)	Y	N	N	N	N	Y	Y	N	Y	Y	5/10
Mesquita et al. (38)	Y	N	Y	N	N	Y	Y	N	Y	Y	6/10
Roller et al. (37)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Surbala et al. (32)	Y	Y	Y	N	N	Y	Y	Y	N	Y	7/10
Vieira et al. (36)	Y	Y	Y	N	N	N	N	N	Y	Y	5/10
Badiei et al. (11)	Y	N	N	N	N	N	Y	Y	Y	Y	5/10

"dose," and "type of Pilates method" could not be considered in the meta-analysis The strength of this study design is in its synthesisation of the results from the RCTs and the outcomes of fall risk factors. (*It is not always feasible to conduct randomized trials of all intervention types [e.g., the "structural" interventions mentioned in Section 17.2.3]* [cited in Cochrane interventions handbook Section 17.2.5.).

Period of Pilates Exercise

The Pilates intervention period was from 4 to 24 weeks. The 12-week period was more common among the studies (8, 10, 34–36) (see **Table 3**).

The following studies had different periods of interventions: Mesquita et al. (38) 4 weeks; Bird et al. (31) 5 weeks; Surbala et al. (32) 6 weeks; Donath et al. (30) and Badiei et al. (11) 8 weeks; and Roller et al. (37) 10 weeks. The study by Barker et al. (19) included three analyses at baseline, after 12 weeks and after 24 weeks; the 24-week period was the longest follow-up period that recorded falls.

Number of Sessions

One to three Pilates sessions were held per week for 45–60 min each.

Eight studies (8, 10, 30–33, 35, 36) included two sessions per week for 60 min each. Three studies (11, 34, 38) included three sessions per week for 50 min each. Only one study included a single session per week lasting only 45 min (37).

Materials

Two studies included only mat Pilates (11, 30); Badiei et al. (11) used the programme from Pérez et al. (40).

Six studies included mat Pilates with accessories (10, 32, 34, 36, 38); one was in the traditional group (35).

Three studies included the use of Pilates equipment (8, 35, 37), which Josephs had two Pilates groups (accessories vs. equipment).

Three studies used a mix of Pilates techniques, including the mat with accessories, standing position (31–33) and equipment (31, 33).

Three studies included supplementary at-home exercises (31, 33, 35). Barker et al. (33) included educational materials for falls prevention and suggested that participants should exercise for 20 min on a daily basis. At-home Pilates exercise with mat were performed occasionally each week (31) participants performed the exercise for 15–20 min on the day that there was no intervention program and after the program ended, participants continued to do the exercises for 8 weeks (35).

Outcomes

The outcomes are focused on reducing fall risk for the following outcome measures: history of falls, mobility, functional mobility, fear of falling, gait, and postural stability.

A total of 565 participants were included in the meta-analysis, with 282 allocated to PG and 283 to CG. A third exercise group included 37 participants.

Number of Fallers

Only Josephs et al. (35) ($n = 31$ participants) compared Pilates vs. the traditional group (other exercise group), allocating $n = 10$ fallers to the Pilates group and $n = 8$ fallers to other exercise group.

Barker et al. (33) was the only study to report the CI; no statistical significance was found—fallers n (%) = 7.5% (95% CI, −20.40 to 35.40, $p = 0.601$).

Roller et al. (37) reported the number of fallers as mean (SD) = 2.00 (2.30) in the Pilates group and as mean (SD) = 3.21 (5.57) in the control group.

Number of Falls During the Intervention Programme

Josephs et al. (35) reported that the number of falls in the Pilates group was 0–4, with Mean (SD) = 1.5 (1.3). In the traditional group, the number of falls was 0–7, with mean (SD) = 1.8 (2.2) and $p = 0.703$; no statistical significance was found.

TABLE 3 | Pilates exercise intervention, outcomes measures, participants analyzed and recommendations.

References	Pilates intervention	Outcome measures of interested	Participants (*n*) analyzed intention to treat (IT)	Recommendations
Aibar-Almazán et al. (10) Spain	12 weeks / 2 sessions per week / 60 min The last sessions involved equipment such as resistance bands, rings, and balls.	International Falls Efficacy Scale- FES-16 Force platform Number of participants falls in the past year, *n (%)* Pilates, 25 (45.45%) Control, 17 (32.69%)	IT- yes PG = 55 CG = 52	Future studies should consider the mid- and long-term effects, on both men and women, of the intervention here described.
Barker et al. (33) Australia	24 weeks / 2 sessions per week / 60-min Pilates class practice guidelines for exercise to prevent falls (educational letter). Home exercises (20 min) >50 h over total study period Standing exercises. Equipment: reformer, trapeze, Wunda chair, chi ball, elastic band and foam roller.	Functional reach test- FRT Timed Up and Go- TUG Dynamic gait index -DGI Number of participants falls in the past year, *n (%)* Pilates, 6 (30%) Control, 9 (38%) Number of Falls Pilates, *n* = 13 Control, *n* = 11	IT- yes PG = 20 CG = 29, and CG = 24 (fall)	Pilates exercise is an enjoyable and acceptable form of exercise in community-dwelling older people at risk of falling. An appropriately designed Pilates exercise program appears to improve standing balance and reduce the risk of falls. Based on the fall injury rates estimated here, we can estimate (with 80% power) that a future definitive study would require 402 participants per arm to detect a 30% difference in fall injury rates. These estimations are based on a negative binomial distribution and a 6-month follow-up period. A large RCT that includes around 804 people is warranted to confirm effects.
Bird et al. (31) Australia	5 weeks / 2 sessions per week / 60 min After a 6-week washout period, participants perform the alternate intervention. Classes consisted of standing exercises / Pilates reformer and mat-based exercises. Home-based with a diary	Force platform The Timed Up and Go –TUG	IT- yes PG = 27 CG = 27	Although there were no between-condition differences between the Pilates and control conditions, significant improvements were observed in the pooled static and dynamic balance data from the 2 Pilates conditions. The reported improvements in mediolateral sway range and dynamic balance may have positive functional implications for physical fall risk factors in an older population.
Oliveira et al. (8) Brazil	12 weeks / 2 sessions per week /60 min Equipment: combo chair, Cadillac trapeze table, universal Reformer and ladder barrel. All exercises were performed with one set of 10 repetitions. The Borg CR10 scale 21 was used to determine the level of effort and load progression.	The Timed Up and Go-TUG -	IT – yes PG = 16 CG = 16	Further studies are needed to determine the effects of Pilates for older adults. Based on the present findings, Pilates performed with equipment elicits improvements in lower limb muscle strength, static and dynamic postural balance, functional mobility and quality of life of older adults when performed in two weekly sessions for 12 weeks.
Donath et al. (30) Switzerland	8 weeks/ 2 sessions per week/ 60 min Mat Pilates 6–12 repetitions were performed during each exercise.	Force Platform	No- IT PG = 17 BAL = 16 CG = 15	Pilates training did not cause relevant adaptations. Future studies may also observe specific adaptations in neuromuscular, cognitive function and psychosocial health parameters could be assessed upon Pilates training, e.g., in frailer and residential seniors. In these cases, randomized controlled three armed study designs are recommended. Accordingly, any control condition should then consider appropriate group allocation and social gatherings, in order to avoid socially confounding situations.
Gabizon et al. (34) Israel	12 weeks / 3 times a week / 60 min Classical Pilates method with Thera-Band elastic resistance bands and Swiss balls	Force Platform Number of participants falls in the past year, *n (%)* Intervention 3 (6.8) Control 0 (0.0)	No-IT PG = 44 CG = 44	Further research should be conducted to assess the potential effect of Pilates training on a population of weaker older adults who have a history of falls.

(Continued)

TABLE 3 | Continued

References	Pilates intervention	Outcome measures of interested	Participants (*n*) analyzed intention to treat (IT)	Recommendations
Josephs et al. (35) USA	12 weeks/ 2 times week / 60 min Pilates with Reformer, Cadillac and Chair apparatus. Each exercise 10 repetitions. The traditional group: elastic resistance bands, ankle weights, foam balance pads, boxes of varying heights and half foam rollers were props performed 20 repetitions. Home exercises 15–20 min. Monthly calendar to record their home exercise participation.	The Timed Up and Go-TUG Number of participants falls in the past year: Pilates, $n = 10$ Traditional, $n = 8$ Number of falls Mean (SD) Pilates= 1.5 (1.3) ranged 0–4 Traditional = 1.8 (2.2) ranged 0–7	No- IT PG = 13 CG = 11	Future research ideas include having three groups, Pilates, traditional and a control group and following the results longer term. This study indicates that balance and balance confidence can be improved in <50 h in patients with fall risk. A future research study should investigate this further in adults with fall risk.
Mesquita et al. (38) Brazil	4 weeks / 3 times a week/ 50 min Mat Pilates, with Swiss ball, TheraBand, and magic circle.	Force platform The Timed Up and Go-TUG Functional reach test -FRT	No-IT PG = 20 CG = 18 PNFG = 20	Recommend that further studies include larger samples of elderly women and greater numbers of sessions. This will help to elucidate the optimal alternatives that can be applied to increase balance, allowing PNF and Pilates exercises to be used not only for rehabilitation, but also as a preventive method.
Roller et al. (37) California	10 weeks / Once a week / 45-min Pilates with Reformer 10 repetitions each, using progressive resistance of 2–4 springs Falls diary	The Timed Up and Go-TUG 10 Min walk test-10 MWT Number of participants falls in the past year Mean (SD) Pilates = 2.00 (2.30) Control = 3.21 (5.57)	IT- yes PG = 27 CG = 28	Future studies examining the effect of Pilates Reformer exercises on balance, gait, and fall risk in older adults may also want to consider performing exercises that work specifically on balance in upright postures such as standing on a moving carriage
Surbala et al. (32) India	6 weeks / 2 times per week/ 45 min Mat Pilates, ball exercise and in standing position. All exercises were done for 10 repetitions with a rest period of 2 min before commencing the next exercise.	Functional reach test -FRT The Timed Up and Go-TUG Dynamic Gait Index-DGI	IT- yes PG = 17 CBT = 17 CG = 17	Future research with cross over designs may also be conducted to determine the participants' preference of exercise program between PI and CBT. Further controlled comparative studies with larger sample size are recommended in community dwelling old elderly (over 75 years) individuals and those with pathological conditions (e.g., Stroke, Parkinsonism, etc.) who are at higher risk of falls and falls related injuries
Vieira et al. (36) Brazil	12 weeks / 2 times per week / 60 min Mat Pilates using accessories such as exercise rubber, bands, swiss and exercise balls.	Timed Up and Go-TUG 6-min walk test-6 MWT	No – IT PG = 21 CG = 19	Pilates-inspired exercises improved dynamic balance, lower-extremity strength, and cardiovascular fitness in community-dwelling older women. Therefore, it might be a potentially effective exercise regimen to maintain physical fitness and, possibly, to prevent disability and falls in old age. Yet, further investigation is needed to evaluate the effectiveness of the Pilates method on functional and physical fitness of older adults with characteristics that differ from those of our sample.

(Continued)

TABLE 3 | Continued

References	Pilates intervention	Outcome measures of interested	Participants (*n*) analyzed intention to treat (IT)	Recommendations
Badiei et al. (11) Iran	8 weeks / 3 times per week / 60 min Mat Pilates by Pérez et al. (40)	Falls Efficacy Scale-FES-16 ITEM Number of participants falls in the past year Mean (SD) Pilates = 1.54 (1.79) Control = 2 (2.4), $p = 0.4$ Pilates, *n (%)* YES 15 (68.2) NO 5 (22.7) Control, *n (%)* YES 17 (77.3) NO 7 (31.8), $p = 0.5$	IT- yes PG = 22 CG = 22	The findings of the present study can help in creating a new attitude toward the possible roles of exercising in decreasing the risk of falling and other related factors in the elderly population, especially elderly women. In addition, health care providers can use this study to formulate similar interventional strategies that can improve the quality of life of the elderly.

n, Number; %, percentage; IT, Intention to treat; SD, Standard Deviation; TUG, Timed Up and Go; 6 MWT, 6-minute walk test; FRT, Functional Reach Test; DGI, Dynamic Gait Index; 10 MWT, 10 Minute walk test; FES-I, International Falls Efficacy Scale; RCT, Randomized controlled trial; PG, Pilates group; CG, control group; CBT, Conventional Balance Training; PI, principal investigator; TUG, Time Up and Go; PNF, Proprioceptive neuromuscular facilitation.

Barker et al. (33) reported the total number of falls in the Pilates group ($n = 13$) and control group ($n = 11$) during the 24-week follow-up intervention programme. This study was the only one to report the rate of falls per 1,000 person-days across groups, which was calculated as the difference incidence rate ratio = 1.17 (95% CI, 0.43–3.16, $p = 0.0754$). They also stated that $n = 2$ falls (10%) occurred during the Pilates classes.

FES

Two studies (10, 11) included the Pilates group ($n = 77$) and the control group with no intervention ($n = 74$). Badiei et al. (11) and Aibar-Almazán et al. (10) used the FES of a 16-item questionnaire on the fear of falling (see **Figure 2**).

The results show a decreased fear of falling score and statistically significant between groups in favor of the Pilates group: (MD = −8.61, 95% CI, −10.16 to −7.07, $p < 0.00001$, heterogeneity: $I^2 = 88\%$).

Postural Stability

Four studies (10, 31, 34, 38) included two subgroups for mediolateral directions (MLEO; MLEC) ($n = 516$) and two subgroups for anteroposterior directions (APEO; APEC) ($n = 408$) in the meta-analysis. All participants ($n = 924$) were allocated to the Pilates ($n = 450$) and control (no intervention, $n = 474$) subgroups. The three-arm study (Pilates vs. other interventions) by Mesquita et al. (38) was excluded. Other studies have not compared the Pilates to other interventions.

Participants performed the balance test on a firm surface (platform) for 30 s in all the included studies. The studies included balance bipedal performance (38), quiet standing trials with eyes open and more than 10 s with eyes closed /blindfolded (34) and the Romberg test (10).

Mediolateral

Of the 516 participants included in this analysis, 264 were assigned to the Pilates group and 264 to the control group. The pooled overall balance improved, as seen in a decrease in scores after Pilates and was statistically significant between groups in favor of the Pilates group: (MD = −1.77, 95% CI, −2.84 to −0.70, $p = 0.001$, heterogeneity: $I^2 = 3\%$)—the postural stability of the subjects increased (see **Figure 3**).

The following four subgroups were shown separately on the forest plots:

MLEO: Four studies (10, 31, 34, 38) included the Pilates group ($n = 136$) and the control group with no intervention ($n = 141$). MLEO showed improvement in controlling postural stability with a decrease in the score and significant differences were found between the groups in favor of Pilates intervention: (MD = −1.62, 95% CI, −2.91 to −0.34, $p = 0.01$; heterogeneity: $I^2 = 24\%$).

MLEC: Three studies (10, 31, 34) included the Pilates group ($n = 116$) vs. the control group with no intervention ($n = 123$). MLEC showed improvement in controlling postural stability with a decrease in the score and significant differences were found between the groups in favor of Pilates intervention:(MD = −2.09, 95% CI, −4.01 to −0.16, $p = 0.03$, heterogeneity: $I^2 = 4\%$).

Anteroposterior

Of the 418 participants included in this study, 198 were assigned to the Pilates group and 210 to the control group.

The pooled overall balance had a decrease in scores after Pilates and no statistical significance between groups was found: (MD = −1.58, 95% CI, −3.74 to −0.59, $p = 0.15$, heterogeneity: $I^2 = 51\%$) —the postural stability of the subjects increased (see **Figure 4**).

The following four subgroups were shown separately on the forest plots:

APEO: Three studies (10, 34, 38) included the Pilates group ($n = 109$) vs. the control group with no intervention ($n = 114$). No difference was found between the groups: (MD = −1.85, 95% CI, −4.40 to 0.70, $p = 0.15$, heterogeneity: $I^2 = 46\%$).

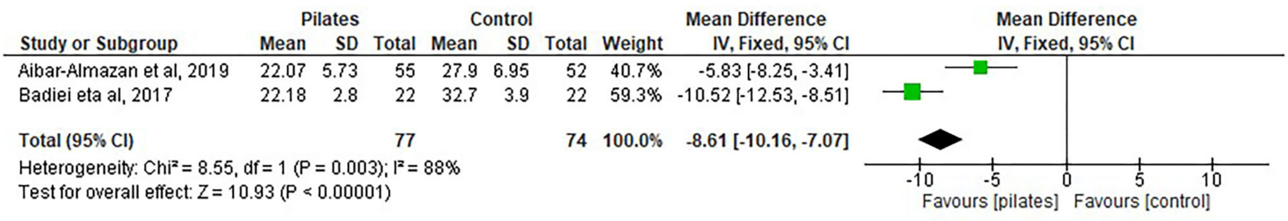


FIGURE 2 | Fear of falling.

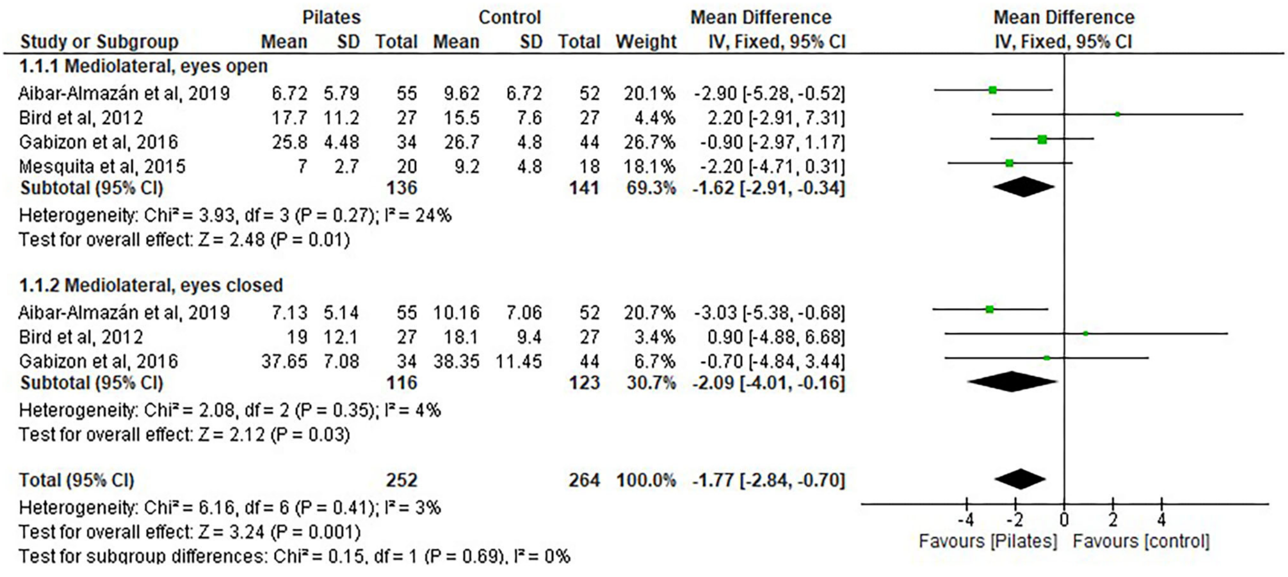


FIGURE 3 | Postural stability-mediolateral.

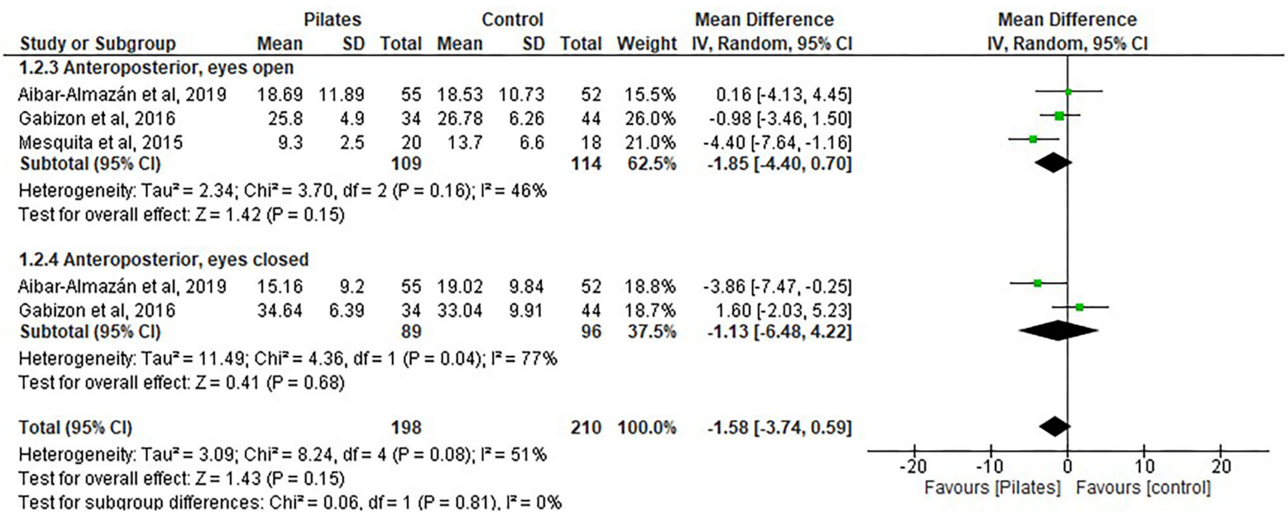


FIGURE 4 | Postural stability-anteroposterior.

APEC: Two studies (10, 34) included the Pilates group (n = 89) vs. the control group with no intervention (n = 96). No difference was found between the groups: (MD = −1.13, 95% CI, −6.48 to 4.22, $p = 0.68$, heterogeneity: $I^2 = 77\%$).

Gait

Two studies (36, 37) included exploratory results. Of the 95 participants included in this study, 48 were assigned to the Pilates group and 47 to the control group. Pilates improved the endurance of the participants, as measured by the increase in the distance of (∼30 m, $p < 0.01$) the individual could walk in 6 min (6 MWT) (36) and the increase in velocity of (0.13 m/s) after Pilates measured by the 10-min walking test (10 MWT) (37).

DGI

Two studies were included in this meta-analysis (32, 33), with a total of 37 participants in the Pilates group and 46 participants in the control group (see **Figure 5**).

Participants showed an increase in their balance and gait scores with Pilates intervention; however, no significant difference was found between groups: (MD = 2.26, 95% CI, −0.05 to 4.56, $p = 0.06$, heterogeneity: $I^2 = 86\%$).

TUG Analysis for Pilates vs. Control Groups

Five studies (31, 33, 36–38) were included in the analysis, with a total of 115 participants in the Pilates group and 121 participants in the control group (see **Figure 6**).

The results show no significant difference between the groups. There was a decrease in the time score (seconds) after Pilates intervention in favor of Pilates: (MD = −1.24, 95% CI, −2.48 to −0.00, $p = 0.05$, heterogeneity: $I^2 = 87\%$).

TUG Analysis for Pilates vs. Other Exercise Groups

Four studies (8, 32, 35, 38) were included in the analysis with a total of 66 participants in the Pilates group and 64 participants in the control group (see **Figure 7**).

The results show a statistically significant difference between the groups and improvements in functional mobility in favor of the Pilates group by a decrease in the time score (seconds) after Pilates intervention: (MD= −1.21, 95% CI, −2.30 to −0.11, p = 0.03, heterogeneity: $I^2 = 80\%$).

FRT Analyzed for Pilates vs. Control Group

Three studies (32, 33, 38) were included in the analysis, with a total of 57 participants in the Pilates group and 64 participants in the control group (see **Figure 8**).

There was a statistically significant difference between the groups and an increase in scores after Pilates intervention: (MD = 9.23, 95% CI, 5.74 to 12.73, $p < 0.00001$, heterogeneity: $I^2 = 75\%$).

FRT Analyzed for Pilates vs. Other Exercise

Two studies (32, 38) were included in the analysis, with a total of 37 participants in the Pilates group and 37 participants in the control group (see **Figure 9**).

There was a statistically significant difference between the groups and an improvement in the Pilates group, as evident from an increase in the score after Pilates intervention (fixed-effects estimation): (MD = 3.25, 95% CI, 1.46 to 5.04, $p < 0.0004$, heterogeneity: $I^2 = 0\%$). There was no evidence of heterogeneity.

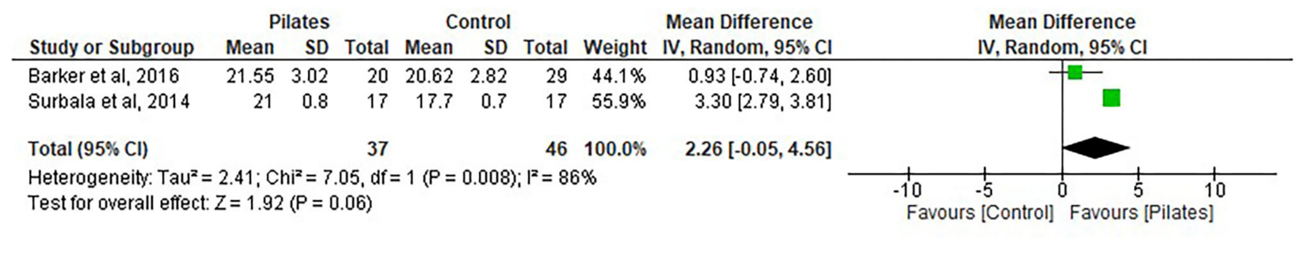
DISCUSSION

The aim of this systematic review and meta-analysis was to explore the effects of Pilates interventions on the following risk factors of falls; mobility, functional mobility, fear of falling, postural stability gait, and falls recorded during the Pilates intervention. To determine if Pilates interventions reduced the risk of falls in healthy older adults, who have maintained functional ability, including participants of both genders, those with a falls history, non-fallers, and individuals who were considered to be sedentary or active. All included studies were RCTs comparing Pilates intervention to control groups. However, only the TUG and FRT measures could be included in the model to compare Pilates to other exercises in the meta-analysis. The main findings of the review show that functional mobility, mobility, gait, postural balance and fear of falling have improved in older participants after practicing Pilates.

Functional Mobility and Mobility

Participants who undertook Pilates showed greater improvement in mobility/balance than functional mobility in healthy participants when comparing the Pilates group to the control group and to other form of exercises. With regard to FRT, no heterogeneity was found between the two studies presented (32, 38). There were similarities between the number of weeks of intervention (4–6) and in the use of mat Pilates with a ball. Pilates intervention showed sufficient effects to improve mobility/balance in older adults. Barker et al. (19) included exercises involving the standing position with a narrow base, as the standing balance stimulated the vestibular, visual and proprioceptive challenge. The Pilates intervention included a reformer, a trapeze, a Wunda chair, a ball, an elastic band and a foam roller for a 12-week programme with a practice guideline for falls prevention. In Surbala et al. (32), the intervention included mat Pilates with a ball and compared to conventional balance training in fallers, was for a 6-week period, with a frequency of twice per week and a duration of 45 min. In a study by Oliveira et al. (8), Pilates improved functional mobility after two weekly sessions for 12 weeks and included the use of equipment. In the control group, the participants performed static stretching. The exercises in the mat Pilates intervention, which used accessories, were effective for that population. Mesquita et al. (38) found a significant effect in both groups in terms of Pilates and proprioceptive and neuromuscular adaptations in the mat Pilates with accessories class after 4 weeks of intervention in sedentary women. Josephs et al. (35) indicated better improvement in the traditional group (mat with accessories) than in the Pilates group that used equipment. In addition, participants performed home-based exercises after the 12-week programme.

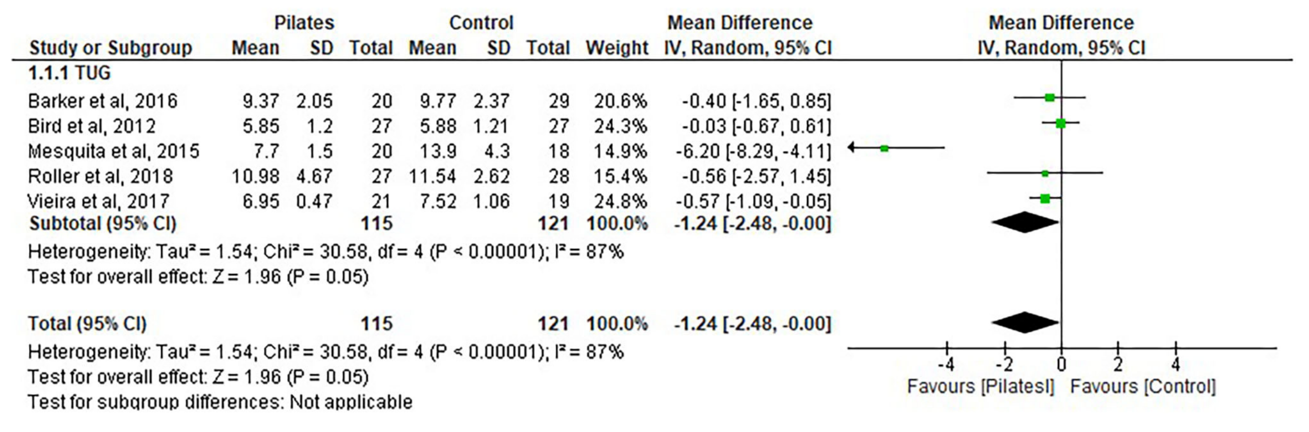
With regard to TUG participants' functional mobility did not improve when compared to the control group. This may be due to the heterogeneity of the methods in the studies, which included



Study or Subgroup	Pilates Mean	Pilates SD	Pilates Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Barker et al, 2016	21.55	3.02	20	20.62	2.82	29	44.1%	0.93 [-0.74, 2.60]
Surbala et al, 2014	21	0.8	17	17.7	0.7	17	55.9%	3.30 [2.79, 3.81]
Total (95% CI)			**37**			**46**	**100.0%**	**2.26 [-0.05, 4.56]**

Heterogeneity: Tau² = 2.41; Chi² = 7.05, df = 1 (P = 0.008); I² = 86%
Test for overall effect: Z = 1.92 (P = 0.06)

FIGURE 5 | Dynamic Gait Index (DGI).

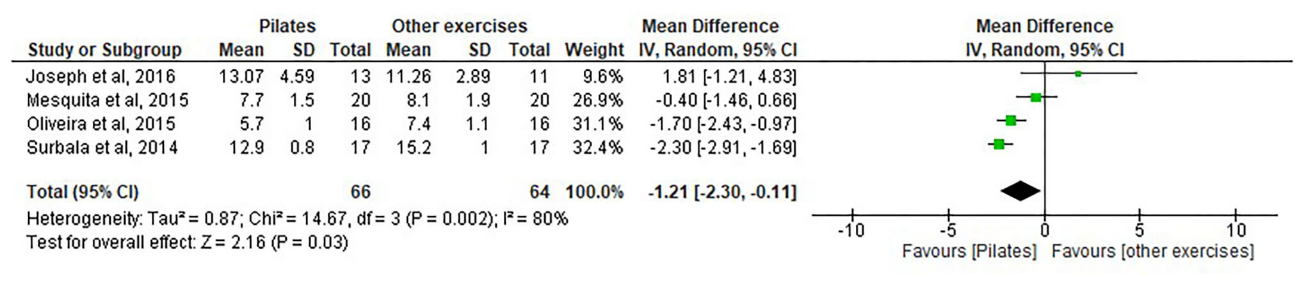


Study or Subgroup	Pilates Mean	Pilates SD	Pilates Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 TUG								
Barker et al, 2016	9.37	2.05	20	9.77	2.37	29	20.6%	-0.40 [-1.65, 0.85]
Bird et al, 2012	5.85	1.2	27	5.88	1.21	27	24.3%	-0.03 [-0.67, 0.61]
Mesquita et al, 2015	7.7	1.5	20	13.9	4.3	18	14.9%	-6.20 [-8.29, -4.11]
Roller et al, 2018	10.98	4.67	27	11.54	2.62	28	15.4%	-0.56 [-2.57, 1.45]
Vieira et al, 2017	6.95	0.47	21	7.52	1.06	19	24.8%	-0.57 [-1.09, -0.05]
Subtotal (95% CI)			**115**			**121**	**100.0%**	**-1.24 [-2.48, -0.00]**
Total (95% CI)			**115**			**121**	**100.0%**	**-1.24 [-2.48, -0.00]**

Subtotal: Heterogeneity: Tau² = 1.54; Chi² = 30.58, df = 4 (P < 0.00001); I² = 87%
Test for overall effect: Z = 1.96 (P = 0.05)

Total: Heterogeneity: Tau² = 1.54; Chi² = 30.58, df = 4 (P < 0.00001); I² = 87%
Test for overall effect: Z = 1.96 (P = 0.05)
Test for subgroup differences: Not applicable

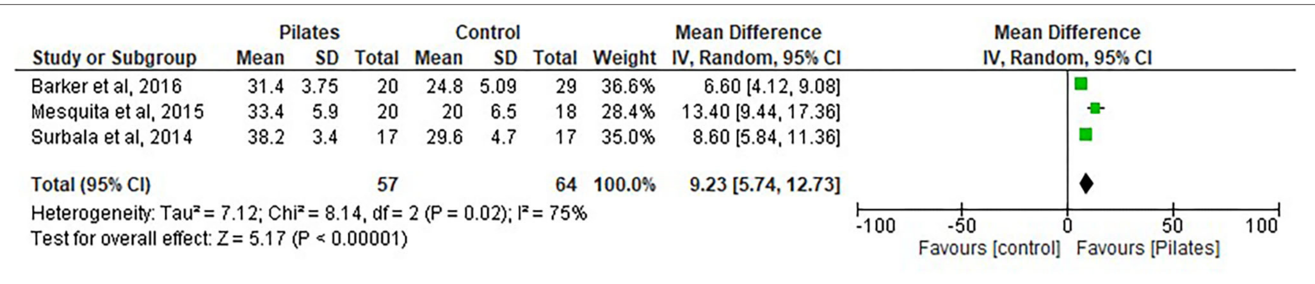
FIGURE 6 | Time Up and Go (TUG1).



Study or Subgroup	Pilates Mean	Pilates SD	Pilates Total	Other exercises Mean	Other exercises SD	Other exercises Total	Weight	Mean Difference IV, Random, 95% CI
Joseph et al, 2016	13.07	4.59	13	11.26	2.89	11	9.6%	1.81 [-1.21, 4.83]
Mesquita et al, 2015	7.7	1.5	20	8.1	1.9	20	26.9%	-0.40 [-1.46, 0.66]
Oliveira et al, 2015	5.7	1	16	7.4	1.1	16	31.1%	-1.70 [-2.43, -0.97]
Surbala et al, 2014	12.9	0.8	17	15.2	1	17	32.4%	-2.30 [-2.91, -1.69]
Total (95% CI)			**66**			**64**	**100.0%**	**-1.21 [-2.30, -0.11]**

Heterogeneity: Tau² = 0.87; Chi² = 14.67, df = 3 (P = 0.002); I² = 80%
Test for overall effect: Z = 2.16 (P = 0.03)

FIGURE 7 | Time Up and Go (TUG2).



Study or Subgroup	Pilates Mean	Pilates SD	Pilates Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Barker et al, 2016	31.4	3.75	20	24.8	5.09	29	36.6%	6.60 [4.12, 9.08]
Mesquita et al, 2015	33.4	5.9	20	20	6.5	18	28.4%	13.40 [9.44, 17.36]
Surbala et al, 2014	38.2	3.4	17	29.6	4.7	17	35.0%	8.60 [5.84, 11.36]
Total (95% CI)			**57**			**64**	**100.0%**	**9.23 [5.74, 12.73]**

Heterogeneity: Tau² = 7.12; Chi² = 8.14, df = 2 (P = 0.02); I² = 75%
Test for overall effect: Z = 5.17 (P < 0.00001)

FIGURE 8 | Functional Reach Test (FRT1).

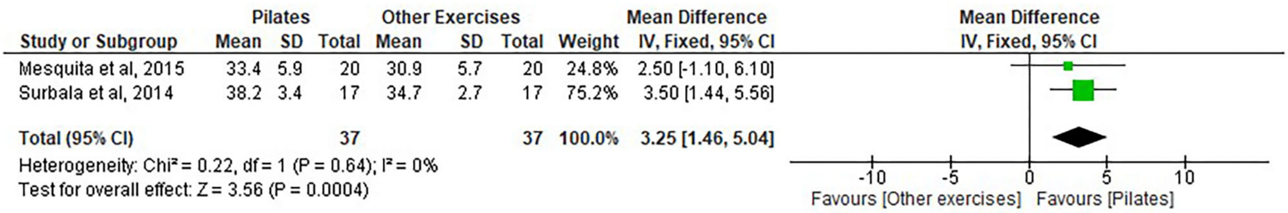


FIGURE 9 | Functional Reach Test (FRT2).

both healthy participants and participants with a previous history of falls. Vieira et al. (36) included active participants who might not have had improvement in functional mobility, while Roller et al. (37) included participants with the risk of falls and had not shown much improvement as well.

Balance Test

In this meta-analysis, Pilates had a positive effect on postural balance in healthy individuals. Considering the mediolateral variable under eyes-open and eyes-closed conditions, there were statistically significant differences between the Pilates and control groups, indicating that Pilates has positive effects and reduces the risk of falls. In an RCT crossover study, Bird et al. (31) also reported a significant improvement in the mediolateral direction under eyes-closed conditions on foam, rather than on a firm surface; however, there was no statistical difference between the groups. It must be emphasized, however, that the washout period of 6 weeks was insufficient to remove the effects of Pilates and after this period, the participants showed neuromuscular adaptation. In contrast, Donath et al. (30) found no significant results among their participants after Pilates training. However, their suggestions for future studies include adaptations in neuromuscular capability, cognitive function and psychosocial health and the use of a three-armed study design. Barker et al. (19) concluded that the control group may have had ceiling effects and a third arm would avoid the effects of Pilates intervention and benefit falls prevention exercises. Furthermore, Gabizon et al. (34) showed no improvement in postural stability after 12 weeks of training. This may be due to the Pilates protocol used, which did not include balance exercises for healthy participants. However, their exercises comprised three levels: 1- traditional Pilates with accessories, 2- Pilates with a Swiss ball, and 3- Pilates involving sitting on a ball using a Theraband (34).

In the present study, postural balance outcomes were evaluated by only comparing the Pilates group to the control group. The quality of the included studies was medium to high on the PEDro scale. Overall, as well as considering the subgroups, the variables analyzed separately for mediolateral directions demonstrated good improvement and good homogeneity and the anteroposterior directions of balance showed heterogeneity. The APEC results should be interpreted with caution because only two studies were included in the meta-analysis for this variable. Further, a random effect estimating for overall for the anteroposterior subgroup was applied due to no homogeneous studies included; however, the forest plot showed a similar weight between them (10, 34). Aibar-Almazan et al.' study had shown great improvement in the decrease score for balance and it was the only study included in this review that was graded at the highest quality. The intervention was a 12-week period of Pilates undertaken twice a week and the authors found improvement in balance confidence, the fear of falling and postural stability; however, the author stated that the best improvement was achieved with variables such as velocity of the COP with eyes open and APEC (10).

Mesquita et al. (38) was deemed to be a medium-quality study. It did not include the intention to treat analysis and allocation was not concealed. Moreover, unblinded assessors and therapists were employed in the study. The intervention period was 4 weeks. The authors found improvement in postural static and functional test performance in both groups of Pilates and neuromuscular facilitation. However, there was no significant difference between the groups (38). It needs to be considered that the consequences of aging affect muscle strength, proprioception, vision and balance of the standing body. Thus, there is a high dependence on the vestibular afferents due to small changes in the body when getting older (41).

In the present study, the balance parameters in the anteroposterior direction under both conditions with eyes opened and eyes closed showed no significant difference between the groups. In another recent meta-analysis, different variables were included to analyse postural balance. Casonatto and Yamacita (20) included six studies in their meta-analysis. Participants performed the balance test on a force platform, with COP directions of ML and AP, area and velocity in the same analysis. Overall, the authors determined SMD to be 0.89 (0.29–1.49) and concluded that the effects of duration and quantity of intervention per week, as well as the quality of the intervention studies, are unrelated to the effects of postural balance.

De Souza et al. (21), another Pilates meta-analysis, also used SMD and included two studies for the total sway area (force platform) and another task—one-leg standing. There was no statistically significant difference between the intervention groups. Low et al. (42) warned that the results of postural control studies can be misinterpreted because the variables are not always analyzed separately or the model employed does not use SMD.

Gait

In Roller et al. (37), healthy participants improved and increased their speed after a Pilates intervention used a reformer equipment after 4 weeks for once a week to decrease the risk of falls;

however, participants who had more functionality had greater improvements in static and dynamic balance. Improved speed was related to increased strength. The study included the 10 MWT test using a timed test to measure participants' speed (43). It was noted that there was an improvement in gait. According to Verghese et al. (28), if each participant walked 10 cm/s, a reduced gait speed is associated with a 7% increase in the risk of falls.

A Pilates study found that participants improved their aerobic capacity and functional exercise by increasing the distance of a 6 MWT after 12 weeks of mat Pilates with accessories such as rubber bands and Swiss balls; however, lower-limb strength could influence the performance test, as the participants were active (36). The study was considered of a lower quality and was unblinded. Moreover, the follow up was inadequate and there was no intention to treat analysis. De Souza et al. (21) evaluated participants after 12 and 24 weeks of intervention and found statistically significant differences between the groups for a 6 MWT (SMD = 2.00, 95% CI 1.44–2.56).

Fear of Falling and Falls

Participants decreased their concern about falling while doing activities through Pilates intervention compared to control groups. Two studies (10, 11) included healthy older women. Kumar et al. (44). If fear of falling affects an individual's health and social activities, they will experience a decrease in physical abilities and reduce their daily living activities. However, in Badiei et al. (11), the mat Pilates exercises ran for 8 weeks, three times a week. The study included women who were sedentary due to their sociocultural conditions and limited the women to practiced exercises. In Aibar-Almazán et al. (10), the Pilates exercise ran for 12 weeks, twice weekly and used accessories such as resistance bands, rings and balls. The study was considered to be of a high quality, was blinded, had the intention to treat and had a sample size greater than the other studies.

Fear of falling is more apparent among individuals who have experienced previous falls and there is an association with reduced gait speed, stride length, double support time (45, 46).

In the present study, there was a lack of data for fallers and no fallers, these dichotomous variables were not analysis the risk of falls; there were only two studies that included the number of falls that occurred during this period—Barker et al. (33) evaluated the risk factors, which included falls and injuries; however, the results showed that there was no significant difference between the Pilates and control groups for the rate of falls. Barker et al. (33) and Josephs et al. (35) showed that there was a reduction in scores, favoring the Pilates group. Four studies (10, 11, 34, 37) did not include data on the number of falls occurring during their intervention programme. Roller et al. (37) reported that the number of falls during the intervention programme was missing. A further meta-analysis found that Pilates prevented falls (19). However, that study included only one study in the analysis; hence, the results could have been misinterpreted.

Studies' Recommendations for Fall Prevention

Barker et al. (33) recommended specific training with a physical therapist, including exercises in a standing position, to reduce the risk of falls. Bird et al. (31) noted an improvement in the mediolateral directions of balance and participants' dynamic balance showed the intervention's positive implications for physical fall risk factors in older adults. Roller et al. (37) noted that more studies are needed to assess the effects of Pilates using Reformer equipment as related to balance, gait and falls risk in older adults. Further specific exercises focused on balance in upright postures for standing, moving and carriage were advised.

Limitations of the Review

This systematic review and meta-analysis have some limitations. The study included only RCTs, full-text versions and articles published in English. However, the study included studies that ranged in quality from medium to high. It was not possible in this study to analyse Pilates interventions in comparison to other exercise groups in terms of the most selected measures, and not all studies included focused on falls. Some low-quality studies included other forms of exercise, and the studies included focused on the outcome measures to decrease fall risk, where the primary outcomes of this study were functional mobility and postural balance.

There is still insufficient evidence in the literature to state conclusively that Pilates is an effective form of exercise to prevent falls. Concerning the number of falls and the number of fallers reported during the intervention programme, there were other limitations related to the low number of studies included. Moreover, meta-analyses are also dependent on heterogeneity among studies, such as in the clinical implications, Pilates methods and test measures used. However, according to Casonatto and Yamacita (20), the heterogeneity of Pilates intervention methods (frequency, duration, and quality of studies) previously mentioned was unrelated to the effects on postural balance. This study followed the PICO criteria to focus on measures to decrease fall risk. In addition, due to the lower number of RCTs in Pilates, it was preferred to include all types of Pilates interventions.

Implications of the Results for Practice

There was no improvement in dynamic gait index and it was not possible to analyse the spatiotemporal parameters of gait due to the lack of research data in this area. Thus, the spatiotemporal parameters of gait were lacking in the RCT Pilates studies. Most of RCT Pilates studies that have analyzed gait parameters have considered neurological participants for the inclusion criteria. Further, Pilates studies that have included gait parameters did not have groups comparison for healthy participants. With these gaps this study did not include the spatiotemporal parameters of gait outcomes. However, we have included the clinical assessments (MWT) for gait. Moreover, it was not possible to analyse gait due to the lower number of studies included.

Future Research

This systematic review and meta-analysis included only RCTs, meaning the quality and rigor of the methodology were increased. Further outcomes and more evidence from RCTs must be provided. Future studies should consider the number of falls and of faller participants among their primary outcomes during the intervention programme. In addition, studies should include a diary of falls for everyone or an electronic app to monitor the daily falls of each participant. Future studies should investigate any benefits in saving cost of groups and classes with a supplementary home-based Pilates intervention or an individual home-based exercise. May the risk of bias increasing; however, it is difficult to blind the participants and the instructor. Studies with a longer follow-up period are warranted.

CONCLUSION

There is some evidence to suggest that Pilates reduces certain risk factors for falls in healthy older adults. Pilates intervention, when compared to control groups, was shown to improve functional mobility, general mobility, postural balance, gait, and fear of falling of healthy older adults, which may decrease their risk of falls. Pilates intervention, when compared to control groups, showed no improvement in functional mobility than other exercises. Pilates did, however, show greater improvement in mobility than other exercises. It is evident that 4–6 weeks of Pilates intervention without equipment had positive results on general mobility. Pilates was found to improve fear of falling and postural stability in the mid-lateral directions with eyes open and closed, thereby potentially decreasing the risk of falls. Other evidence has shown conflicting results with regard to balance and postural stability including different measures. Further robust studies are needed to evaluate the number of falls and to incorporate falling participants into a Pilates intervention programme with longer follow-up. The intervention programme, including different methods, has implications for future research with regard to the use of mat Pilates, equipment and the number of weeks required for the Pilates intervention.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

LD: study design, database management and search strategies, screened studies for inclusion, extracted data, quality of data extraction, and data extraction for meta-analysis, analysis, acquisition, or interpretation of data, and drafting of the manuscript, wrote and reviewed the manuscript, critical revision of the manuscript for important intellectual content. CM: designed the review, screened studies for inclusion, extracted data, checked quality of data extraction, contributed to writing and editing the review, advised on the review, and approved final review prior to publication, critical revision of the manuscript for important intellectual content. AS: study design and reviewed the manuscript. All authors contributed to the article and approved the submitted.

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Hypothetical Interventions for Falls Among Older Adults: An Application of the Parametric G-Formula

Jiaojiao Ren, Guangyou Li, Liju Zhang, Na Zhang and Juan Ren*

Department of Preventive Medicine, Zhuhai Campus of Zunyi Medical University, Zhuhai, China

Introduction: Falls, which have a higher incidence and mortality due to accidental injuries, are a major global health challenge. The effects of lifestyle factor, health indicator, psychological condition, and functional status interventions on the risk of falls are unknown and the conventional regression model would not adjust for the confounders. This study aimed to evaluate the 4-year risk of falls on the basis of these hypothetical interventions among Chinese older adults.

Methods: Data were obtained from 9,692 aged 65 years and over older adults in the China Health and Retirement Longitudinal Study wave, from 2011 to 2015. We used the parametric g-formula to evaluate the risk of falls on the basis of independent hypothetical interventions of sleep duration, social activities, smoking status, drinking status, body mass index (BMI), systolic blood pressure (SBP), vision, depression, activities of daily living (ADL), and their different joint intervention combinations.

Results: During the follow-up of 4 years, we documented 1,569 falls. The observed risk of falls was 23.58%. The risk ratios (95% confidence intervals [CIs]) of falls under the intensive hypothetical interventions on increasing sleep duration, participating in more social activities, quit smoking and drinking, reducing BMI and SBP, better vision, alleviating depressive symptoms, and improving ADL capability were 0.93 (0.87–0.96), 0.88 (0.79–0.92), 0.98 (0.95–1.03), 0.97 (0.95–1.02), 0.92 (0.86–1.03), 0.93 (0.87–1.04), 0.86 (0.74–0.91), 0.91 (0.85–0.96), and 0.79 (0.74–0.85), respectively. The feasible and intensive joint hypothetical intervention reduced the 4-year fall risk by 22% (95% CI: 0.52–0.91) and 33% (95% CI: 0.56–0.72), respectively.

Conclusions: Hypothetical interventions for increasing sleep duration, participating in more social activities, better vision, alleviating depressive symptoms, and improving ADL capability help protect older adults from falls. Our findings suggest that a combination of lifestyle factors, health indicators, psychological conditions, and functional status may prove to be an effective strategy for preventing falls among older adults.

Keywords: falls, g-formula, hypothetical intervention, older adults, primary prevention

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Heart Science, National Heart and Lung Institute, United Kingdom*

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*Roman Romero-Ortuno,
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*Francesco De Micco,
University of Molise, Italy*

****Correspondence:***
*Guangyou Li
ahlgyou@zmu.edu.cn*

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INTRODUCTION

China is rapidly entering an aging society along with its longer life expectancy. At the end of 2018, 17.9% of the population was aged 60 years and older (1). By 2050, it is estimated that the population aged 60 years and older will increase by 33.6% (2).

Falls, which have a higher incidence and mortality due to accidental injuries, are a major global health challenge. Older adults are more likely to experience falls, which adversely affect their quality of life (3). Falls impose a huge burden on families and healthcare systems in China, including medical and rehabilitation payments, the costs resulting from death, disability, and decline in the ability of daily living (4, 5). Falls increase with advancing age. Previous literature showed that the prevalence of falls among older adults aged over 65 years was 28.0–35.0%, and 32.0–42.0% in those aged over 75 years in China (6). Hence, more effective primary prevention is particularly important for reducing the risk of falls.

Several observational studies have evaluated the risk factors of falls, including biological, psychosocial, socioeconomic, behavioral, and environmental factors (7). The risk of falls in older adults with impaired vision has been reported as 1.7 times higher than that of those with normal vision (8). Less sleep duration or with depressive symptoms are associated with a higher risk of falls in older adults (9, 10). Moreover, body mass index (BMI) and blood pressure are risk factors for falls in older adults (11). However, the existing literatures have the following limitations: most have focused on specific populations (in-hospital or nursing facilities' older adults), and representative community-based older adult study is rare. Moreover, previous studies used either baseline data of fall risk factors or data without adjusting for time-varying confounders (12, 13).

A special methodological challenge is the assessment of an unbiased effect of time-varying exposures in the presence of time-varying confounding factors when confounders are affected by previous exposures (14). In this case, the conventional regression model would not adjust for the confounders and may introduce bias. The parametric g-formula has been developed to deal with such situations and is more effective when exploring the causal effect of intricate interventions (15). In the current study, we performed the parametric g-formula to evaluate the 4-year risk of falls under hypothetical interventions using data from a nationally representative cohort of the China Health and Retirement Longitudinal Study (CHARLS), to provide intervention strategies for older adults aged 65 years and older.

MATERIALS AND METHODS

Study Sample

Data were taken from the CHARLS, which targeted middle-aged and older populations aged 45 years and older, selected through a multistage probability proportional to size sampling. The first baseline survey carried out in 2011 involved 17,705 respondents, covering 150 county-level units and 450 village-level units from 28 provinces (16). It was a longitudinal study, and performed every 2 years for a total of three waves from 2011 to 2015. All the respondents were required to sign informed consent, and the Medical Ethics Committee of Peking University approved the CHARLS study (IRB00001052-11015).

This study used the baseline (from the 2011 study) and follow-up (from 2013 and 2015 study) data. We excluded 3,293 participants who at baseline had had falls, incomplete covariate data, or were younger than 65 years (**Figure 1**). Finally, our study included 9,692 respondents aged 65 years and older.

Ascertainment of Outcome

In this study, the outcome variable was falls. Participants were asked to provide a "yes" or "no" response to the question "Have you fallen down in the last 2 years?" or "Have you fallen down since the last interview?"

Ascertainment of Hypothetical Interventions

Our study included four categories of intervention measures: lifestyle factors (sleep duration, social activities, smoking status, and drinking status), health indicators (BMI, systolic blood pressure [SBP], and vision), psychological condition (depression), and functional status (activity of daily living [ADL]). Sleep duration was assessed by the question "During the past month, how many hours of actual sleep did you get at night?." Social activities were assessed using the following question: "Have you done any of these activities in the last month? (interacted with friends; played Ma-jong, cards, or went to a community club; provided help to family, friends, or neighbors; took part in a community-related organization; went to a sport, social, or other kind of club; done voluntary or charity work; cared for a sick or disabled adult; attended an educational or training course; stock investment; used the Internet; and others). According to the responses, participants who participated in one or more items were defined as "participating in social activities," otherwise they were regarded as "not participating in social activities." Smoking status was assessed by the question "Have you ever chewed tobacco, smoked a pipe, smoked self-rolled tobacco, or smoked cigarettes/cigars?" (yes, no, or quit). Drinking status was assessed by the question "Did you drink any alcoholic beverages in the past year. How often?" (drink alcohol more than once a month, drink alcohol but less than once a month, and do not drink alcohol). BMI was calculated and categorized as: <18.5, 18.5–23.9, and ≥24.0 kg/m^2. SBP was calculated as the average of three blood pressure measurements using a sphygmomanometer. The vision level of the participants was assessed by the following question: "Would you say your eyesight for seeing things up close is excellent, very good, good, fair, or poor?." We categorized "excellent, very good, and good" as "good," others as "fair or poor." Depressive symptoms were measured by the Center for Epidemiological Studies Depression Scale (CES-D-10), which consisted of 10 items with 4 response options (rarely or none of the times, some or a few times, occasionally or a moderate amount of time, and most or all of the time). The values for the 4 options ranged from 0 to 3. A cutoff score of ≥10 was defined as having depressive symptoms in participants (17). ADL was measured using the ADL scale, including dressing, bathing, eating, getting out of bed, using the toilet, controlling urination and defecation,

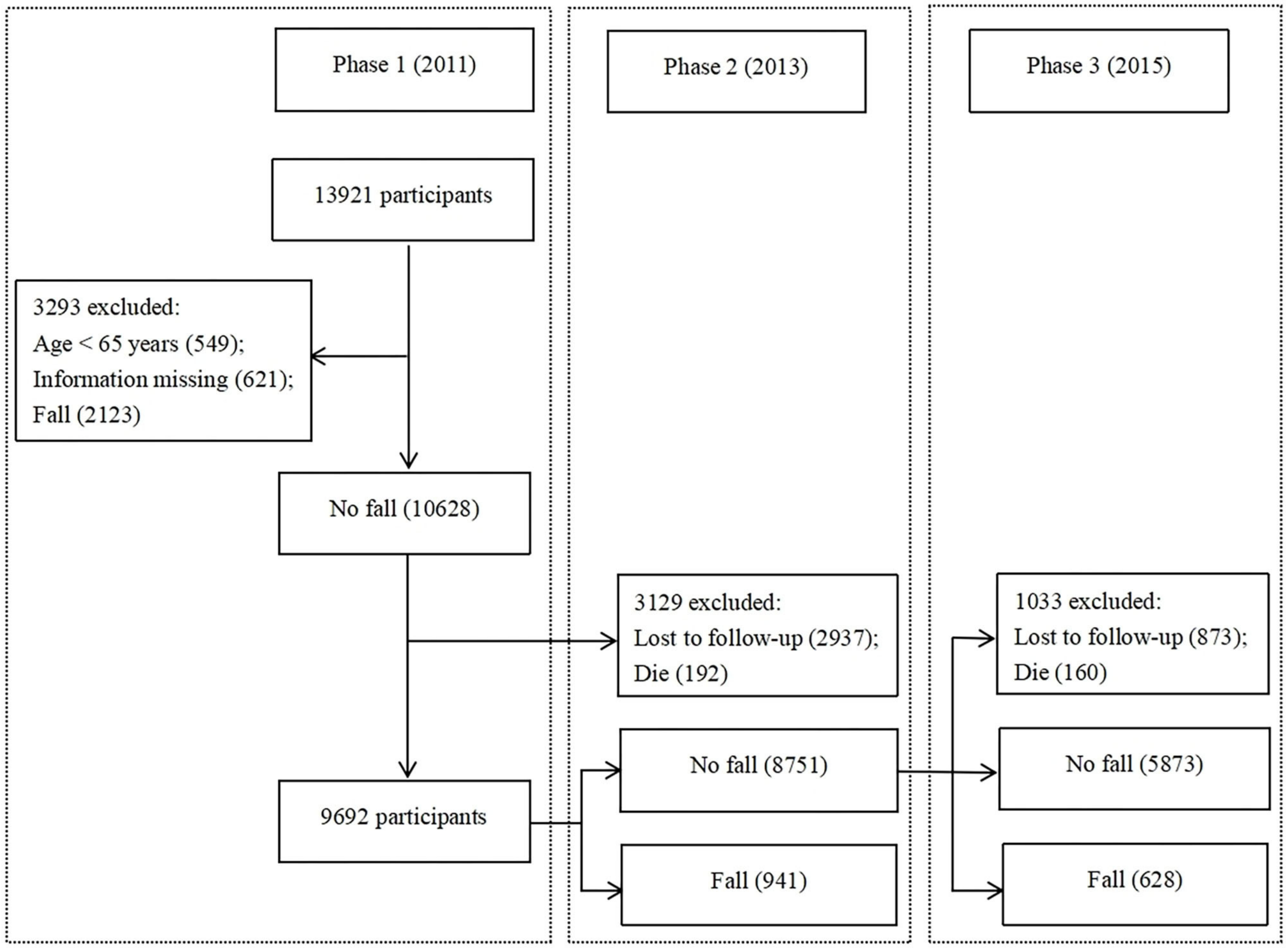

FIGURE 1 | Flow chart of participant enrolment.

doing chores, preparing hot meals, shopping, managing money, and taking medications (18). The responses comprised of four options (having no difficulty, having difficulty but can still do it, having difficulty and need help, and cannot do it). In the participants, we regarded having the ability to complete all these items without difficulty as being ADL independent, and having difficulty with any item as having restricted ADL.

Ascertainment of Covariates

The sociodemographic characteristics included age (60–74 years or ≥75 years), sex (men or women), education level (no more than elementary school, middle school, or high school and above), and marital status (married, widowed, or others). The time-varying variables included residence (urban or rural), chronic condition (lived with one or more of the 14 chronic conditions diagnosed by a doctor in the previous 6 months), self-assessed health status (good, fair, or poor), and cognitive function. Cognitive function was measured using three tests: episodic memory, figure drawing, and Telephone Interview for Cognitive Status (TICS). The episodic memory, figure drawing, and TICS scores ranged from 0 to 10, 0 to 1, and 0 to 10, respectively. The cognitive function score was the sum of the three test scores and ranged from 0 to 21 (19).

Hypothetical Interventions on Risk Factors for Falls

We presented nine feasible and nine intensive hypothetical interventions, and the joint interventions. The feasible interventions were determined in view of evidence from randomized controlled trials (RCTs) or clinical guidelines (20–22). These were: 50% of individuals had increased sleep duration from <8 to 8 h; all individuals participated in social activities every week; 13% of smokers quit smoking; 20% of drinkers quit drinking; all individuals maintained BMI ≤ 27.9 kg/m^2; all individuals maintained SBP < 140 mmHg; 50% of individuals had fair or good vision; 50% of depressed individuals were no longer depressive; and 50% of individuals did not have restricted ADL. The intensive interventions were as follows: all individuals had increased sleep duration from <8 to 8 h; all individuals participated in social activities every day; all smokers quit smoking; all drinkers quit alcohol; all individuals maintained BMI ≤ 23.9 kg/m^2; all individuals maintained SBP < 120 mmHg;

all individuals had fair or good vision; all individuals were not depressed; and all individuals did not have restricted ADL.

Statistical Analysis

The parametric g-formula, which indicated the standardization generalization for time-varying exposures and confounders, was performed to estimate the 4-year cumulative risk of falls on the basis of hypothetical interventions (23). We conducted regression models for the time-varying covariates (deaths and falls). Furthermore, we simulated the risk of falls under each intervention through these models by the following steps: using the observed values of covariates at baseline; using a parametric model to evaluate the combined distribution of time-varying covariates; intervening by setting the value of the covariate to the values based on the hypothetical intervention; and assessing the predicted risk of falls and death by the new values.

The estimated fall risks were compared under different interventions to the 4-year risk under no intervention to calculate the risk ratios (RRs) and risk differences (RDs) for the population. We conducted subgroup analyses to assess potential effects by sex (men or women), and age (60–74 years or ≥75 years). We also conducted sensitivity analyses, in which we changed the order of the time-varying covariates under interventions in the model and excluded the participants who reported falls with SBP < 100 mmHg. We used nonparametric bootstrapping with 500 samples to estimate the 95% confidence intervals (CIs). The proportion of individuals who were intervened at any period, as well as the average proportion of individuals intervened at each 2-yearly period, were calculated. All analyses were performed using SAS (version 9.4; SAS Institute, Cary, NC, USA).

RESULTS

During the follow-up of 4 years, we documented 1,569 falls. Of the 9,692 eligible participants, the mean age was 73.2 (8.6) years, and 4,900 (50.6%) were women. Overall, 5,373 individuals (55.4%) participated in social activities, and over half (53.1%) had chronic disease. Only 15.2% had restricted ADL, and ∼30.0% had good vision. The mean scores of depression and cognitive function were 10.2 and 11.0, respectively. The mean sleep duration was 6.2 h. The characteristics of the eligible participants are shown in **Table 1**.

The simulated 4-year risk of falls under no intervention was 22.21% (95% CI: 20.41–24.20), similar to the observed risk of 23.58%. The model performed well-based on the relatively small error between the simulated and observed values of each covariate in this study (**Table 2**).

The feasible interventions can substantially reduce the risk of falls. Specifically, compared to no intervention, increasing sleep duration to 8 h; participating in social activities every week; improving the vision, depression condition, and ADL capability in 50% of individuals would reduce fall risk by 4.0, 5.0, 4.0, 4.0, and 15%, respectively; whereas 13% of smokers quit smoking, 20% of drinkers quit drinking, and reducing BMI and SBP did not substantially alter the fall risk (**Table 3**).

Under intensive interventions for the same interventions, increasing sleep duration to 8 h and the frequency of

TABLE 1 | Demographic characteristics of study participants (2011).

Characteristics	*N*	%
Age, years		
65–74	7,771	80.2
≥75	1,921	19.8
Sex, *n* (%)		
Men	4,792	49.4
Women	4,900	50.6
Level of education, *n* (%)		
No more than elementary school	3,835	39.6
Middle school	3,751	38.7
High school and above	2,106	21.7
Marital status, *n* (%)		
Married	8,439	87.1
Widowed	1,035	10.7
Others	218	2.2
Residence, *n* (%)		
Urban	6,022	62.1
Rural	3,670	37.9
Smoking status, *n* (%)		
Yes	849	8.8
No	8,843	91.2
Drinking status, *n* (%)		
Yes	3,576	36.9
No	6,116	63.1
Participating in social activities, *n* (%)		
Yes	5,373	55.4
No	4,319	44.6
Chronic condition, *n* (%)		
Yes	5,147	53.1
No	4,545	46.9
Self-assessed health status, *n* (%)		
Good	1,566	16.2
Fair	5,869	60.6
Poor	2,257	23.2
Restricted ADL, *n* (%)		
Yes	1,475	15.2
No	8,217	84.8
Vision, *n* (%)		
Good	2,850	29.4
Fair	4,485	46.3
Poor	2,357	24.3
BMI, *n* (%)		
<18.5 kg/m^2	2,370	24.4
18.5–23.9 kg/m^2	4,884	50.4
≥24.0 kg/m^2	2,438	25.2
SBP, *n* (%)		
<120 mmHg	3,343	34.5
121–139 mmHg	3,620	37.4
>140 mmHg	2,729	28.2
Depression score, mean (SD)	10.2	4.5
Sleep duration, mean (SD), h	6.2	2.1
Cognitive function score, mean (SD)	11.0	3.4

ADL, Activity of daily living; BMI, Body Mass Index; SBP, Systolic Blood Pressure.

TABLE 2 | The comparison of actual observation and simulated average values.

	2011			2013			2015		
	Observed data	Simulated data	Relative error (%)	Observed data	Simulated data	Relative error (%)	Observed data	Simulated data	Relative error (%)
Residence	0.34	0.34	1.00	0.34	0.34	1.00	0.32	0.34	6.90
Chronic condition	1.31	1.32	1.90	1.56	1.71	9.10	1.14	1.46	28.10
Self-assessed health status	1.95	1.95	0.30	1.96	1.95	0.40	1.96	1.80	7.80
Smoking	0.72	0.72	0.40	0.72	0.73	1.50	0.70	0.73	6.50
Drinking	0.60	0.60	0.40	0.59	0.60	1.50	0.61	0.63	4.50
Social activities	1.14	1.13	1.40	1.19	1.15	3.40	1.17	1.04	11.60
Vision	0.76	0.76	0.40	0.75	0.74	1.50	0.78	0.76	4.60
Body mass index	1.56	1.56	0.40	1.62	1.62	0.50	1.62	1.61	0.50
Systolic blood pressure	2.02	2.01	0.40	2.06	2.05	0.90	2.00	2.07	3.50
Activity of daily living	0.12	0.12	0.40	0.17	0.18	16.70	0.20	0.26	34.50
Depression	9.70	9.74	0.50	7.96	8.82	10.50	8.92	10.26	16.00
Sleep duration	6.33	6.34	0.10	6.20	6.13	1.60	6.43	6.20	3.70
Cognitive function	0.40	0.40	0.20	0.62	0.68	8.00	0.43	0.52	20.50

TABLE 3 | Risk of fall under feasible hypothetical interventions (CHARLS 2011–2015).

No.	Intervention	4-year risk of fall (%) (95% CI)[a]	RR (95% CI)[b]	RD (95% CI)[b]	Cumulative intervention (%)	Average intervention (%)
0	No intervention	22.21 (20.41, 24.20)	1.00	0.00	0	0
1	Sleep duration increased to 8 h for 50% of individuals	21.35 (20.44, 23.58)	0.96 (0.92, 0.98)	−0.86 (−0.95, −0.43)	76	36
2	Participating in social activities every week	21.20 (17.34, 24.99)	0.95 (0.70, 0.99)	−1.01 (−1.12, −0.49)	98	90
3	13% of smokers quit smoking	21.86 (21.18, 24.01)	0.98 (0.96, 1.02)	−0.35 (−0.51, 0.85)	21	7
4	20% of drinkers quit drinking	21.77 (21.04, 23.85)	0.97 (0.96, 1.02)	−0.44 (−0.62, 1.02)	36	22
5	BMI reduced to ≤27.9 kg/m^2	22.10 (21.54, 23.68)	0.99 (0.98, 1.03)	−0.11 (−0.26, 0.52)	30	11
6	SBP reduced to <140 mmHg	21.96 (21.23, 24.12)	0.98 (0.97, 1.03)	−0.25 (−0.43, 0.73)	45	20
7	50% of individuals intervened as fair or good vision	21.46 (20.62, 23.17)	0.96 (0.92, 0.99)	−0.75 (−0.87, −0.40)	80	48
8	50% of depressed individuals were not depressive	21.40 (20.84, 23.97)	0.96 (0.95, 0.98)	−0.81 (−0.94, −0.42)	37	18
9	ADL for 50% of individuals was not restricted	20.21 (19.03, 21.46)	0.85 (0.82, 0.89)	−2.00 (−2.52, −1.03)	36	21

[a] *The observed risk is 23.58%.*

[b] *Estimated using the parametric g-formula with covariates: age, sex, marital status, education level, and marital status; time-varying covariates: residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.*

ADL, Activity of daily living; BMI, Body Mass Index; SBP, Systolic Blood Pressure; RR, Risk Ratio; RD, Risk Difference; CI, Confidence Interval.

participation in social activities to every day, and improving the vision, depression condition, and ADL capability in 100% of individuals reduced the 4-year fall risk by 7.0, 12.0, 14.0, 9.0, and 21%, respectively. Other intensive interventions did not substantially change the risk of falls (**Table 4**). Subgroup analyses showed the estimated effect of intensive intervention stratified by sex and age. Compared to no intervention, women had a higher risk of falling than men. In addition to the intervention for sleep duration, other interventions were more effective in women than in men. However, the heterogeneity test showed that the effects of all the intensive interventions in men and women were not statistically significant (**Table 5**). Furthermore, participants aged 65–74 years had a lower risk of falls than those aged ≥75 years under no intervention. For the intervention of sleep duration and the frequency of social activities, fall risk in the 65–74 years group would be better intervened in than that in the ≥75 years group. Similarly, there were no differences between being aged 65–74 years and ≥75 years under intensive interventions (**Table 6**).

The results of the analyses for the joint interventions are presented in **Table 7**, which excluded four interventions (smoking status, drinking status, BMI, and SBP) that were not statistically significant in the single intervention analysis. All intensive combination interventions could significantly reduce the risk of falls in older adults. The five complicated intensive interventions, which included increasing sleep duration and the frequency of participating in social activities; and improving the vision, depression condition, and ADL capability reduced the risk of falls the most (RR: 0.67, 95% CI: 0.56–0.72). These were followed by interventions that combined increasing sleep

TABLE 4 | Risk of fall under intensive hypothetical interventions (CHARLS 2011–2015).

No.	Intervention	4-year risk of fall (%) (95% CI)[a]	RR (95% CI)[b]	RD (95% CI)[b]	Cumulative intervention (%)	Average intervention (%)
0	No intervention	22.21 (20.41, 24.20)	1.00	0.00	0	0
1	Sleep duration increased to 8 h for all individuals	21.12 (20.44, 23.58)	0.93 (0.87, 0.96)	−1.09 (−1.21, −0.12)	95	71
2	Participating in social activities every day	20.13 (19.31, 22.67)	0.88 (0.79, 0.92)	−2.08 (−4.34, −1.15)	98	84
3	All smokers quit smoking	21.57 (20.89, 23.46)	0.98 (0.95, 1.03)	−0.64 (−0.76, 0.19)	48	18
4	All drinkers quit drinking	21.30 (19.97, 23.24)	0.97 (0.95, 1.02)	−0.91 (−1.03, 0.24)	49	20
5	BMI reduced to ≤23.9 kg/m^2	21.01 (20.34, 22.92)	0.92 (0.86, 1.03)	−1.20 (−1.31, 0.45)	42	17
6	SBP reduced to <120 mmHg	21.04 (20.22, 22.84)	0.93 (0.87, 1.04)	−1.17 (−1.30, 0.68)	78	45
7	All individuals intervened as fair or good vision	20.42 (20.03, 23.52)	0.86 (0.74, 0.91)	−1.79 (−1.95, −0.76)	83	49
8	All depressed individuals were not depressive	20.97 (18.84, 23.31)	0.91 (0.85, 0.96)	−1.24 (−1.37, −0.23)	71	36
9	ADL for all individuals was not restricted	18.11 (17.06, 19.42)	0.79 (0.74, 0.85)	−4.10 (−5.72, −3.15)	86	51

[a] *The observed risk is 23.58%.*
[b] *Estimated using the parametric g-formula with covariates: age, sex, marital status, education level, and marital status; time-varying covariates: residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.*
ADL, Activity of daily living; BMI, Body Mass Index; SBP, Systolic Blood Pressure; RR, Risk Ratio; RD, Risk Difference; CI, Confidence Interval.

TABLE 5 | Risks of falls under intensive interventions by sex.

No.	Intervention	Men		Women		Heterogeneity
		4-year risk of fall (%) (95% CI)[a]	RR (95% CI)[b]	4-year risk of fall (%) (95% CI)[c]	RR (95% CI)[b]	*P*-value
0	No intervention	20.64 (19.22, 22.31)	1.00	25.27 (24.21, 26.73)	1.00	–
1	Sleep duration increased to 8 h for all individuals	18.68 (17.21, 20.16)	0.91 (0.88, 0.97)	24.15 (22.96, 26.01)	0.96 (0.91, 1.00)	0.580
2	Participating in social activities every day	19.67 (16.41, 23.34)	0.97 (0.72, 1.12)	21.89 (22.96, 26.01)	0.85 (0.70, 1.05)	0.644
3	All smokers quit smoking	20.21 (19.43, 22.89)	0.99 (0.98, 1.03)	24.20 (22.59, 25.89)	0.96 (0.93, 1.07)	0.606
4	All drinkers quit alcohol	20.12 (19.32, 23.12)	0.98 (0.97, 1.03)	23.89 (22.04, 25.71)	0.95 (0.92, 1.05)	0.581
5	BMI reduced to ≤ 23.9 kg/m^2	20.09 (19.30, 23.08)	0.98 (0.96, 1.02)	23.54 (21.96, 25.45)	0.95 (0.92, 1.04)	0.523
6	SBP reduced to < 120 mmHg	20.01 (19.17, 23.02)	0.98 (0.95, 1.02)	23.26 (21.43, 25.22)	0.94 (0.91, 1.03)	0.519
7	All individuals intervened as fair or good vision	19.75 (18.52, 20.48)	0.97 (0.93, 0.99)	24.38 (23.03, 26.08)	0.97 (0.94, 0.98)	0.678
8	All depressed individuals were not depressive	19.36 (17.92, 20.47)	0.95 (0.91, 0.96)	23.51 (22.06, 24.87)	0.92 (0.90, 0.96)	0.458
9	ADL for all individuals was not restricted	16.84 (15.67, 19.03)	0.81 (0.76, 0.89)	18.12 (15.54, 20.73)	0.70 (0.61, 0.82)	0.302

[a] *The observed risk is 21.60%.*
[b] *Estimated using the parametric g-formula with covariates: age, marital status, education level, and marital status; time-varying covariates: residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.*
[c] *The observed risk is 26.23%.*
ADL, Activity of daily living; BMI, Body Mass Index; SBP, Systolic Blood Pressure; RR, Risk Ratio; CI, Confidence Interval.

duration and the frequency of participating in social activities, and improving the vision and depression condition (RR: 0.74, 95% CI: 0.62–0.79); increasing sleep duration combined with the frequency of participating in social activities and improving the vision (RR: 0.78, 95% CI: 0.65–0.86); and increasing sleep duration combined with the frequency of participating in social activities (RR: 0.81, 95% CI: 0.71–0.90). The sensitivity analysis, which examined whether the order of the variables and the participants who reported falls with SBP < 100 mmHg could affect the results, revealed that the RR and RD did not change materially (**Tables 8, 9**).

DISCUSSION

Our study found that a feasible hypothetical intervention of a functional status factor (ADL) was associated with decreased fall risk (15%) during the 4-year follow-up in Chinese older adults, whereas intensive hypothetical intervention decreased fall risk (21%). A combination of feasible modifications (sleep duration, social activities, vision, depression, and ADL) led to a 22% reduction in the risk of falls, and a more intensive combined intervention could reduce the risk of falls by 33%. Recently, a meta-analysis of RCTs on preventing falls in community-dwelling older adults also showed that multifactorial interventions could reduce the risk of falls by 34 and 28% in the high-risk and healthy groups, respectively (24). This revealed that the reduced fall rates in this study was very close to that of our study.

The results of our hypothetical interventions for improving the effect of ADL capability on falls, which would reduce the 4-year fall risk, are in line with those of previous studies. Prospective studies reported that older adults with higher ADL

TABLE 6 | Risks of falls under single intensive interventions by age.

No.	Intervention	60–74 years		≥75 years		Heterogeneity
		4-year risk of fall (%) (95% CI)[a]	RR (95% CI)[b]	4-year risk of fall (%) (95% CI)[c]	RR (95% CI)[b]	*P*-value
0	None	22.38 (21.42, 24.49)	1.00	24.19 (22.90, 26.08)	1.00	–
1	Sleep duration increased to 8 h for all individuals	20.54 (19.02, 22.94)	0.91 (0.87, 1.08)	23.25 (21.11, 24.52)	0.96 (0.90, 0.98)	0.481
2	Participating in social activities every day	16.47 (15.02, 22.75)	0.73 (0.62, 1.02)	25.10 (19.17, 31.88)	1.02 (0.78, 1.35)	0.420
3	All smokers quit smoking	21.94 (20.17, 24.10)	0.97 (0.93, 1.04)	23.98 (22.70, 25.22)	0.97 (0.94, 1.08)	0.543
4	All drinkers quit alcohol	21.73 (20.03, 24.01)	0.95 (0.91, 1.03)	23.74 (22.46, 25.01)	0.98 (0.93, 1.07)	0.502
5	BMI reduced to ≤23.9 kg/m^2	21.67 (19.89, 23.84)	0.95 (0.91, 1.03)	23.45 (22.13, 24.89)	0.97 (0.92, 1.07)	0.535
6	SBP reduced to <120 mmHg	21.45 (19.72, 23.56)	0.94 (0.90, 1.02)	23.36 (22.07, 24.68)	0.97 (0.92, 1.06)	0.591
7	All individuals intervened as fair or good vision	21.37 (20.29, 24.23)	0.94 (0.91, 1.04)	23.23 (21.90, 24.53)	0.96 (0.91, 0.98)	0.668
8	All depressed individuals were not depressive	21.15 (20.15, 24.05)	0.93 (0.91, 0.97)	22.57 (21.36, 24.86)	0.94 (0.89, 0.97)	0.707
9	ADL for all individuals was not restricted	16.20 (15.27, 17.70)	0.70 (0.66, 0.77)	19.36 (16.35, 21.18)	0.79 (0.70, 0.83)	0.125

[a]The observed risk is 22.04%.
[b]Estimated using the parametric g-formula with covariates: sex, marital status, education level, and marital status; time-varying covariates: residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.
[c]The observed risk is 25.93%.
ADL, Activity of daily living; BMI, Body Mass Index; SBP, Systolic Blood Pressure; RR, Risk Ratio; CI, Confidence Interval.

TABLE 7 | Effect of joint hypothetical interventions on 4-years fall risk (CHARLS 2011–2015).

No.	Intervention	4-year risk of fall (%) (95% CI)[a]	RR (95% CI)[b]	RD (95% CI)[b]	Cumulative intervention (%)	Average intervention (%)
0	No intervention	22.21 (20.41, 24.20)	1.00	0.00	0	0
Feasible joint interventions						
1	Sleep duration, and social activities	20.96 (15.01, 24.25)	0.92 (0.74, 1.04)	−1.25 (−6.76, 1.05)	100	94
2	Sleep duration, social activities, and vision	20.57 (14.86, 23.74)	0.89 (0.65, 1.04)	−1.64 (−7.19, 1.12)	100	95
3	Sleep duration, social activities, vision, and depression	20.24 (14.34, 23.28)	0.86 (0.61, 1.03)	−1.97 (−7.54, 0.96)	100	95
4	Sleep duration, social activities, vision, depression, and ADL	19.87 (13.59, 22.57)	0.78 (0.52, 0.91)	−2.34 (−7.91, −1.80)	100	96
Intensive joint interventions						
1	Sleep duration, and social activities	19.14 (17.23, 21.25)	0.81 (0.71, 0.90)	−3.07 (−5.23, −0.74)	100	97
2	Sleep duration, social activities, and vision	18.56 (16.63, 20.81)	0.78 (0.65, 0.86)	−3.65 (−5.92, −1.38)	100	97
3	Sleep duration, social activities, vision, and depression	17.53 (15.56, 19.72)	0.74 (0.62, 0.79)	−4.68 (−7.04, −2.45)	100	98
4	Sleep duration, social activities, vision, depression, and ADL	16.42 (14.40, 18.61)	0.67 (0.56, 0.72)	−5.79 (−8.21, −3.76)	100	98

[a]The observed risk is 23.58%.
[b]Estimated using the parametric g-formula with covariates: age, sex, marital status, education level, and marital status; time-varying covariates: residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.
ADL, Activity of daily living; RD, risk difference; CI, Confidence Interval.

capability had a lower risk of falls, especially for those with a higher frequency of shopping activities and doing chores (25, 26). It has been suggested that restricted ADL is associated with decreased strength, balance, and endurance (27, 28). As a result, the risk of falls increases. The present study also found that the association between being aged ≥75 years and fall risk became stronger. This may be because the decline in ADL capability increases with age (29).

We found that better vision could protect older adults from falls. Considerable studies have shown that older adults with impaired vision have a higher risk of falls (30, 31). Among explanations regarding the reasons why impaired vision may be associated with increased risk of falls, most are related to processes that are implicated in body balance, such as the coordination of visual and vestibular system, muscle strength, and reaction time.

The hypothetical interventions of participating in social activities from our results could reduce the 4-year risk of falls in older adults. A prospective study provided clear evidence of the association between participating in more social activities and a lower risk of falls among older adults (32). In a meta-analysis of RCTs, dance-based mind-motor activities were significantly

TABLE 8 | Sensitivity analyses for risks of falls by changing the order of time-varying covariates under interventions.

Interventions	4-year risk of fall (%) (95% CI)	RR (95% CI)[a]
None	22.03 (20.41, 24.20)	1.00
Feasible intervention		
Sleep duration increased to 8 h for 50% of individuals	21.15 (20.24, 23.28)	0.94 (0.91, 0.97)
Participating in social activities every week	21.32 (17.54, 25.02)	0.96 (0.72, 0.99)
13% of smokers quit smoking	21.70 (20.97, 23.81)	0.98 (0.96, 1.02)
20% of drinkers quit drinking	21.78 (21.05, 23.89)	0.98 (0.96, 1.03)
BMI reduced to ≤27.9 kg/m^2	22.06 (21.46, 23.58)	0.99 (0.98, 1.04)
SBP reduced to <140 mmHg	21.87 (21.13, 23.25)	0.98 (0.97, 1.03)
50% of individuals intervened as fair or good vision	21.23 (20.42, 22.87)	0.96 (0.92, 0.99)
50% of depressed individuals were not depressive	21.44 (20.74, 23.40)	0.97 (0.96, 0.98)
ADL for 50% of individuals was not restricted	20.29 (19.13, 21.84)	0.86 (0.83, 0.89)
Intensive intervention		
Sleep duration increased to 8 h for all individuals	20.97 (20.13, 23.28)	0.91 (0.85, 0.95)
Participating in social activities every day	20.15 (19.34, 22.69)	0.88 (0.78, 0.91)
All smokers quit smoking	21.69 (21.01, 23.57)	0.97 (0.93, 1.02)
All drinkers quit drinking	21.20 (19.77, 23.04)	0.96 (0.94, 1.05)
BMI reduced to ≤23.9 kg/m^2	21.03 (20.36, 22.95)	0.92 (0.86, 1.03)
SBP reduced to <120 mmHg	21.01 (20.18, 22.81)	0.92 (0.87, 1.04)
All individuals intervened as fair or good vision	20.40 (20.07, 23.47)	0.86 (0.73, 0.90)
All depressed individuals were not depressive	20.95 (18.82, 23.29)	0.91 (0.84, 0.96)
ADL for all individuals was not restricted	18.31 (17.45, 19.71)	0.81 (0.72, 0.83)

[a] *The order of time-varying covariates was residence, cognitive function, smoking status, drinking status, social activities, self-assessed health status, vision, chronic condition, ADL, BMI, depression, SBP, and sleep duration; the order of time-varying covariates in this study was residence, chronic condition, self-assessed health status, cognitive function, sleep duration, social activities, smoking status, drinking status, BMI, SBP, vision, depression, and ADL.*

ADL, Activity of Daily Living; BMI, Body Mass Index; SBP, Systolic Blood Pressure; RR, Risk Ratio; CI, Confidence Interval.

TABLE 9 | Sensitivity analyses for risks of falls by excluding the participants who reported falls with SBP < 100 mmHg under interventions.

Interventions[a]	4-year risk of fall (%) (95% CI)	RR (95% CI)
None	21.86 (20.12, 23.94)	1.00
Feasible intervention		
Sleep duration increased to 8 h for 50% of individuals	21.01 (20.04, 22.96)	0.93 (0.89, 0.96)
Participating in social activities every week	21.18 (17.21, 24.80)	0.95 (0.75, 0.98)
13% of smokers quit smoking	21.56 (20.66, 23.70)	0.97 (0.94, 1.01)
20% of drinkers quit drinking	21.60 (20.89, 23.62)	0.97 (0.94, 1.02)
BMI reduced to ≤27.9 kg/m^2	21.91 (21.26, 23.36)	0.98 (0.96, 1.03)
SBP reduced to <140 mmHg	21.72 (20.91, 23.05)	0.97 (0.96, 1.03)
50% of individuals intervened as fair or good vision	21.03 (20.26, 22.62)	0.95 (0.90, 0.98)
50% of depressed individuals were not depressive	21.32 (20.65, 23.27)	0.95 (0.94, 0.98)
ADL for 50% of individuals was not restricted	20.14 (18.97, 21.78)	0.84 (0.81, 0.87)
Intensive intervention		
Sleep duration increased to 8 h for all individuals	20.81 (20.01, 23.12)	0.90 (0.83, 0.95)
Participating in social activities every day	20.01 (19.14, 22.49)	0.87 (0.76, 0.90)
All smokers quit smoking	21.54 (20.87, 23.36)	0.96 (0.91, 1.01)
All drinkers quit drinking	21.04 (19.55, 22.84)	0.95 (0.93, 1.04)
BMI reduced to ≤23.9 kg/m^2	20.93 (20.16, 22.80)	0.92 (0.85, 1.02)
SBP reduced to <120 mmHg	20.85 (20.02, 22.73)	0.91 (0.87, 1.03)
All individuals intervened as fair or good vision	20.24 (19.92, 23.32)	0.85 (0.71, 0.88)
All depressed individuals were not depressive	20.81 (18.68, 23.13)	0.90 (0.82, 0.96)
ADL for all individuals was not restricted	18.17 (17.25, 19.52)	0.81 (0.70, 0.82)

[a] *ADL, Activity of daily living; BMI, body mass index; SBP, Systolic blood pressure; RR, risk ratio; CI, confidence interval.*

associated with a 37% reduced risk of falls among older adults (33). Dance offers older people an opportunity for greater social activities, thereby contributing to falls prevention.

The significant risk reduction for falls by alleviating depressive symptoms in this study is consistent with previous evidence connecting depressive symptoms with falls (34, 35). A prospective study found that alleviating depressive symptoms was associated with a decline in fall risk in a large sample of community-dwelling older people (36).

The hypothetical intervention of extending the sleep duration to 8 h can effectively reduce the risk of falls among older adults. Existing literature reveals that participants who have a sleep duration of $\leq$5 h are more likely to report falls, whereas no association was found between sleep duration > 8 h and falls (37). However, a meta-analysis of observational studies concluded that an approximately U-shaped curve was observed between sleep duration and falls; that is, both short and long sleep durations are significantly associated with falls (38). Since only 4.21% of the included samples had sleep durations longer than 8 h, an intervention analysis on the impact of excessive sleep duration on falls was not conducted in this study. Future research need to be launched on an intervention with longer sleep duration to further explore the effect of sleep duration on falls.

We did not found a significant effect of cessation of smoking or alcohol on falls. There was a hysteresis effect of the hypothetical intervention of smoking and drinking, which resulted in health benefits that could not be observed in the short term or during the follow-up period. Similarly, a study of stroke showed that the excess risk of stroke among former smokers disappeared from 2 to 4 years after cessation (39). In addition, an effect of reducing BMI and SBP on falls was not found. A longitudinal population-based survey suggested that obesity (BMI $\geq$ 28.0 kg/m^2) appeared to be associated with a greater risk of falls in older adults (40). Possible mechanisms include lower levels of physical activity, postural balance, and vitamin D deficiency (41). In our study, reducing the BMI to overweight or normal levels did not significantly decrease the risk of falls. One plausible explanation is that the proportion of overweight or obese participants was low, and the hypothetical intervention result was not obvious. The relationship between SBP and falls is complex. Evidence of SBP and the risk of falls in older adults are inconsistent. While an observational study has demonstrated that SBP is a significant risk factor for falls (42), other studies showed no association (43, 44). The recent studies concluded that orthostatic hypotension and low SBP were significantly positively correlated with falls in older adults (45, 46). However, the sensitivity analysis in our study showed no substantial change when we excluded the participants who reported falls with SBP < 100 mmHg during the follow-up.

Our study has several strengths, including its population-based longitudinal design, standardized survey methods, and longer follow-up time. We applied the parametric g-formula with adjustment for time-varying confounders by risk factors of falls and simulated interventions on lifestyle factors, health indicators, psychological conditions, and functional status. However, there were several limitations to this study. First, the assumptions for the observational study were no model misspecification, no measurement error, and no unmeasured confounding, which determined the validity of the parametric g-formula in our study. We have adjusted for multiple risk factors to alleviate the problems of no unmeasured confounding factors that are inevitable in an observational research. Second, the simulated data from the parametric g-formula was similar to the observed data, which revealed the necessary condition of the absence of model misspecification, and the results of the sensitivity analyses were robust across different specifications. Third, our study assumed that the counterfactual result of each scenario should be the same with the results observed under the observed exposure history, which requires consistency. This assumption may have been met for sleep duration and social activities, but less likely for BMI, SBP, depression, and ADL. Hence, the hypothetical effects of BMI, SBP, depression, and ADL should be interpreted as the influence of the combination of factors that can change these interventions. Fourth, we could not provide information on subdivision of falls (recurrent, unexplained, and injurious falls), polypharmacy, and orthostatic hypotension because of the lack of these information in the survey. Finally, in the parametric g-formula in this study, the risk was standardized based on the distribution of confounding factors, and caution should be exercised when generalizing these results to other populations.

CONCLUSION

This study found that hypothetical interventions for increasing sleep duration, participating in more social activities, better vision, alleviating depressive symptoms, as well as improving ADL capability, were beneficial to protect older adults from falls by applying a parametric g-formula on the CHARLS data. Our findings suggest that a combination of lifestyle factors, health indicators, psychological conditions, and functional status may prove to be an effective strategy for preventing falls among older adults.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Medical Ethics Committee of Peking University (IRB00001052-11015). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JiR and GL contributed to conception, design, data acquisition and interpretation, and critically revised the manuscript. LZ contributed to conception, data interpretation, and performed all statistical analyses. NZ contributed to conception and drafted manuscript. JuR contributed to data cleaning and critically revised the manuscript. All authors gave their final approval and agree to be responsible for all aspects of the work.

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Association Between Sensory Loss and Falls Among Middle-Aged and Older Chinese Population: Cross-Sectional and Longitudinal Analyses

Yifan Zhou[1], Yanping Hu[2], Jianfeng Luo[3], Yinwen Li[4,5,6], Haiyun Liu[4,5,6], Xiaodong Sun[4,5,6]* and Minwen Zhou[4,5,6]*

[1] Department of Ophthalmology, Putuo People's Hospital, Tongji University, Shanghai, China, [2] Shanghai Putuo Center for Disease Control and Prevention, Shanghai, China, [3] School of Public Health, Fudan University, Shanghai, China, [4] Department of Ophthalmology, Shanghai General Hospital (Shanghai First People's Hospital), School of Medicine, Shanghai Jiao Tong University, Shanghai, China, [5] National Clinical Research Center for Eye Diseases, Shanghai, China, [6] Shanghai Key Laboratory of Fundus Diseases, Shanghai, China

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Tzvi Dwolatzky,
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Peking University, China

****Correspondence:***
Minwen Zhou
zmw8008@163.com
Xiaodong Sun
xdsun@sjtu.edu.cn

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Introduction: Previous studies have suggested that sensory loss is linked to falls. However, most of these studies were cross-sectional designed, focused on single sensory loss, and were conducted in developed countries with mixed results. The current study aims to investigate the longitudinal relationship between hearing loss (HL), vision loss (VL) and dual sensory loss (DSL) with falls among middle-aged and older Chinese population over 7 years.

Methods: The data was obtained from the China Health and Retirement Longitudinal Survey (CHARLS). In total, 7,623 Chinese older adults aged over 45 were included at baseline 2011 in this study. Self-reported falls and HL/VL/DSL were accepted. Other confounding variables included age, sex, BMI, educational level, marital status, various physical disorders and lifestyles. The impact of baseline sensory status on baseline prevalence of falls and incident falls over 7 years were assessed using logistic regression analyses. A logistic mixed model was used to assess the association between time-varying sensory loss with incident falls over 7 years after adjusted with multi-confounding factors.

Results: Single and dual sensory loss groups had significantly higher prevalence of falls compared to no sensory loss (NSL) group (DSL: 22.4%, HL: 17.4%, VL: 15.7%, NSL: 12.3%). Baseline HL (OR: 1.503, 95% CI: 1.240–1.820), VL (OR: 1.330, 95% CI: 1.075–1.646) and DSL (OR: 2.061, 95% CI: 1.768–2.404) were significantly associated with prevalence of falls. For longitudinal observation over 7 years, baseline HL/DSL and persistence of all types of sensory loss were associated with incidence of falls. Time-varying HL (OR: 1.203, 95% CI: 1.070–1.354) and DSL (OR: 1.479, 95% CI: 1.343–1.629) were associated with incident falls after adjusted with multi-confounders, while VL was not.

Conclusion: HL and DSL are significantly associated with both onset and increased incidence of falls over 7 year's observation in middle-aged and elderly Chinese population. Persistence or amelioration of sensory loss status could exert divergent influences on incidence of falls, which should be considered in the development of falls-prevention public health policies for aging population.

Keywords: hearing loss, vision loss, dual sensory loss, falls, CHARLS

INTRODUCTION

Falls and fall-induced injuries are leading causes of morbidity and mortality among older people (1). Falls can cause moderate to severe events, such as bone fractures, head trauma, or even increased risk of early death (1). Among elderly people, falls are the leading cause of death due to injury. The frequency of falls increases with aging. Approximately, 28–35% of people all over the world aged over 65 fall every year, and this number increases to 32–42% for those who aged over 70 (2). With the rapid growth of the world's older population, falls has become a major concern of the public health problems worldwide.

As the world's most populous country, China has accelerated aging population with increasing average life expectancy. It is estimated that the number of Chinese people aged 80 years or older will quadruple over the next two decades (3, 4). Until now, according to WHO reports, the annual prevalence of falls among older Chinese population has reached 6.5 to 30.6% (3). Thus, falls, fall-induced injuries and related events in older Chinese population are of great significance. To date, numerous researchers have explored the incidence, risk factors and socio-economic burden of fall and related injuries in Chinese population (4). As for risk factors, some have mentioned the association of sensory loss with falls (5–8).

Sensory loss, consisting of hearing loss (HL), vision loss (VL), and dual sensory loss (DSL, co-occurrence of vision and hearing loss), is one of the most common problems experienced by older people. Although consensus has yet to be reached, the relationship between sensory loss and falls in older population had aroused great concern in both developed and developing countries (6, 9–13). Among older Chinese, the prevalence of self-reported HL, VL, and DSL is relatively higher than the prevalence reported in many developed countries (14). Due to traditional attitudes regarding sensory loss as a normal part of aging life, older Chinese people are likely to ignore problems related to sensory loss, which may further contribute to the higher prevalence of sensory loss and incidence of related problems in our population (14).

Very recently, a small number of cross-sectional studies have reported the potential relationship between vision impairment and falls/fall-related injuries among Chinese population (5, 6, 8). Therefore, longitudinal study is needed. However, researches on hearing loss and falls have yield mixed results (6, 10, 15, 16). Also, the impact of Dual Sensory Loss (DSL) on falls has been barely explored before in our population as well. Thus, allowing for the specific cultural background, attitudes toward sensory loss, and public health system in mainland China, it is necessary to investigate the longitudinal correlation between sensory loss (vision, hearing or both) and falls among older Chinese population.

The China Health and Retirement Longitudinal Study (CHARLS) is the first nationally representative survey of the health status and well-being in middle-aged and older population in China, which provides high-quality longitudinal data of massive amounts of personal health-related information including sensory loss and self-reported falls. The purpose of this study is to verify single/dual sensory loss as risk factors of falls among older Chinese population according to cross-sectional study and longitudinal observation spanning 7 year of follow-up.

METHODS

Participants and Public Involvement

We obtained data from the China Health and Retirement Longitudinal Study (CHARLS), the first nationally representative longitudinal survey sampling residents (middle-aged and older adults, over 45 years old) from 450 villages/neighborhoods, 150 counties across 28 provinces in China. With response rate over 80%, CHARLS provides the most up-to-date longitudinal data sets for studying the health status and well-being of middle-aged and older population in China. There were 17,708 participants interviewed in the 2011 baseline (Wave 1). According to the purpose of the current study, participants with missing data of any variables at 2011 baseline and lost follow-up in falls and sensory loss were excluded, which led to a final sample size of 7,623 (**Figure 1**).

Measures

Outcome

The main outcome in this study is falls, which was determined by the question "Have you fallen down in the last 2 years?" Possible answers included "yes" or "no." We therefore treated the outcome variable as binary. In each follow-up survey, the participants were asked "Have you fallen down since the last interview?" Baseline assessment of falls was used for cross-sectional study and incidence of falls reported during 3 waves of follow-up were used for longitudinal analysis.

Exposure

The main exposure in this present study are self-reported vision loss and hearing loss. In CHARLS, vision loss (VL) included distal vision impairment and near vision impairment. Distal vision impairment was assessed by asking the participants whether their eyesight was excellent, very good, good, fair, or poor when seeing

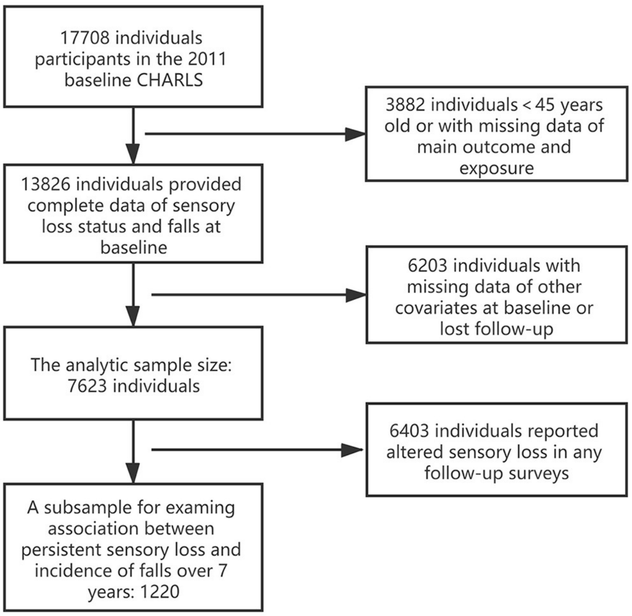

FIGURE 1 | Sample reduction from the 2011 baseline sample of China Health and Retirement Longitudinal Survey (CHARLS) to current analytic sample.

things at a distance. Reporting of fair or poor eyesight was classified as distal vision impairment. Near vision impairment was assessed by asking participants whether their eyesight was excellent, very good, good, fair, or poor when seeing things up close. Reporting of fair or poor eyesight was classified as near vision impairment. To assess hearing loss (HL), the question was: "Is your hearing excellent, very good, good, fair, poor (with a hearing aid if you normally use it and without if you normally don't)." A response to this question stating fair or poor hearing was classified as HL. Such categorization of sensory loss assessment was used in previous studies (17–19). DSL referred to participants with both VL and HL.

In realized that the status of sensory loss could alter during 7 years of observation, we thought that it might be less prudent to only consider the baseline sensory loss status and its association with falls. Persistent exposure to specific sensory loss and altered sensory loss statuses during follow-up should be taken into account in longitudinal study as well. Thus, to assess the impact of persistent exposure condition of different types of sensory loss status on incidence of falls in our participants, the answer to vision/hearing status at each follow-up time point should be the same (e.g., participants with cataract-caused vision impairment and visual improvement after cataract surgery would probably report different vision statuses at different timepoints. Such participants would be regarded as break down of persistent vision loss status and excluded). On the other hand, participants without sensory loss at baseline could develop sensory impairment during follow-up for 7 years and vice versa. Thus, we further treated sensory loss statuses of our participants as time-varying variable to tolerate alterations in surveys at different time points over 7 years. The impact of time-varying sensory loss on incidence of falls appeared during follow-up was also assessed.

Other Variates

Socio-Demographic Characteristics

Gender was a binary variable: male and female. Age was treated as a continuous variable. Marital status indicated whether the respondent lived alone or got accompanied. Participants who were separated, divorced, widowed or never married were coded as "living alone" group, while those who were married or partnered were coded as "living with partner" group. Educational attainment was used to represent social economic status, which could probably affect people's access to health services and other social and economic resources. Educational status was categorized into 5 groups: illiterate, less than elementary school, elementary school, middle school and high school or above as previously reported (20, 21).

Lifestyle

The lifestyle variables included smoking status, drinking status, and physical activities status. Smoking status was categorized as current/former smoker or never smoked. Drinking was a 3-category variable indicating the frequency of drinking: none, less than once a month and more than once a month. Physical activities status was categorized as taking vigorous activity, moderate activity, light activity, or insufficient activity.

Physical Disorders

In CHARLS, most health status and physical disorders were assessed according to self-reports. Only a few diseases could be defined at a relatively precise level based on both self-reported medical history and reference definition like blood test results and physical examinations. Thus, we took only seven main physical disorders into account in the present study: hypertension (22, 23), diabetes (24, 25), dyslipidemia (22, 26), kidney diseases (27), emotional disorders, memory-related diseases and stroke (28). The criteria of identifications of physical disorders used in the current study was also adopted by numerous researchers using CHARLS datasets.

Statistical Analysis

Statistical analyses were performed using SAS, version 9.4 (SAS Institute, Cary, NC, US). In this study, the primary exposure of interest was sensory loss status (HL/VL/DSL), while the other independent variables served as control variables and were reported as means ± SD or numbers (%). Baseline characteristics were compared between participants with different sensory loss statuses (4 groups) using the Chi-square test, Cochran-Mantel-Haenszel (CMH) test or analysis of variance depending on the data type and distribution. Logistic regression analyses were conducted to assess the associations between prevalence/incidence of falls and baseline/persistent sensory loss. While the longitudinal associations between time-varying sensory loss and incident falls were examined using mixed logistic models. Mixed logistic models took into account within-subject correlation of time-varying sensory loss and fall over 7 years of follow-up (3 waves). Multi-confounders including

TABLE 1 | Baseline characteristics of participants by sensory loss.

Variables	No sensory loss (*N* = 2,136)	Hearing loss (*N* = 1,320)	Vision loss (*N* = 1,004)	Dual sensory loss (*N* = 3,163)	*P*-value
Falls					<0.01
Yes	263 (12.3%)	230 (17.4%)	158 (15.7%)	710 (22.4%)	
No	1,873 (87.7%)	1,090 (82.6%)	846 (84.3%)	2,453 (77.6%)	
Gender					<0.01
Male	1,071 (50.1%)	711 (53.9%)	432 (43.0%)	1,435 (45.4%)	
Female	1,065 (49.9%)	609 (46.1%)	572 (57.0%)	1,728 (54.6%)	
Age					<0.01
	59.80 ± 9.20	63.17 ± 9.73	61.75 ± 9.17	64.09 ± 9.30	
BMI					<0.01
	23.51 ± 4.10	23.20 ± 4.03	23.35 ± 3.81	23.10 ± 3.81	
Marital status					<0.01
Yes	1,762 (82.5%)	1,052 (79.7%)	841 (83.8%)	2,495 (78.9%)	
No	374 (17.5%)	268 (20.3%)	163 (16.2%)	668 (21.1%)	
Educational level					<0.01
Illiterate	530 (24.8%)	383 (29.0%)	315 (31.4%)	1,127 (35.6%)	
Less than elementary school	371 (17.4%)	275 (20.8%)	202 (20.1%)	667 (21.1%)	
Elementary school	477 (22.3%)	304 (23.0%)	221 (22.0%)	729 (23.0%)	
Middle school	459 (21.5%)	233 (17.7%)	174 (17.3%)	460 (14.5%)	
High school or above	299 (14.0%)	125 (9.5%)	92 (9.2%)	180 (5.7%)	
Smoking status					<0.01
Yes	860 (40.3%)	590 (44.7%)	359 (35.8%)	1,233 (39.0%)	
No	1,276 (59.7%)	730 (55.3%)	645 (64.2%)	1,930 (61.0%)	
Drinking status					<0.01
Never	553 (25.9%)	351 (26.6%)	237 (23.6%)	740 (23.4%)	
Drink more than once a month	175 (8.2%)	106 (8.0%)	63 (6.3%)	228 (7.2%)	
Drink but less than once a month	1,408 (65.9%)	863 (65.4%)	704 (70.1%)	2,195 (69.4%)	
Physical activity					<0.01
Vigorous	760 (35.6%)	393 (29.8%)	352 (35.1%)	871 (27.5%)	
Moderate	583 (27.3%)	365 (27.7%)	293 (29.2%)	837 (26.5%)	
Light	454 (21.3%)	293 (22.2%)	212 (21.1%)	751 (23.7%)	
Insufficient	339 (15.9%)	269 (20.4%)	147 (14.6%)	704 (22.3%)	
Diabetes					<0.01
Yes	244 (11.4%)	180 (13.6%)	166 (16.5%)	462 (14.6%)	
No	1,892 (88.6%)	1,140 (86.4%)	838 (83.5%)	2,701 (85.4%)	
Hypertension					<0.01
Yes	953 (44.6%)	648 (49.1%)	467 (46.5%)	1,576 (49.8%)	
No	1,183 (55.4%)	672 (50.9%)	537 (53.5%)	1,587 (50.2%)	
Dyslipidemia					0.981
Yes	707 (33.1%)	431 (32.7%)	335 (33.4%)	1,038 (32.8%)	
No	1,429 (66.9%)	889 (67.3%)	669 (66.6%)	2,125 (67.2%)	
Kidney diseases					<0.01
Yes	322 (15.1%)	291 (22.0%)	183 (18.2%)	748 (23.6%)	
No	1,814 (84.9%)	1,029 (78.0%)	821 (81.8%)	2,415 (76.4%)	
Emotional problems					0.07
Yes	15 (0.7%)	14 (1.1%)	13 (1.3%)	47 (1.5%)	
No	2,121 (99.3%)	1,306 (98.9%)	991 (98.7%)	3,116 (98.5%)	
Memory-related diseases					<0.01
Yes	12 (0.6%)	17 (1.3%)	15 (1.5%)	72 (2.3%)	
No	2,124 (99.4%)	1,303 (98.7%)	989 (98.5%)	3,091 (97.7%)	
Stroke					0.02
Yes	35 (1.6%)	36 (2.7%)	30 (3.0%)	92 (2.9%)	
No	2,101 (98.4%)	1,284 (97.3%)	974 (97.0%)	3,071 (97.1%)	

socio-demographic factors, lifestyles and physical disorders were adjusted in logistic models.

RESULTS

In total, 7,623 Chinese older adults aged over 45 at baseline 2011 were deemed eligible for the current study (**Figure 1**). Socio-demographic characteristics, physical conditions and lifestyles of the study sample were grouped by sensory status and presented in **Table 1**. The number of participants at baseline was 7,263 in the current study. For each group, the sample size was 2,136 (NSL), 1,320 (HL), 1,004 (VL), 3,163 (DSL). The DSL group had the highest prevalence of falls (22.4%, $n = 3,163$). Participants with single sensory loss had relatively higher prevalence of falls than those who without sensory loss (HL: 17.4%, VL: 15.7%, NSL: 12.3%, $p < 0.001$).

The univariate logistic regression analysis indicated the potential associated factors of fall in our sample at baseline 2011. Sensory loss including VL, HL, and DSL, along with other factors including gender, age, marital status, educational level, smoking status, physical activities status, diabetes, hypertension, kidney diseases, emotional problems, memory-related diseases and stroke were all found to be significantly associated with fall (all $p < 0.05$, **Table 2**). Compared to single sensory loss, DSL had a higher odds ratio, which means a potentially greater impact on prevalence of falls (OR-DSL: 2.061, OR-HL: 1.503, OR-VL: 1.330).

The results of the univariate logistic regression indicated probabilities that certain covariables that could confound the relationship between sensory loss and falls in multivariate regression models. **Table 3** showed the impact of baseline sensory status on prevalence of falls at baseline and incidence of falls over 7 years according to adjusted multivariable logistic models. At baseline, HL and DSL remained significantly correlated with falls in all 4 Models. VL was found to be significantly correlated with falls in Model 1&2&3, however, after being adjusted with various physical disorders, such correlation become less significant ($p = 0.08$). Similarly, baseline HL and DSL were found to have significant correlation and prediction for higher incidence of falls over 7 year follow-up longitudinal observation after being adjusted with multiple confounding factors, but it was not the case of VL (**Table 3**).

In **Table 4**, we noticed that, compared to baseline sensory loss only, all types of persistent sensory loss statuses (HL/VL/DSL) were significantly and more strongly correlated with incidence of falls over 7 year of follow-up even after adjusting for multi-confounding factors. Mixed logistic regression showed that time-varying HL (OR: 1.203, 95% CI: 1.070–1.354) and DSL (OR: 1.479, 95% CI: 1.343–1.629) were significantly correlated with incident falls during longitudinal observation after adjusting multiple confounding factors. But it was not the case of VL.

TABLE 2 | Univariate logistic regression model to describe the correlation between univariates and prevalence of falls at baseline.

Variables	OR (95% CI)	*P*-value
Main exposure		
No sensory loss	Reference	
Hearing loss	1.503 (1.240,1.821)	< 0.01
Vision loss	1.330 (1.075,1.646)	< 0.01
Dual sensory loss	2.061 (1.768,2.404)	< 0.01
Gender		
Female	Reference	
Male	0.734 (0.652,0.827)	< 0.01
Age	1.021 (1.015,1.027)	< 0.01
BMI	1.003 (0.988,1.018)	0.72
Marital status		< 0.01
Living with partner	Reference	
Living alone	1.220 (1.057,1.408)	
Educational level		
Illiterate	Reference	
Less than elementary school	0.935 (0.797,1.096)	0.41
Elementary school	0.713 (0.607,0.838)	< 0.01
Middle school	0.605 (0.504,0.727)	< 0.01
High school or above	0.462 (0.358,0.597)	< 0.01
Smoking	1.146 (1.015,1.293)	0.03
Drinking status		
Never	Reference	
Drink more than once a month	1.109 (0.968,1.271)	0.14
Drink but less than once a month	1.178 (0.947,1.464)	0.14
Physical activity		
Insufficient	Reference	
Vigorous	0.760 (0.643,0.899)	< 0.01
Moderate	0.754 (0.635,0.896)	< 0.01
Light	0.960 (0.806,1.142)	0.64
Diabetes	1.391 (1.187,1.630)	< 0.01
Hypertension	1.194 (1.061,1.342)	< 0.01
Dyslipidemia	1.007 (0.889,1.141)	0.91
Kidney diseases	1.278 (1.112,1.470)	< 0.01
Emotional problems	2.621 (1.693,4.058)	< 0.01
Memory-related diseases	1.547 (1.012,2.364)	0.04
Stroke	1.587 (1.141,2.206)	< 0.01

DISCUSSION

This study contributes to the current literature examining the relationship between sensory loss and falls in Chinese population. We performed cross-sectional study and 7 year follow-up longitudinal observation to verify sensory loss including vision loss, hearing loss and dual sensory loss as risk factors of falls among older Chinese population for the first time.

The overall prevalence of falls in our sample was around 17.85%. such prevalence was similar to that found in other studies performed in other Asian community-dwelling older (5, 29–31). Since falls has become one of the most common causes of injuries among older people, which could lead to long-term disability or even death, exploration of risk factors associated with falls in older people was warranted. Among various potential risk factors of falls, sensory loss including vision loss and hearing loss has raised great concern in recent years.

TABLE 3 | Multivariate logistic regression models for the associations between baseline sensory loss, baseline prevalence of falls and incident falls over 7 years.

Variables	Baseline sensory loss and baseline prevalence of falls							
	Model 1		Model 2		Model 3		Model 4	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
No sensory loss	Reference		Reference		Reference		Reference	
Hearing loss	1.503***	(1.240, 1.821)	1.440***	(1.186, 1.748)	1.417***	(1.166, 1.721)	1.394***	(1.147, 1.694)
Vision loss	1.330**	(1.075, 1.646)	1.260*	(1.017, 1.562)	1.246	(1.004, 1.546)	1.21	(0.974, 1.502)
Dual sensory loss	2.061***	(1.768, 2.404)	1.899***	(1.624, 2.220)	1.846***	(1.577, 2.161)	1.801***	(1.538, 2.110)

Variables	Baseline sensory loss and incidence of falls over 7 years							
	Model 1		Model 2		Model 3		Model 4	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
No sensory loss	Reference		Reference		Reference		Reference	
Hearing loss	1.345***	(1.161, 1.558)	1.299***	(1.119, 1.508)	1.295***	(1.115, 1.504)	1.282**	(1.104, 1.490)
Vision loss	1.174*	(0.998, 1.381)	1.103	(0.936, 1.299)	1.105	(0.938, 1.303)	1.089	(0.924, 1.285)
Dual sensory loss	1.623***	(1.442, 1.826)	1.487***	(1.318, 1.677)	1.477***	(1.307, 1.668)	1.454***	(1.287, 1.643)

The results of the logistic regression models were expressed as odds ratios (OR) and 95% confidence intervals (CI). The analytic sample size was 7,623.
Model 1: unadjusted.
Model 2: adjusted for demographic factors including age and sex.
Model 3: adjusted for factors in Model 2, as well as social-economic and life style factors including BMI, marital status, educational level, smoking, alcohol consumption and physical activity status.
Model 4: adjusted for factors in Model 3, as well as physical disorders including hypertension, diabetes, dyslipidemia, kidney diseases, emotional disorders, memory-related diseases and stroke.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 4 | The impact of persistent/time-varying sensory loss status on incidence of falls over 7 years.

Variables	Persistent sensory loss and incidence of falls over 7 years							
	Model 1		Model 2		Model 3		Model 4	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
No sensory loss	Reference		Reference		Reference		Reference	
Hearing loss	3.379***	(1.808, 6.317)	3.235***	(1.720, 6.084)	3.302***	(1.745, 6.248)	3.282***	(1.728, 6.234)
Vision loss	2.599*	(1.102, 6.133)	2.431*	(1.023, 5.778)	2.382*	(0.992, 5.716)	2.596*	(1.076, 6.262)
Dual sensory loss	3.486***	(2.641, 4.603)	3.108***	(2.339, 4.130)	3.122***	(2.317, 4.207)	3.045***	(2.252, 4.116)

Variables	Time-varying sensory loss and incidence of falls over 7 years							
	Model 1		Model 2		Model 3		Model 4	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
No sensory loss	Reference		Reference		Reference		Reference	
Hearing loss	1.196**	(1.065, 1.343)	1.204**	(1.071, 1.354)	1.209**	(1.075, 1.360)	1.203**	(1.070, 1.354)
Vision loss	1.111	(0.969, 1.273)	1.102	(0.961, 1.265)	1.112	(0.969, 1.277)	1.11	(0.967, 1.274)
Dual sensory loss	1.504***	(1.366, 1.655)	1.489***	(1.353, 1.640)	1.491***	(1.354, 1.642)	1.479***	(1.343, 1.629)

There were 1,220 participants whose sensory loss status was consistent over 7 years. The analytic sample size was 7,623 in the mixed logistic regression models for association between time-varying sensory loss and incidence of falls.
Model 1: unadjusted.
Model 2: adjusted for demographic factors including age and sex.
Model 3: adjusted for factors in Model 2, as well as social-economic and life style factors including BMI, marital status, educational level, smoking, alcohol consumption and physical activity status.
Model 4: adjusted for factors in Model 3, as well as physical disorders including hypertension, diabetes, dyslipidemia, kidney diseases, emotional disorders, memory-related diseases and stroke.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Single Vision Loss

A decrease in visual acuity could probably lead to inaccurate assessment of environmental obstacles and deficits in daily activities, which eventually prevent older people from avoiding falls and fall-related injuries (5). In our cross-sectional study, we found significant correlation between VL and prevalence of falls in our sample according to univariate logistic regression (OR: 1.330, 95% CI: 1.075–1.646). After adjusting various confounders including age, sex, BMI, marital status, educational level, smoking status, drinking status and physical activity, single VL was still significantly correlated to fall. To our surprise, with physical disorders added into the model, such correlation became less significant ($p = 0.08$, Model 4, **Table 3**).

Decline in vision may also contribute to the development of fear of falling, which are related to increased fall risk in older adults (32). However, we found relatively less significant correlation between baseline single VL with incidence of falls over 7 year of follow-up in our participants (**Table 3**). Such finding indicated that baseline single VL may not be an appropriate indicator for higher incidence of falls. Similar results were also found that time-varying VL was not significantly correlated with incidence of falls during longitudinal observation (**Table 4**). This may be explained by the fact that amelioration of poor vision status is relatively accessible and effective for older people in our country. For example, patients who had cataract at baseline and later underwent successful cataract surgery for vision improvement could report different vision status in the following surveys. Therefore, to persevere same exposure status, we then filtered our participants according to the criteria of consistent VL status to further verify the impact of persistent VL on incidence of falls over 7 years. Persistent single VL was found to be strongly and significantly correlated with incidence of falls over 7 year of follow-up, even after being adjusted for multi-confounding factors in all models (**Table 4**). These findings indicated that baseline VL may not be appropriate for prediction of higher incidence of falls in older Chinese population, but the persistence of poor vision status could probably lead to more falls in older Chinese. Alteration or amelioration of poor vision status would possibly lower the appearance of falls in older adults.

Single Hearing Loss

HL has also been regarded as a risk factor of falls. HL contributes to balance difficulties, greater stride length variability and poorer postural control related to fall occurrence in older people (33–35). Numerous studies carried out across various ethnics and population in different countries have reached a consistent result of the potential correlation between HL and falls (36–40). Some researchers have also suggested that HL could be a clinical indicator of increased fall risk (11, 12). However, some researchers did not find significant correlation between HL and falls (13). Potential reasons may lie in the variability in how HL and falls were assessed and cohort characteristics. Similarly, several cross-sectional studies performed in our population have yielded mixed results as well (6, 10, 15, 16).

Thus, the present study provided important evidence on the correlation between single HL and falls in our older population from a nation-wide level according to both cross-sectional and longitudinal analyses for the first time. Baseline HL, persistent HL status and longitudinal time-varying HL were all found to be significantly associated with prevalence and incidence of falls in our samples even after being adjusted for all other confounders (all models, **Tables 3**, **4**). These findings further indicated that single HL could be regarded as a risk factor of falls in middle-aged and older Chinese population. Our findings are consistent to several population-based nation-wide surveys performed in other countries (11, 12, 36, 37, 40).

HL, HL-related falls and HL interventions among older adults in our country should arouse enough concern. Interventions like wearing hearing aids for improvement of hearing status has been proved to be very helpful to improve postural stability and offer a significant public-health benefit for avoiding falls, particularly in older people (41, 42). However, according to the previous research in over 15 million older Chinese people with HL from the China National Sample Survey on Disability, researchers pointed out that there is less uptake of hearing aid use than expected (43). Reasons for the poor uptake of hearing aids included financial constraints, unfamiliarity with hearing aids, difficulties in manipulating hearing aids, and traditional attitudes toward HL in older people as a normal part of aging life (43). Furthermore, besides amplifying desired sounds, hearing aids would amplify noises as well, thus making users feel too loud and noisy. Such muffled effect also jeopardize their belief in hearing aid (43). Thus, we need to realize that the hearing healthcare services for older people in China is still under-developed and worthy of further improvement in the future.

Dual Sensory Loss

In old age, sensory impairments often coexist. Thus far, the combined effects of HL and VL on falls have been barely explored in our population. According to the present study, the DSL group had the highest prevalence of falls among these sensory loss groups (22.4%, $n = 3{,}163$). The correlation between DSL and falls was apparently stronger than that between single sensory loss and falls (DSL: OR: 2.061, 95% CI: 1.768–2.404; HL: OR: 1.503, 95% CI: 1.240–1.820; VL: OR: 1.330, 95% CI: 1.075–1.646). Baseline DSL, persistent DSL status and time-varying DSL were all found to be significantly associated with prevalence and incidence of falls in our samples in both cross-sectional and longitudinal analyses even after being adjusted with all other confounders (all models, **Tables 3**, **4**). These consistent results in the present study indicated the strong correlation between DSL and falls in middle-aged and older Chinese people for the first time.

Some researchers have also noticed the relatively higher risk of combined effect of DSL on falls in older people, which is consistent to our results (44–46). Older people with DSL may be exposed to jointly negative influences of HL and VL. Concomitant dysfunction of both the cochlear and vestibular sense organs were ubiquitous in older people with HL (36). On the other hand, weakened vestibulo-ocular reflex and worse balance maintenance could also be found in older people with a decrease in visual acuity (5, 47). In addition, older people with DSL may develop a greater fear of falling behavior, reduced mobility, restricted activity and a decline in social interactions, which could further lead to sarcopenia, depression, poorer cognitive status, and reduced attentional resources. All these factors could contribute to the increased incidence of falls (17, 18, 32, 36, 46, 48).

Strengths and Limitations

There are several strengths in our study. First, CHARLS is a national study with large sample size, and the national representativity of CHARLS has been widely recognized and acknowledged. Thus, our work could be generalized to the entire country. Second, to our knowledge, the current study is the first nation-wide Chinese population-based study to verify the sensory-fall association among middle-aged and older population according to both cross-sectional study and longitudinal observation over 7 years. Results in our study could not only be used as evidence for falls-prevention among older population in China but also reference for future studies in other countries (especially in developing countries). Lastly, multiple fall-associated factors were included and adjusted in this study analyses, which could otherwise potentially confound the relationship between sensory loss and falls.

Meanwhile, we acknowledge some limitations. First, data of sensory loss and falls was collected by self-reports. Date for falls and frequency of falls was unavailable as well. Although this method has been used in previous studies (49–53), possible misclassification of sensory loss status or inaccurate reports may lead to bias. Also, the causal effects of sensory loss on falls could not be reached according to the present study. Second, some previously reported confounding factors of incident falls, such as physical environment, sarcopenia and nutrient intake were not available in CHARLS and were not adjusted in our study. Third, in a longitudinal observation over 7 years in older population, it is inevitable that the attrition in the panel over time could not be completely random. Lost follow up in following visits and the exclusion criteria of the present study could probably lead to sampling bias as well. Whatsoever, CHARLS is the first nationally representative survey of the health status and well-being in middle-aged and older population in China, which provides high-quality data of massive amounts of personal health-related information.

CONCLUSION

Our work is the first to verify sensory loss including vision loss, hearing loss and dual sensory loss as risk factors of falls among older Chinese population according to cross-sectional study and 7 year follow-up longitudinal observation. Hearing loss and dual sensory loss are significantly associated with both prevalence and increased incidence of falls over 7 year's observation in middle-aged and older Chinese population. Persist or altered vision loss status could exert divergent influences on incidence of falls. These findings deserve further consideration in the development of falls-prevention public health policies for older population in China.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: The current study is a secondary analysis of public data of CHARLS. The original datasets of CHARLS is accessible on http://charls.pku.edu.cn/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Biomedical Ethics Review Committee of Peking University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

MZ, YZ, HL, and XS designed the research. JL, YH, and YL analyzed the data. YZ drafted the manuscript. YZ and YH contributed equally to this research and should be considered as equivalent authors. All authors read and approved the final manuscript.

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Effects of Health Qigong Exercise on Lower Limb Motor Function in Parkinson's Disease

Xiying Li[1], Chuanfen Lv[2], Xiaolei Liu[3] and Xia Qin[4]**

[1] School of Physical Education, Yunnan Minzu University, Kunming, China, [2] School of Physical Education, Zhengzhou University of Light Industry, Zhengzhou, China, [3] Chinese Traditional Regimen Exercise Intervention Research Center, Beijing Sport University, Beijing, China, [4] Foreign Language School, Yunnan Minzu University, Kunming, China

Purpose: This study explored the effects of Health Qigong exercise on lower limb motor function in patients with Parkinson's disease (PD).

Patients and Methods: A total of 40 patients with PD were recruited and randomly allocated into the experimental group and the control group. The experimental group completed an intervention of Health Qigong exercise over 12 weeks, while the control group did not perform any regular physical activity. Data relating to gait, lower-limb joint range of motion, Timed Up and Go, as well as scores for motor function scale from the Unified Parkinson's Comprehensive Rating Scale III (UPCRS III) before and after the intervention were collected for Repeated Measure ANOVA.

Results: Compared to the control group, Health Qigong exercise improved the constant- and high-speed stride length and gait velocity of patients, but not constant- and high-speed stride frequency. Left and right hip flexion and extension range were improved as well as left and right knee flexion range. Finally, Timed Up and Go time became significantly slower and UPCRS III score significantly decreased.

Conclusion: Health Qigong exercise can improve walking ability and lower limb joint range of motion in patients with PD, lessen motor difficulties, and improve the quality of life. This non-pharmacological exercise intervention may be a useful adjustment treatment for PD.

Keywords: Health Qigong, exercise, Parkinson's disease, lower limbs, motor function

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Tzvi Dwolatzky,
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Si-Tong Chen,
Victoria University, Australia

****Correspondence:***
Xiaolei Liu
liuxiaolei99@hotmail.com
Xia Qin
shirleysoar@163.com

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INTRODUCTION

Epidemiologically, there are more than 10 million patients with Parkinson's disease (PD) worldwide, of whom nearly 30% are in China where it represents an annual increase of 100,000 (1). As it develops, PD creates difficulties with walking, destroys the motor function of the lower limbs, impairs the stability and balance of the lower limbs, and further increases the risk of falls. Studies show that about 70% of patients with PD experience falls, leading to secondary harm to patients and long-term disability in severe cases (2).

Studies on lower limb motor function rehabilitation mainly involve the electrical stimulation therapy, mirror therapy, lower limb rehabilitation robots acupuncture, aerobics, square dance, yoga, Tai Chi, and therapy of sports in water (3–10). This study is to apply Health Qigong to explore its effect on lower limb motor function in patients with PD. With the joint evaluation of multiple indicators, the positive effect will be more objective, providing a sound scientific evidence for Health Qigong as a new means of exercise rehabilitation to improve lower limb motor function in patients with PD, which will cut down their economic expense and improve their quality of life. Health Qigong, as a Chinese traditional sport, practices slow and soft tension and tightness in turn, and the body and mind are integrated with harmony (11). Demanding the combination of the center of gravity (CG) with body position and the stability of lower limbs, Health Qigong develops body coordination and bodily mechanisms. It includes Daoyin Health Qigong, Baduanjin Health Qigong, Mawangdui Daoyinshu Health Qigong, Liuzijue Health Qigong, Yijinjing Health Qigong, Wuqinxi Health Qigong, and so on. Health Qigong is becoming increasingly popular because it is simple and easy to learn with low intensity. People can practice Health Qigong anytime and anywhere without any equipment. The unique advantages of Health Qigong have attracted the attention of researchers, with studies confirming that it is valuable for the prevention and treatment of various chronic diseases.

Previous studies have suggested that Health Qigong helps the elderly to improve muscle strength, proprioception, joint range of motion, balance, and body stability of lower limbs. Fu (12) concluded that a 16-week intervention of Baduanjin Qigong increases body flexibility in the elderly, improves the balance of lower limbs, and enhances body stability. Tang (13) proposed that a 3-month intervention of Baduanjin Qigong enlarges the range of motion in the shoulders, neck, elbows, wrists, hips, knees, and ankle joints in elderly women, enhancing body flexibility. Jiang and his team (14) proposed that a 12-week exercise intervention of Health Qigong helps increase the lean mass of the lower limbs in patients with knee osteoarthritis and relieves the pain in the lower limbs. Ma and Zhang (15) found that that a 6-month intervention of Baduanjin Qigong improves balance in the elderly and lessens the risk of falls. Health Qigong helps patients with PD to effectively improve body coordination, stability, muscle rigidity, and gait disorder. Liu et al. (16) proved that, during the practice of Health Qigong, exercising the distal-to-proximal contraction of the lower limbs helps to improve body recognition, strengthens control, and enhances lower limb strength and body stability. Zhang (17) proposed that Wuqinxi Qigong improves gait velocity and balance in PD. The vestibular system and proprioception of patients improve in taking turns and rotations with the left and right limbs. Exercising the muscles of the lower limbs makes them stronger, improving balance, and by imitating the five animals, which is part of the intervention, all the muscles are stretched for a better range of motion in the joints and improved walking ability.

These studies all support the benefits and efficacy of a certain type of Health Qigong separately as an intervention to improve the lower limb motor function of patients with PD. This study was designed to prove whether 12 weeks of the ten exercises combined from the six sets of Health Qigong from Daoyin Health Qigong, Baduanjin Health Qigong, Mawangdui Daoyinshu Health Qigong, Liuzijue Health Qigong, Yijinjing Health Qigong, Wuqinxi Health Qigong can improve the lower limb motor function of patients with PD.

METHODS

Participants

A total of 40 patients with PD at stages 1–3 as diagnosed by neurologists at Beijing Aerospace Hospital were recruited and randomly allocated into the experimental group and the control group. The sample size was obtained according to the formula: $N = z2σ2/d2$. A written informed consent was obtained from the patients with PD. The inclusion criteria were: (1) meeting the clinical diagnostic criteria for primary PD by the UK Parkinson Disease Association Brain Bank; (2) no changes in medication recently nor during the trial; (3) no deep brain stimulation surgery before or during the study; (4) aged between 50 and 80 years and without cognitive impairment; (5) able to walk without equipment; and (6) not in any other training program for behavioral or pharmacology research. The exclusion criteria were: (1) no other chronic diseases besides PD or neurological damage; (2) poor physical health, impairments to vision, or hearing leading to difficulty in understanding the test; (3) having already learned Health Qigong; and (4) unwilling to provide informed consent to participate. All the participants were required to maintain and record their living activities as usual during the trial, so as to guarantee the experimental data were as true as possible.

Intervention of Health Qigong

The intervention duration was 12 weeks. The control group did not receive any special exercise intervention during the trial, but after it they could also receive Health Qigong intervention. The participants in the experimental group were instructed to perform the Health Qigong exercise. They attended the exercise five times a week, 60 min each time. Given the clinical motor symptoms and the idea of traditional Chinese medicine that a person keeps healthy as a unity, the intervention involved ten exercises, which practiced the lower limb motor function of patients with PD, combined from the six sets of Health Qigong as promoted by the General Administration of Sport of China. The combined set of Health Qigong exercises includes many lower limb exercises such as moving left or right foot aside, bringing feet together, horse step, heel raising, squat, and standing on a single foot, which drives patients with PD to exercise their lower limbs from multiple angles, dimensions, and ways, so as to have a positive effect on their lower limb motor function. These included Qian Yuan Qi Yun (praying for good fortune at the beginning of the creation of the heaven) and Yun Duan Bai He (white crane flying high in the clouds) in the twelve steps of Daoyin Health Qigong (physical and breathing exercises), Liang Shou Tuo Tian Li San Jiao (holding the hands high with palms up to regulate the internal organs), Wu Lao Qi Shang Wang Hou Qiao (looking backward to prevent sickness and strain), Cuan Quan Nu Mu Zeng Qi Li (thrusting the fist and glaring the eyes to enhance strength) in Baduanjin Health Qigong (eight silken movements), Long Deng (dragon flying) in Mawangdui Daoyinshu Health Qigong, Xu and Xi exercises in Liuzijue Health Qigong (six-character pronunciation), Chu Zhua Liang Chi Shi (showing talons and spreading wings) in Yijinjing Health Qigong, and Niao Fei (flying like a bird) in Wuqinxi Health Qigong (five animals playing). The intervention was led by an experienced Health Qigong instructor who has practiced Health Qigong for more than 3 years, received professional guidance, and won the first prize in the national Health Qigong competition. And the participants followed and performed practice in an exclusive place without outside disturbance.

Measurement

Gait

A Victor Company of Japan (JVC) camera of Canon EOS70D was used for two-dimensional image capture with 50 frames per s. This was placed at the height of 1.4 m from the horizontal ground, a distance of 5 m from the motion plane of patients, and with the principal optical axis perpendicular to the motion plane. A scale of 1 m was used for calibration in all the shooting. The gait test includes the measurement of constant speed and high speed. For the former, the patient walked on flat ground for a distance of 10 m along a straight line at his usual walking pace; for the latter, the patient did the same but at maximum speed. The gait in the middle 3 m was also available for analysis, measured twice at each speed. All gait videos were converted to audio video interleaved (AVI) format by Kinovea software and then the heel points were digitized using visual motion system software to obtain the heel point coordinates for one gait cycle. Each gait cycle was defined as the time from one heel hitting the ground to the same heel hitting the ground again. The horizontal anteroposterior distance between the heels hitting the ground in a gait cycle was stride length, the time for one stride length was gait velocity, and gait velocity divided by stride length was stride frequency. All the gait parameters for constant- and high-speed walking were calculated as the average of the two tests.

Lower-Limb Joint Range of Motion

The measuring instrument of the lower-limb motion range was the joint range ruler. For hip flexion, the patient laid supine with the arm fixed by the joint range ruler passing by the trochanter and parallel to the midaxillary line of the trunk. The greater trochanter was the axis and the femur was the longitudinal axis. Afterward, the patient performed knee flexion and leg lift before measurement. For hip extension, the patient laid prone on the same axis, one leg fixed, and mobile leg as described above with fixed pelvis, while it was ensured the patient moved their lower limbs backward as close as possible to the head on the sagittal plane for measurement. For knee flexion, the patient laid supine and then moved the lower leg between the caput fibulae and the lateral malleolus with the lateral femur condylar as the axis and the femur as the longitudinal axis, with the joint range ruler fixed on it. While the patient performed knee flexion and leg lifts, a researcher fixed the pelvis of the patient and held the upper part of the ankle, but did not press it down to make the patient move the heel close to the buttocks for measurement.

Timed Up and Go

The instruments for the Timed Up and Go test were a JVC camera of Canon EOS80D and a chair. A chair with a backrest and a height of 45 cm without an armrest was used. In the test area, a measuring tape was used to measure a distance of 3 m in a straight line and mark it. Two-dimensional shootings were taken at 50 frames per s. The camera was placed 1.4 m high from the horizontal ground and 2 m away from the plane of motion of the patient. When the experiment started, patients would stand up, walk 3 m as fast as possible, and then return to the chair again with their back against the backrest to complete the test. Time was recorded on video from when the patient left the backrest of the chair and returned to it. The starting frame was taken as when the patient left the backrest and the ending frame was taken as when the patient returned to the backrest. All videos were named and imported into Kinovea software. The ending frame was subtracted by the starting frame and then was divided by the frame rate to obtain the total time in seconds.

Motor Function

Motor function was evaluated using the motor function assessment of the Unified Parkinson's Comprehensive Rating Scale (UPCRS).

Data Analysis

All the data have been tested for homogeneity test and conformed to normal distribution. SPSS version 23.0 software was used for statistical analysis. The repeated measure ANOVA was used to compare the data relating to lower limb motor function measured before and after the intervention both between and within groups. The Fisher's least square difference method was used for subsequent statistical analysis when the main effect was significant without *time* (pretest and posttest) and *group* (experimental group and control group) interaction. When the interaction effects were significant, a simple effect analysis for differences between the groups and within the group at different time points was conducted. The results are presented as mean ± SD.

RESULTS

The participants were allocated randomly to either the experimental group or the control group ($n = 20$ in each group). Nine participants dropped out during this study. There were no significant differences in gender, age, height, weight, or disease course between the two groups ($p > 0.05$, **Table 1**).

Gait Parameters Pre- and Posttest by the Group

Stride Length

Results indicated that there was a *group* by *time* interaction effect on constant- and high-speed stride length ($p < 0.05$). *Group* and *time* effects were found for high-speed stride length, while only *time* effect was found for constant-speed stride length. The constant- and high-speed stride length of the experimental group significantly increased from pre- to posttest, whereas in the control group it decreased from pre- to posttest but not

TABLE 1 | Participant demographics and anthropometrics.

	Experimental ($n = 15$)	Control ($n = 16$)	*t*-value	*P*-value
Gender ratio (male: female)	5:10	6:10		
Age (years)	65.87 ± 6.13	63.25 ± 6.70	1.132	0.597
Height (cm)	162.53 ± 6.90	162.49 ± 6.45	0.016	0.700
Weight (kg)	66.51 ± 7.73	66.84 ± 7.99	−0.117	0.816
Course of disease (years)	5.60 ± 1.72	6.13 ± 1.96	−0.789	0.554

TABLE 2 | Gait outcome measures before and after 12 weeks of intervention.

		Experimental ($n = 15$)		Control ($n = 16$)		Time effect		Interaction effect	
		Pre	Post	Pre	Post	*f*	*P*	*f*	*P*
Constant-speed	Stride length (m)	0.71 ± 0.11	0.78 ± 0.09*	0.74 ± 0.10	0.72 ± 0.09	1.616	0.214	5.516	0.026
	Stride frequency (times/min)	59.72 ± 3.42	61.51 ± 4.68	60.83 ± 4.33	61.35 ± 8.92	1.271	0.269	0.379	0.543
	Gait velocity (m/s)	0.76 ± 0.12	0.90 ± 0.20*	0.75 ± 0.15	0.78 ± 0.19	4.380	0.045	1.438	0.240
High-speed	Stride length (m)	0.78 ± 0.09	0.92 ± 0.21*	0.80 ± 0.12	0.78 ± 0.98	3.091	0.089	4.219	0.049
	Stride frequency (times/min)	62.30 ± 6.00	63.45 ± 6.21	63.43 ± 6.54	64.51 ± 6.58	1.974	0.171	0.002	0.964
	Gait velocity (m/s)	0.94 ± 0.13	1.07 ± 0.10*	0.94 ± 0.12	0.97 ± 0.18	4.344	0.046	1.919	0.177

*$p < 0.05$.

significantly. There was no significant difference for constant-speed stride length between the two groups either before or after the intervention, while a significant difference after the intervention showed for high-speed stride length. It was implied that over time, Health Qigong exercise had benefits on constant- and high-speed stride length and there was a wider gap between the groups for the latter.

Stride Frequency

No significant main and interaction effects were observed for constant- and high-speed stride frequency.

Gait Velocity

There was no *group* by *time* interaction effect but a *time* main effect on constant- and high-speed gait velocity ($p > 0.05$). The constant- and high-speed gait velocity of the experimental group significantly increased from pre- to posttest. No differences were found between the groups neither before nor after the intervention. It was shown that over time, Health Qigong exercise benefitted constant- and high-speed gait velocity. All the results of gait outcome measures in pre- and posttest are shown in **Table 2**.

Lower Limb Joint Range of Motion Pre- and Posttest by the Group

Hip Flexion and Extension

Results demonstrated a *group* by *time* interaction effect on left and hip flexion range ($p < 0.01$). A significant *time* effect was found. Left and right hip flexion range in the experimental group significantly increased from pre- to posttest, but no statistical difference was found for the control group pre- to posttest. No differences were observed between the groups either before or after the intervention. It was demonstrated that over time, Health Qigong exercise benefitted left and right hip flexion range of motion.

A *group* by *time* interaction effect was shown in left ($p < 0.05$) and right hip extension range ($p < 0.01$; **Table 3**). There were significant effects of *group* and *time* in the right, while a *time* effect was there in the left. In the experimental group, the left and right hip extension range significantly increased from pre- to posttest, but no statistical difference was found for the control group pre- to posttest. No differences were found between the groups neither before nor after the intervention for the left but for the right, a significant difference ($p < 0.01$) was thereafter the intervention. It was indicated that over time, Health Qigong exercise benefitted left and right hip extension range of motion and there was a wider gap between the groups for the right.

Knee Flexion

Results of knee flexion showed a *group* by *time* interaction and significant *group* and *time* effects on left and right knee flexion range ($p < 0.05$). In the experimental group, left and right knee flexion range significantly increased from pre- to posttest, while the decrease from pre- to posttest in the control group was not significant. There was no significant difference between the two groups before the intervention, but a significant difference after it. It was implied that over time, Health Qigong exercise benefitted left and right knee flexion range, enhanced by the wider gap between the groups. All the results of joint range of motion outcome measures in pre- and posttest are given in **Table 3**.

Timed Up and Go Pre- and Posttest by the Group

No *group* by *time* interaction effect was observed in the Timed Up and Go test ($p > 0.05$). There was a significant *time* main

TABLE 3 | Joint range of motion outcome measures before and after 12 weeks of intervention.

			Experimental ($n = 15$)		Control ($n = 16$)		Time effect		Interaction effect	
			Pre	Post	Pre	Post	*f*	*P*	*f*	*P*
Hip	Flexion	Left	73.40 ± 7.78	79.60 ± 7.50**	76.13 ± 8.48	74.44 ± 6.68	3.085	0.090	9.426	0.005
		Right	72.40 ± 10.32	79.07 ± 10.53**	76.06 ± 6.48	75.19 ± 11.09	4.794	0.037	8.128	0.008
	Extension	Left	8.20 ± 1.47	10.07 ± 0.88*	8.44 ± 1.41	8.06 ± 4.31	1.868	0.182	4.218	0.049
		Right	8.47 ± 1.30	10.27 ± 1.33**	8.63 ± 1.02	8.56 ± 0.96	21.629	0.000	24.853	0.000
Knee	Flexion	Left	52.73 ± 9.25	56.80 ± 3.26*	54.19 ± 4.48	52.88 ± 3.16	1.245	0.274	4.748	0.038
		Right	54.60 ± 8.75	58.40 ± 3.07*	52.81 ± 5.48	50.25 ± 4.78	0.234	0.632	6.198	0.019

*$p < 0.05$; **$p < 0.01$.

TABLE 4 | Timed Up and Go outcome measures before and after 12 weeks of intervention.

	Experimental ($n = 15$)		Control ($n = 16$)		Time effect		Interaction effect	
	Pre	Post	Pre	Post	*f*	*P*	*f*	*P*
Timed Up and Go(s)	11.49 ± 2.26	9.00 ± 2.25*	13.78 ± 7.29	13.61 ± 6.57	4.314	0.047	3.255	0.082

*$p < 0.05$.

effect. In the experimental group, the time for Timed Up and Go was significantly shortened from pre- to posttest, while the decrease for the control group was not significant. There were no significant differences between the two groups neither before nor after the intervention. The results showed that over time, Health Qigong exercise benefitted walking ability. All the results of TUG outcome measures in pre- and posttest are shown in **Table 4**.

Functional Assessment in the Unified Parkinson's Comprehensive Rating Scale III Pre- and Posttest by the Group

Results of the UPCRS III demonstrated a *group* by *time* interaction effect. *Group* and *time* effects were found for motion function ($p < 0.05$). In the experimental group, the score significantly dropped from pre- to posttest, while the score in the control group rose, but not significantly. There was no significant difference between the two groups before the intervention but after the intervention. It was shown that over time, Health Qigong exercise benefitted motor function, enhanced by the wider gap between the groups. All the results of the UPCRS III outcome measures in pre- and posttest are given in **Table 5**.

DISCUSSION

This study aims to explore the effects of Health Qigong exercise on lower limb motor function in patients with PD. The results of this study demonstrate that the intervention involved ten exercises from the six sets of Health Qigong do have positive effects on gait, lower limb joint range of motion, Timed Up and Go test, and the score for motion function in the UPCRS III. Correspondingly, they eventually improve the lower limb motor function in PD. More detailed information will be discussed as follows.

Gait

Patients with PD suffer from disordered gait and a smaller range of motion in the lower limb joints and their walking ability becomes weak with an unstable center of gravity. Patients with PD fall frequently and may suffer from secondary damage (18). Disordered gait is one of the primary clinical motor symptoms in patients with PD and is the critical cause of lower limb motor dysfunction. As the effects of PD on the central nervous system progress, its regulation of the limb motor system weakens or is even lost (19). The ability of patients with PD to perform daily activities, such as wearing shoes, walking upstairs, or crossing the street alone, decreases and their body control reduces. The muscle strength of the affected side weakens due to a sustained lack of active exercise, which further reduces the proprioceptive input to the joint, restricts the exercise capacity of the patient and reduces balance and stability. The proprioception is weakened. Qigong exercise is one type of mind-body exercise. It involves the cooperation and coordination of all the parts of the body and the mind. While the patient completes a movement, he/she controls the change in the body position, such as moving left or right, lifting the heel, turning the body or the head, and so on. After practicing these complex, slow and changeable exercises, body proprioception significantly improved.

In this study, gait involves stride length, frequency and gait velocity at a constant speed and high speed. After 12 weeks of Health Qigong intervention, the constant- and high-speed stride length of patients and gait velocity significantly increased (although constant- and high-speed stride frequency did not increase). This positive effect was increased as intervention duration was prolonged, especially for high-speed stride length and gait velocity. In the Cuan Quan Nu Mu Zeng Qi Li (thrusting the fist and glaring the eyes to enhance strength) move, the patient squats the legs in a horse stance with the toes fully on the ground, effectively making them concentrate CG on the toes.

TABLE 5 | Unified Parkinson's Comprehensive Rating Scale III (functional assessment) before and after 12 weeks of intervention.

	Experimental ($n = 15$)		Control ($n = 16$)		Time effect		Interaction effect	
	Pre	Post	Pre	Post	*f*	*P*	*f*	*P*
Motor function score (Points)	14.67 ± 1.63	12.47 ± 1.77**	14.88 ± 2.42	15.13 ± 3.81	6.497	0.016	10.256	0.003

**$p < 0.01$.

Movements such as thrusting the fist, grasping, and rotating the wrist for both hands stimulate the meridians of the hands and feet, increasing strength, and making the lower limb muscles more powerful. In the Long Deng (dragon flying) move, the individual squats to stand up slowly then lifts the heels, stretches the legs, and squats down again. The up and down movement of the CG in this process strengthens body stability. Exercising the lower limb muscles, extensibility of ligaments, and the motion range of the hip and knee, increased flexibility of the hip and knee joints, stability of lower limbs, balance, and greater capacity for the exercise of the lower limbs is achieved. In addition, in the Qian Yuan Qi Yun (praying good fortune at the beginning of the creation of heaven) move, Xu exercise move, and Wu Lao Qi Shang Wang Hou Qiao (looking backward to prevent sickness and strain) move, the body and the limbs turn or rotate creating more flexible joints. The nerves, muscles, and joints are stimulated and the proprioception of the limbs and trunk is effectively enhanced. So is core strength. All these lead to better body stability, so that patients with PD enjoyed better walking and suffered less gait disorder.

Lower Limb Joint Range of Motion

After 12 weeks of Health Qigong exercise, the ranges of the left and right hip flexions and extensions and of left and right knee flexions in patients became significantly broader in the experimental group. The positive effect was enhanced as the intervention duration was prolonged. Besides, the experimental and control groups showed significant differences in the ranges of the right hip extension, left, and right knee flexions.

Patients with PD often experience stiffness and weakness of the lower limb muscles, which is the primary cause of the small motion range of lower limb joints. In the Health Qigong intervention, most strength training of the lower limbs is stance training (and in particular, horse stance training) which is static, such as in the Cuan Quan Nu Mu Zeng Qi Li (thrusting the fist and glaring the eyes to enhance strength) move. Static strength training can more effectively improve muscle tone and enhance neuromuscular control, increasing the stability of the joints. Moreover, changes of walking patterns help to train the quadriceps femoris and hamstrings of the lower limbs, thereby improving muscle strength and increasing the stability of the joints. At the same time, right and left CG movement can also enhance the patient's sense of direction, such as in the Qian Yuan Qi Yun (praying for good fortune at the beginning of the creation of heaven) and Liang Shou Tuo Tian Li San Jiao (holding the hands high with palms up to regulate the internal organs) moves with the change of walking patterns and the shift of the CG between the left and right (20).

In addition, in the Niao Fei (flying like a bird) move, the practitioner is required to complete knee-lifting movements independently on the left or right leg (21) and remain stable during the process. Doing these helps exercise the range of motion of the hip joint, the strength of the legs, and the body stability of the patient. Long-term and regular Health Qigong exercise can effectively enhance lower limb strength and as well as the range of motion, thereby improving the balance and quality of life of patients. In the Yun Duan Bai He (white crane flying high in the clouds) move and Long Deng (dragon flying) move, the heel-lift move can effectively improve the extensibility and strength of the lower limb muscles, and increase ankle joint stability. Imagining themselves as birds or cranes during practice (22), patients keep their lower limbs stable and upper body relaxed. This can effectively train the control ability of all skeletal muscles, strengthening control of the surrounding muscles of the hips, knees, and ankle joints, and improving gait so that the patients with PD walk with stability and flexibility.

Timed Up and Go Test

For patients with PD, the difficulty to combine standing up and sitting directly reduces their walking ability for muscle weakness, stiffness, and poor balance caused by PD. These are the critical causes of reduced ability to complete daily activities such as sitting down and standing up.

We observed from the results that patients required significantly less time to complete the Timed Up and Go test than they did before the 12 weeks of Health Qigong intervention. The positive impact became increasingly stronger as intervention duration was prolonged. The Yun Duan Bai He (white crane flying high in the clouds) move involves bending the knees to squat down and get up, and the Niao Fei (flying like a bird) move involves squatting down and getting up while kicking a leg. The Cuan Quan Nu Mu Zeng Qi Li (thrusting the fist and glaring the eyes to enhance strength) move requires the practitioner to squat half in a horse-step state and the Long Deng (Dragon Flying) move requires squatting down entirely from being upright and then getting back up. Practicing these moves, the patients will have muscle control and lower limb strength, suffer less rigidity, and enjoy more balanced walking.

Score for Motion Function in the UPCRS III

As a criterion to evaluate motor function of patients with PD, the UPCRS is composed of four parts. We only applied the third part (motor function rating) to assess lower limb motor function in patients with PD. There are a total of

14 items, each scored 0–4 points. The higher the total score, the more severe the symptoms, and this measure can objectively reflect improvement in motor symptoms in patients with PD.

We found that the scores of motion function of patients significantly decreased after the intervention and the positive effect became stronger as the intervention time lasts longer. In the practice of the Xu and Xi exercises, patients move their lips backward to trigger sounds, which stimulate the facial muscles to improve control of them and help patients with pronunciation. In addition, during practice, teachers and teaching assistants often communicate with patients to ensure the effective completion of movements, while unconsciously encouraging patients to talk to others and effectively train their language skills. In such a positive atmosphere, everyone cares, helps, encourages, and fights against PD. Studies demonstrate that satisfaction in interpersonal relationships helps to enhance the positive mental health of people (23). Health Qigong is an activity that emphasizes harmony between oneself and the outside world, rather than comparing oneself or competing with others. Through this non-competitiveness, Health Qigong has a positive effect on individual personalities and interpersonal skills as well as on mood regulation in a comfortable atmosphere.

In daily life, patients with PD have shaking hands, which affects eating and drinking. When patients with PD are nervous, they have more difficulty in moving their hands freely, which can lead to low self-esteem. Exercise improves fitness, which has a positive correlation with self-efficacy and self-esteem (24). Highly demanding motions in sports promote body perception, which further stimulates the pursuit of health of people. This process can promote both the physical and mental health. The whole set of exercises includes coordinated movements as arm rotation, shoulder extension, wrist folding, finger curling, finger flicking, wrist shaking, flash palm, palm turning, palm supporting, five-finger external supporting, loosening finger, loosening wrist, gripping, and so on. These train the hands, stimulate nerve endings, strengthen nerve conduction, relieve muscle rigidity, and improve shaking hands for better hand function. When patients feel positive change, they are more willing to participate in exercise and this forms a virtuous cycle.

In the whole set of exercises, there are left and right CG movements and up and down movements, such as pushing up, turning the waist left and right, stepping left and right, bringing the feet together, squatting in the horse stance, heel raising, squatting down with knees bent, and standing on one foot with a knee lift. These exercises stretch all the muscles of the whole body, enhance elasticity, increase the range of motion of joints, strengthen the lower limbs, and train body stability and also improve muscle rigidity, postural instability, gait, and reduce the risks of falls.

Strength and Limitations

This study possesses several strengths: (1) determined eligibility criteria of participants through experiment; (2) similar demographic and anthropometric information (age, gender, course of disease, medication); (3) an independent practice place (no outside interference); (4) randomized controlled experimental design; (5) confounding factors controlled with repeated measure ANOVA; (6) side effects on experimental data effectively avoided without other drug therapy; (7) authenticity, scientific nature and timeliness of the data guaranteed thanks to timely testing right before and after patients' practice for. Meanwhile, some limitations of this study need to be acknowledged. First, this study covered only 12 weeks of Health Qigong intervention, which was relatively short. Second, different data and effects may be generated when patients with PD were involved in lower limb motor function intervention at different stages and if the patients with PD had other simultaneous diseases. Third, the sample size of this study was small for patient dropout, since those patients suffered severe disease or had other personal reasons at the beginning of this study. Fourth, Health Qigong may not be practiced with the same quality and standard degree among the participants. Fifth, the follow-up effects of Health Qigong intervention were not known without subsequent visits for evaluation.

CONCLUSION

Health Qigong exercise is a type of mind-body exercise. It involves the cooperation and coordination of all parts of the body and the mind. Patients need to have a high concentration in action during practice, otherwise, stagnation will occur. This exercise stimulates the ability of the brain to control the body with body movements. After 12 weeks of Health Qigong exercise, the gait and lower limb joint range of motion in patients with PD were improved alongside lower limb motor function. The Timed Up and Go test time was reduced, while the walking ability and exercise capacity improved. These benefits also help to improve the quality of life for patients with PD. This study shows that Health Qigong can be used as an auxiliary therapy for exercise rehabilitation in addition to treatments such as drugs and surgery, offering some new ideas for rehabilitation training, which will be of interest to both the researchers and clinical practitioners. From the perspective of clinical benefits, it effectively reduces the social and patients' economic pressure. With its obvious advantages of moderate intensity and being easy to learn, it is suitable for patients with PD. As it is culturally closely related to Chinese people, it has better exercise and treatment compliance.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Beijing Sport University (protocol code 2021002H and January 1st, 2021). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XLi, CL, and XLiu contributed in conceptualization. XLi and XLiu contributed in methodology. XLi and CL contributed in formal analysis, writing—original draft preparation, and data curation. CL, XQ, and XLiu contributed in investigation. XQ and XLiu contributed in resources. XLi, XQ, and XLiu contributed in writing—review and editing. XLiu contributed in funding acquisition. All the authors have read and agreed to the published version of the manuscript.

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Effect of Wii Fit Exercise With Balance and Lower Limb Muscle Strength in Older Adults: A Meta-Analysis

*Haoyan Liu, Yu Xing and Ying Wu**

Department of Physical Education and Training, Shanghai University of Sport, Shanghai, China

Background: Falls and fall-related injuries are not uncommon among older adults and may lead to serious health deterioration and decreased quality of life. Numerous types of physical activity have been proposed to improve balance and strength in older adults with varying degrees of success. Nintendo's Wii Fit video exergame uses body movement as a game controller and provides real-time feedback for games designed to enhance balance and muscle strength. However, whether Wii Fit exercise improves the balance and lower limb muscle strength of older adults remains uncertain.

Objective: To evaluate the current literature by using meta-analyses to assess whether Wii Fit exercise is associated with improved balance and lower limb muscle strength in older adults.

Methods: We searched PubMed, EMBASE, Web of Science, China National Knowledge Infrastructure, and Wanfang Data from inception to February 16, 2022, for relevant studies and conducted a manual search of the literature. Data extraction of the included studies were independently performed by two authors. The methodologic quality of each included study was assessed using the Physical Therapy Evidence Database (PEDro) scale. Meta-analyses were conducted using Review Manager 5.3.

Results: Of 991 articles initially identified, 10 articles (379 participants; aged ≥65 years, range 65–92 years; 188 participants in Wii Fit exercise groups, and 191 participants in control groups), including 8 randomized controlled trials, were assessed in this meta-analysis. The methodologic quality of the included studies evaluated with the PEDro average score was 6.4 and ranged from 5 to 8 points, indicating moderate quality. Compared with no exercise, Wii Fit exercise was associated with significant improved scores on the Berg Balance Scale, which evaluates functional balance (mean difference, 1.38; 95% CI, 0.61–2.16; $I^2 = 31\%$; $P = 0.0005$) and on the Timed Up and Go test, which evaluates static and dynamic balance (standardized mean difference, −0.51; 95% CI,−0.88 to −0.14; $I^2 = 52\%$; $P = 0.007$). However, for the three studies assessed, Wii Fit exercise did not significantly improve scores on the 30-s chair stand test, which evaluates the functional strength and endurance of the lower limb muscles (mean difference, 0.82; 95% CI, −0.14 to 1.77; $z = 1.68$; $P = 0.09$).

Edited by:
Tzvi Dwolatzky, Technion Israel Institute of Technology, Israel

Reviewed by:
Eling D. de Bruin, Karolinska Institutet (KI), Sweden
Beth Orsega-Smith, University of Delaware, United States
Noelia Gonzalez-Galvez, Independent Researcher, Murcia, Spain

***Correspondence:**
Ying Wu
745560601@qq.com

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Conclusions: Our findings indicated that Wii Fit exercise is an effective approach to improve functional, static, and dynamic balance among older adults. Additional meta-analyzes with higher numbers of randomized controlled trials are suggested to confirm the benefits of Wii Fit exercise on balance in older adults, to establish whether functional strength and endurance of lower limb muscles are improved, and to explore the relationship between improved balance and fall prevention in this population.

Keywords: aged, balance, muscle strength, Wii Fit exercise, meta-analysis

INTRODUCTION

Maintaining balance becomes increasingly difficult with age, as age-related changes occur in sensory systems (vestibular, visual, and somatosensory) and with muscle strength, leading to increased risks of falls and fall-related injuries (1–3). Falling is a significant sign of human aging, with approximately one-third of people older than 65 years injured by falls each year (4). As a common form of injury, falling has high rates of injury and mortality in elderly populations. Fall injury is the second major cause of death associated with accidental or unintentional injury (5). Exercise has a positive effect on balance and helps to prevent falls among older adults (5). However, adherence to traditional sports typically decreases with age among older adults (6). Maintaining balance is a complex process that requires coordination between the sensory system (vision, vestibular, proprioception, etc.) and the motor system (7). Therefore, new approaches for performing exercise that are easy to do, are appealing to older adults to maintain high compliance rates, and that engage multisensory systems and muscle strength are needed to improve balance in this population.

The technology for interactive video games involving physical activity, termed exergames, has evolved and has been applied as an effective approach for treating sarcopenia and cognitive impairment. Video game systems are more cost-effective than developing custom-designed rehabilitation equipment and are becoming increasingly more popular among individuals undergoing physical rehabilitation (8). Among the most common video game systems used for this purpose (Wii Fit, Dance Revolution, EyeToy, and Kinect), Nintendo's Wii Fit is the most popular (9). It was the first video game system to use body movements as a game controller. The exerciser stands on an external balance board and controls the movement of a virtual character in the game by changing the center of pressure on the board. The game provides both visual and auditory feedback to the exerciser. This system combines fun with physical exercise for all ages as it allows for work on joint flexibility, muscular strength, and postural ergonomics. Wii Fit exercise has been shown to be safe for healthy older adults (10). However, the effect of Wii Fit exercise on balance and lower limb muscle strength among older adults is controversial (11, 12). In addition, to our knowledge, no meta-analysis has compared no exercise with the effect of Wii Fit exercise among adults 65 years of age or older. Therefore, the aim of this meta-analysis was to assess the effects of Wii Fit exercise on balance and lower limb strength among seniors aged 65 years or older.

METHODS

Ethical approval was not required for this study because all data were obtained from published articles. This study was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline (2009) (13).

Search Strategy

We performed a systematic search of PubMed, EMBASE, Web of Science, China National Knowledge Infrastructure, and Wanfang Data from their inception to February 16, 2022. Search terms, including "Wii Fit exercise," "Wii Fit balance board," "virtual reality," "exergame," "interactive," "video game," "role-playing," "real-time strategy," "balance," "strength," "postural control," "older adults," "elderly," "senior," "older people," "aged," "aging," and "elderly," were used to retrieve articles. A manual search was also performed.

Eligibility Criteria

The criteria for a study to be included in the meta-analysis were the following: (1) population: adults aged ≥65 years; (2) intervention: Wii Fit exercise; (3) comparator: Wii Fit exercise vs. non-exercise control; (4) outcomes: studies reporting balance or lower limb muscle strength outcomes; (5) study designs: randomized or non-randomized controlled trials.

Exclusion criteria were as follows: (1) case reports, animal experimental studies, observational studies, reviews, meeting abstracts, and editorials; (2) cognitively or physically limited participants; (3) lack of adequate published information, with authors not providing the requested data; (4) control group with a physical activity intervention.

Data Extraction

All studies retrieved by our searches were imported into EndNote X9 software, and duplicate studies were removed. First, two independent reviewers (LHY and XY) conducted literature screening. Second, both of these reviewers screened the titles and abstracts and then read the full text of the potentially relevant papers, eliminating irrelevant studies. Third, the two reviewers extracted key information from the included articles. From each included study report, we collected the primary author, country, publication year, age of participants, sample size, characteristics of the Wii Fit exercise program, and outcomes. If there was any disagreement during any portion of the process, the issue was resolved in consensus meetings of the two reviewers.

Quality Assessment

Two investigators (LHY and XY) independently assessed the risk of bias and quality of the included studies by using the Physical Evidence Database (PEDro) scale. This scale includes 11 items for rating studies. Studies scoring 7 or more points are considered to be of high quality; studies with 5 to 6 points of fair quality, and studies with a score <4 points were excluded from this review. Disagreement was resolved by consensus with a third investigator (WY).

Statistical Analysis

Meta-analyses were performed using Review Manager 5.3 software (Cochrane, UK). Data from the included studies were used to estimate the standardized mean difference (SMD) or mean difference (MD). Heterogeneity was calculated using the I^2 statistic. I^2 statistic values of 25–50, 50–75, and 75–100% represented low-, moderate-, and high-level heterogeneity, respectively. When $I^2 \geq 50\%$ or $P < 0.10$, sources of heterogeneity were explored by a subsequent subgroup analysis. A random-effects model was used for $I^2 < 50\%$, and a fixed-effects model was used when $I^2 \geq 50\%$. Egger's test were used to assess publication bias by Stata 1.4. Values of $P < 0.05$ were considered to be statistically significant. Medians and interquartile ranges (IQRs) in studies were replaced by medians with standard deviations (SDs) using the formula SD = IQR/1.35 (14).

RESULTS

Search Results

The selection process using the inclusion/exclusion criteria and the flowchart of study selection is given in **Figure 1**. A total of 991 potentially relevant articles were identified. After the screening process, 235 duplicate articles were removed by EndNote X9. In total, 737 irrelevant articles were removed through the title and abstract screening, 19 full-text articles were read, and 9 articles excluded. Thus, a total of 10 articles (12, 15–23) were selected for the meta-analysis.

Study Characteristics

The study characteristics are presented in **Table 1**. Of 10 included studies, 8 were randomized controlled trials (12, 15–20, 23), and 2 were non-randomized controlled trials with similar baselines (21, 22). The studies were conducted in 6 countries, including the US (n = 4), Korea (n = 2), Australia (n = 1), the UK (n = 1), Denmark (n = 1), and Lebanon (n = 1). Among the 10 included studies, 188 older adults participated in the Wii Fit exercise groups, and 191 older adults participated in the control groups. The ages of the participants ranged from 65 to 92 years. All studies compared Wii Fit exercise with no exercise.

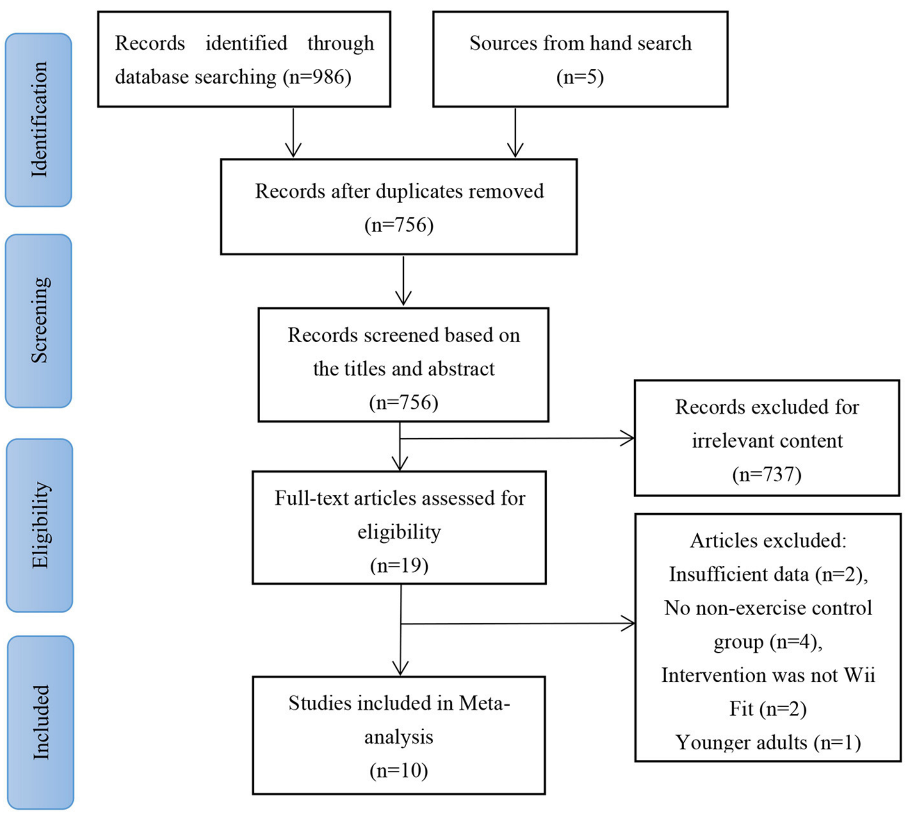

FIGURE 1 | PRISMA flowchart.

TABLE 1 | Baseline characteristics of included studies.

References	Region	Sample No. (Wii Fit/control)	Age (mean ± SD or range, years)	Intervention				Adherence (%)	Outcomes
				Frequency (time/week)	Duration (weeks)	Time (min)	Games (n)		
Bieryla et al. (12)	United States	5/5	81.5 ± 5.5	3	3	30	6	83.3	BBS; TUG
Chao et al. (15)	United States	16/16	85.19 ± 6.47	2	4	30	6	100	BBS; TUG
Fakhro et al. (16)	Lebanon	30/30	72.2 ± 5.2	3	8	30	2	90.9	TUG
Franco et al. (17)	United States	11/10	78.27 ± 6	2	3	13	5	100	BBS
Jorgensen et al. (18)	Denmark	28/30	75 ± 6	2	10	35	6	100	TUG; 30-s chair stand
Lee et al. (19)	Korea	9/8	69–82	2	8	30	9	75	TUG
Lee et al. (20)	Korea	21/19	71–81	2	6	60	6	95.4	BBS; TUG
Nicholson et al. (21)	Australia	19/22	65–84	3	6	30	8	100	TUG; 30-s chair stand
Orsega-Smith et al. (22)	United States	9/9	71.6 ± 7.79	2	8	30	10	100	BBS; TUG; 30-s chair stand
Whyatt et al. (23)	United Kingdom	40/42	69–84	2	5	30	4	95.2	BBS

BBS, Berg Balance Scale; TUG, Timed Up and Go test; SD, standard deviation.

Risk of Bias

The results of the quality assessments conducted using the PEDro scale are shown in **Table 2**. The average score was 6.4 points, and the quality of studies ranged from 5 to 8 points, with five studies scoring 7 or higher points (12, 16, 18, 20, 23), indicating that the quality of the included studies was moderate.

Meta-Analysis

Berg Balance Scale Scores

The BBS score is one of the most common measurements for evaluating functional balance in elderly populations. Six of 10 studies (12, 15, 16, 20, 22, 23) involving 201 elderly participants were included in the analysis of functional balance. The results of the meta-analysis suggested that the Wii Fit exercise program significantly improved functional balance (MD = 1.38, 95% CI, 0.61–2.16; $I^2 = 31\%$; $P = 0.0005$), with low-level heterogeneity and using a fix-effects model (**Figure 2**).

Time Up and Go Test

The TUG test is an effective test to evaluate static and dynamic balance in older adults. Less time to complete the TUG test indicates better balance. The meta-analysis pooled from eight studies (15–23) showed that there was a statistically significant difference in TUG scores between the Wii Fit group and the control group, with the Wii Fit group spent significantly less time completing the TUG (SMD = −0.51; 95% CI, −0.88 to −0.14; $I^2 = 52\%$; $P = 0.007$), with moderate-level heterogeneity and using a random-effects model (**Figure 3**).

Thirty-Second Chair Stand Test

The 30-second chair stand test evaluates the level of functional strength and endurance in the lower limb muscles. Three (18, 21, 22) studies were included in the meta-analysis to determine the effects of Wii Fit exercise on lower limb muscle strength compared with a non-exercise control group (**Figure 4**). The results of the meta-analysis suggested that participants in the Wii Fit exercise program showed improvement in lower limb muscle strength; however, the pooled results showed that strength was not statistically significantly different between the Wii Fit exercise and control groups (MD = 0.82; 95% CI, −0.14 to 1.77; $z = 1.68$, $P = 0.09$), with homogeneity and using a fix-effects model.

Sensitivity Analysis

The results of subgroup analyses suggested that the heterogeneity for two outcomes was reduced ($I^2 = 0\%$ for exercise frequency and number of exercise weeks). Thus, exercise frequency and number of weeks that exercise was performed may be sources of heterogeneity (**Supplementary Table 3**). Excluding one article at a time to assess the influence of a single study on this meta-analysis showed that overall, heterogeneity was not changed and that the conclusions were consistent with the main analyses.

Publication Bias

The results of the Egger's test suggested that there were no significant publication biases in the meta-analyses that included the three measures assessed herein: the Berg Balance Scale (BBS) ($P = 0.898$), the Timed Up and Go (TUG) ($P = 0.364$), and the 30-s chair stand tests ($P = 0.850$).

DISCUSSION

The results of this meta-analysis indicated that Wii Fit exercise may be an effective strategy to improve functional, static, and dynamic balance in older adults. Compared with older adults who did not exercise, those who participated in Wii Fit exercise showed substantial improvement in the BBS and TUG test scores.

TABLE 2 | Evaluation using the Physiotherapy Evidence Database (PEDro) scale for the level of evidence of all included studies.

References	Eligibility criteria specified	Random allocation	Concealed allocation	Baseline comparability	Blinded participants	Blinded therapists	Blinded assessors	Adequate follow-up	Intention-to-treat analysis	Between-group comparison	Point estimates and variability	PEDro Score
Bieryla et al. (12)	1	1	0	1	0	0	0	0	0	1	1	5
Chao et al. (15)	1	1	1	1	0	0	0	1	1	1	1	8
Fakhro et al. (16)	1	1	0	1	0	0	0	1	0	1	1	6
Franco et al. (17)	1	1	0	1	0	0	0	1	1	1	1	7
Jorgensen et al. (18)	1	1	1	1	0	0	0	1	0	1	1	7
Lee et al. (19)	1	1	0	1	0	0	0	1	0	1	1	6
Lee et al. (20)	1	1	1	1	0	0	0	1	0	1	1	7
Nicholsonet al. (21)	1	0	0	1	0	0	0	1	0	1	1	5
Orsega-Smith et al. (22)	1	0	0	1	0	0	0	1	1	1	1	6
Whyatt et al. (23)	1	1	0	1	0	0	0	1	1	1	1	7

However, this meta-analysis failed to observe a significant impact of Wii Fit exercise on lower limb muscle strength, which may be attributable to the small number of evaluated studies ($n = 3$) and adopt different games. Evidence from similar systematic reviews assessing other populations are in agreement with our findings of improved balance through Wii Fit exercise (24–26). For example, a recent meta-analysis concluded that compared with controls, older adults with neurocognitive disorders who performed Wii Fit exercise significantly improved their BBS test scores (25). That study assessed the methodologic quality of studies with the GRADE assessment tool and reported that three of five studies had high risk of bias. Another review that assessed the effect of Wii Fit on BBS scores found that Wii Fit exercise improved BBS scores compared with traditional therapy (26). Unlike our study, that meta-analysis included participants aged 12–86 years as well as participants with various medical conditions, such as Alzheimer's disease, Parkinson's disease, and stroke. Because of the diverse ages and medical conditions, the results of that study should be cautiously interpreted.

The efficacy of Wii Fit exercise to improve balance among older adults remains controversial. Iruthayarajah et al. suggested that Wii Fit exercise was not associated with improved BBS and TUG test scores among individuals with chronic stroke compared with conventional rehabilitation (27). Similarly, a systematic review suggested that Wii Fit training may not improve dynamic balance because Wii Fit exercise uses only stepping actions inside the base of support, and this type of exercise may not improve TUG test scores (28). However, another study stated that most Wii Fit games require participants to shift their weight to the left and right to achieve success, and this type of exercise may improve medial-lateral stability. Improvements in medial-lateral stability may be associated with positive changes in dynamic balance (21). In our meta-analysis, Wii Fit exercise was associated with improved BBS and TUG test scores compared with scores in the non-exercising control group. Our meta-analysis included healthy older adults aged $\geq$65 years, whereas the study by Iruthayarajah et al. included adults with chronic stroke aged $>$19 years. These differences likely contributed to the disparate outcomes between the studies.

Wii Fit exercise provides a sensory-enriched environment for individuals as they adjust their own balance and movements according to visual, auditory, and proprioceptive feedback while performing an exercise (29, 30). This stimulates their vestibular system and proprioceptors and enables exercisers to focus on the mobility required to play the game. A previous study stated that Wii Fit exercisers showed significant improvements in their vestibular integration and visual integration abilities compared with the control group immediately after the training as well as at the 1-month follow-up (31). In addition, impaired lower limb muscle strength is one of the primary factors for fall accidents in elderly (32). Our analyses suggest Wii Fit exercise may be promote adaptations in muscle strength, but do not have significantly different. A randomized controlled trial examined 10 weeks of Wii Fit exercise on lower limb muscle strength in older community-dwelling adults and found a significant improvement, with an increase of ∼20% in maximal muscle

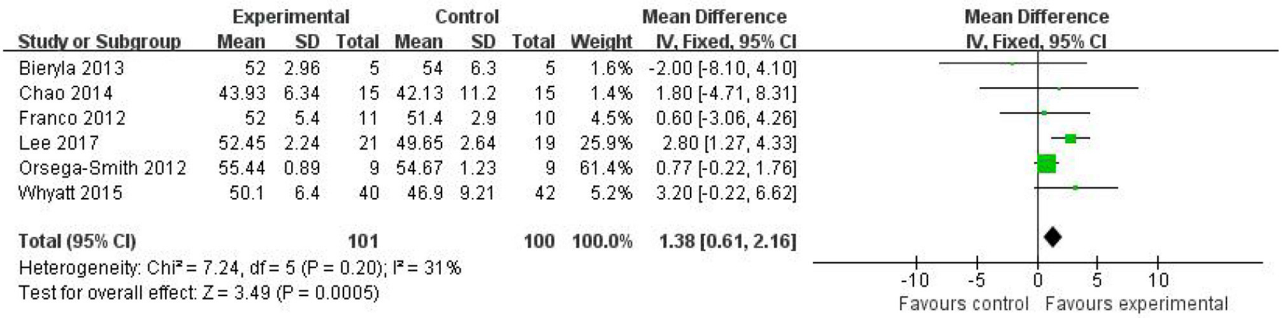

FIGURE 2 | Effect of Wii Fit with berg balance scale.

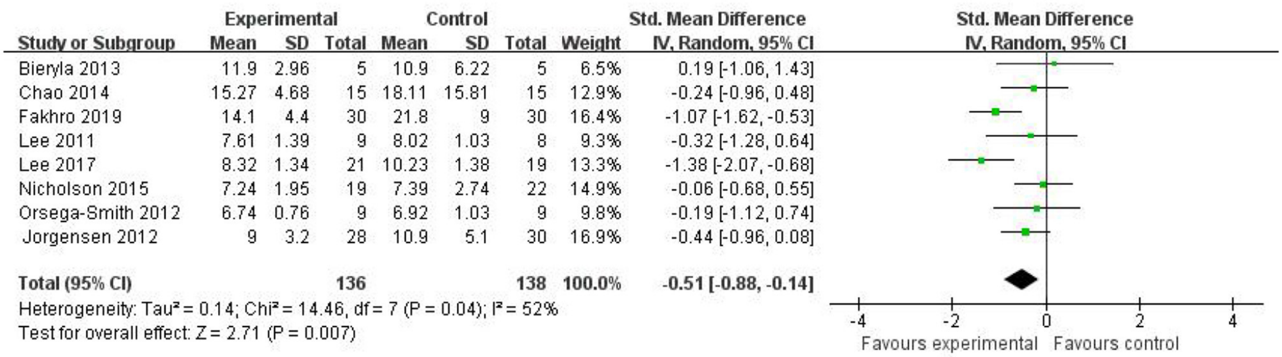

FIGURE 3 | Effect of Wii Fit exercise with timed up and go test.

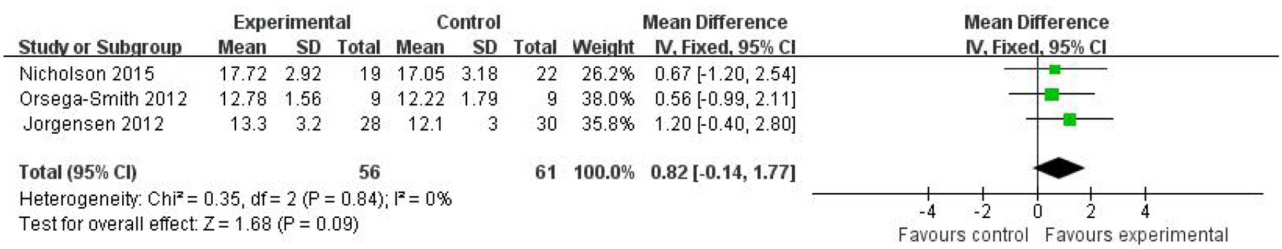

FIGURE 4 | Effect of Wii Fit exercise with 30-s chair stand test.

strength and in rapid force generation (18). The results of another randomized controlled trial suggested that the strength of the hip, knee, and ankle joints of the participants was significantly improved through the Wii Fit exercise and that the effect of the Wii Fit exercise in improving maximal isometric muscle strength in older adults was similar to that of traditional exercise training (31). In the Strength-enhancing Wii Fit exercise study, these protocol involved strength training games. Such as table tilt and slalom ski (18, 31, 33). Future research could explore the effects of different game programs on muscle strength in older adults. In terms of cognitive function, a previous study assessed the effects of Wii Fit exercise on cognitive function among stroke patients and observed significant benefits of interactive physical activity video-game training on cognitive function (34). Wii Fit exercise had significant effect in cognitive function as compared to Tetrax balance system. In short, Wii Fit exercise games may improve balance in older adults by promoting sensory system functions and enhancing muscle strength and cognitive function.

The present study found high adherence (100%) to Wii Fit exercise among older adults in five of 10 Wii Fit exercise studies. A recent meta-analysis demonstrated that Wii Fit exercise was safe, with no adverse events and high adherence (>80%) and low attrition (<20%) rates in four of five Wii Fit exercise studies

(25). Kirk et al. stated that participants reported that Wii Fit exercise was easier to perform and the games was more amusing and engaging compared with traditional balance training. Wii Fit exercise improved participants' enjoyment and motivated them and increased their desire to participate (35), as Wii Fit exergame provides interesting images and music. The system contains a large number of sports games to choose from, allowing older adults to participate in personalized and interesting tasks. Real-time visual and auditory feedback enables the participant to be more interested in Wii Fit exercise and helps to ensure that older adults continue to participate in Wii Fit exercise (18). Moreover, Wii Fit exercise provides opportunities for social interaction with friends and family members, and the cost of Wii Fit video game system is as low as US $250 (15). All those features make Wii Fit exercise attractive to older adults.

LIMITATIONS

There several limitations to this study. First, few studies were included ($n = 10$), two of which were not randomized controlled trials although those two studies reported similar baselines. This small number highlights the need for more randomized controlled trials in general and to confirm our findings in particular. Second, few studies have used an exercise control group when evaluating the effect of Wii Fit exercise in healthy older adults. Third, the generalizability of our results should be considered because the included studies (1) were published only in English and Chinese languages, and (2) recruited only adults ≥65 years of ages. Thus, our findings may not be generalizable to other populations.

CONCLUSIONS

In this meta-analysis, Wii Fit exercise was shown to improve functional, static, and dynamic balance in older adults. Although not statistically significant, perhaps owing to the small sample size, this type of exercise was also associated with enhanced lower limb muscle strength. Future meta-analyses should confirm our results by assessing a larger sample of randomized controlled trials. Future research directions should include exploration of the effect of Wii Fit exercise on the relationship between muscle strength and different games among older adults.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

YL and YW designed the research study. YL and YX conducted the search strategy, conducted study screening and data extraction, and wrote the first draft of the paper. YL analyzed the data. YL, YX, and YW interpreted the data. All authors have read and approved the final manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2022.812570/full#supplementary-material

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ORIGINAL RESEARCH
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Safety Evaluation of Cervical Dorsal Instrumentation in Geriatric Patients: Experience at a Level 1 Center for Spinal Surgery—A Single Center Cohort Study

Ehab Shabo[1], Simon Brandecker[1], Shaleen Rana[1], Gregor Bara[1], Jasmin E. Scorzin[1], Lars Eichhorn[2], Hartmut Vatter[1] and Mohammed Banat[1]*

[1] Department of Neurosurgery, University Hospital Bonn, Bonn, Germany, [2] Department of Anesthesiology and Intensive Care Medicine, University Hospital Bonn, Bonn, Germany

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Tzvi Dwolatzky, Technion Israel Institute of Technology, Israel

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****Correspondence:***
Mohammed Banat
Mohammed.Banat@ukbonn.de
orcid.org/0000-0001-7986-5215

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Objective: Dorsal instrumentation of the cervical spine is an established treatment in spine surgery. However, careful planning is required, particularly in elderly patients. This study evaluates early clinical outcomes in geriatric patients undergoing complex spine surgery.

Methods: In this retrospective, single center cohort study, we included all geriatric patients (aged ≥65 years) who underwent dorsal instrumentation between January 2013 and December 2020. We analyzed postoperative complications and the 30-day in-hospital mortality rate. Furthermore, the Charlson comorbidity index (CCI) and Clavien-Dindo grading system (CDG) were used to assess the patients' comorbidity burden.

Results: In total, 153 patients were identified and included. The mean age of patients was 78 years (*SD* ± 7). Traumatic injury (53.6%) was the most common reason for surgery. 60.8% of the patients underwent dorsal instrumentation with 3 or more levels. The most common comorbidities were arterial hypertension (64%), diabetes mellitus (22.2%), coronary heart disease and atrial fibrillation (19.6%). The most common adverse event (AE) was pneumonia (4%) and the most common surgery-related complication was wound infection (5.2%). Among patients categorized as high risk for AE (CCI > 5), 14.6% suffered a postoperative AE. In our univariate analysis, we found no risk factors for high rates of complications or mortality.

Conclusion: Our data demonstrates that older patients were at no significant risk of postoperative complications. The CCI/CDG scores may identify patients at higher risk for adverse events after dorsal instrumentation, and these assessments should become an essential component of stratification in this older patient population.

Keywords: cervical dorsal instrumentation, geriatric patients, complication rate, comorbidities, CCI and CDG scores

INTRODUCTION

Dorsal instrumentation and fixation of the spine is an established treatment option for a range of spinal pathologies including instability of the spine due to trauma or neoplasia, adult degenerative spine diseases, and infection (1).

Geriatric patients play an increasingly important role in the world of spine surgery as life expectancy and the number of older patients undergoing spinal instrumentation continue to increase worldwide, in particular instrumentation of the cervical spine regardless of the underlying causes (2–6). Furthermore, patients with spine procedures suffer more from complications compared to patients undergoing other types of surgery (e.g., cardiothoracic surgery) (7).

Several studies have described postoperative complications in cervical spine surgery, however with some limitations (8). Complication rates in geriatric patient cohorts are as high as 60% (9, 10). The goal of spinal surgery is to minimize neurological deficits and to improve the patient's quality of life; nevertheless, surgical treatment is associated with a high risk of complications in this group of vulnerable patients, especially in those populations with a high ASA score (11).

This study evaluates early clinical outcomes in geriatric patients undergoing complex spinal surgery at our center. The complication rates and 30 days in-hospital mortality were compared.

METHODS

Patient Selection and Inclusion Criteria

In this retrospective single center cohort study, we analyzed all patients aged ≥65 years who underwent spine surgery by dorsal instrumentation and stabilization at our level 1 spine center between January 2013 and December 2020. The inclusion criteria were primary instability of the cervical spine after trauma, tumor, infection, or a degenerative spine disease such as ossification of the posterior longitudinal ligament (OPLL), amongst others.

We excluded all patients who were deemed not suitable for surgery and those with incomplete data and/or follow-up information.

Patient clinical information including age, sex, BMI, ASA score, associated comorbidities, operative duration, localization, postoperative complications, and 30 days in-hospital mortality were assessed. Furthermore, the Charlson comorbidity index (CCI) and Clavien-Dindo grading system (CDG) were applied to assess the patients' comorbidity burden (12, 13).

Surgery-related and in-hospital postoperative complications were defined as such adverse events occurring within 30 days of the initial surgery (7, 14).

Abbreviations: AE, Adverse events; ASA, American Society of Anesthesiology; BMI, Body Mass Index; C1-7, Cervical vertebrae 1-7; CCI, Charlson comorbidity index; CDG, Clavien-Dindo grading system; CT, Computer tomogram; MRI, Magnetic resonance imaging; OR, Odds Ratio; OPLL, Ossification of the posterior longitudinal ligament; SD, Standard deviation.

Patients underwent standardized preoperative clinical and radiological (MRI and CT) examinations. A follow-up CT scan was routinely performed after surgery. Further clinical and imaging assessments were undertaken in the case of new or worse neurological deficits.

This study was performed in line with the ethical standards of our institutional and national research committee (Ethics committee of the Rheinische Friedrich Wilhelms University Bonn) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The local ethics committee at the University of Bonn approved this study (protocol no. 067/21).

Surgical Procedure

The surgical procedure generally involved general anesthesia and a median dorsal approach. In case of dorsal fixation of the upper cervical vertebrae (C1-2) the Harms technique was used (15), whilst lateral mass screw fixation was used in the subaxial spine (16). A postoperative CT scan was conducted immediately after surgery. To reduce bias due to skill set or experience of the surgeon, all operations were conducted by four experienced neurosurgeons only.

Radiological Evaluation

Postoperative imaging data was analyzed by an independent neuroradiologist in accordance with the institution's standards.

Statistical Analysis

Data analysis was performed using IBM® SPSS® Statistics (version 25, IBM Corp., Armonk, NY). Quantitative, normally distributed data is presented as mean values ± standard deviation (SD), while non-parametric data is summarized by median values [first quartile–third quartile]. In the case of categorical variables, data is given as numbers and percentages. After normality testing via the Shapiro-Wilk test, continuous normally distributed data was compared using t-tests, while the Mann-Whitney U test was used for non-parametric data. Nominal data was tested between groups using Fisher's exact test and in the case of multinomial data with a chi-squared test. P value was calculated by dividing the standard p-value of 0.05 by all equally important variables. Thus in this case, the p-value was $0.05/11 = 0.004545$, which was rounded to 0.005.

A $p < 0.005$ was considered statistically significant. About the chosen the p-value (0.005): statistically, the calculation of p-value when all variables are equally important (such as finding potential risk factors like this paper) is done by dividing the standard p-value (which is worldwide 0.05) by the number of the variables (17).

RESULTS

A total of 153 geriatric patients underwent cervical dorsal instrumentation between January 2013 and December 2020.

Table 1 shows the baseline data. The mean age was 78 ± 7.12 (*SD*) years.

Indications for instrumentation were classified into fractures due to trauma (53.6%), degenerative multisegmental spinal canal stenosis including OPLL (30.1%), metastatic spine tumors (9.8%), and infection with instability (6.5%).

At least one comorbidity was present in 82.4% of the patients. The most common associated comorbidities consisted of arterial hypertension (64.1%), diabetes mellitus (22.2%), coronary heart disease (19.6%), and atrial fibrillation (19.6%) (**Table 1**).

Postoperative Complications

Postoperative complications within 30 days after surgery were classified into surgery-related complications and adverse events (**Table 1**).

Overall, 28 out of 153 patients (18.3%) suffered early postoperative complications, with 14 patients having surgery-related complications and 14 experiencing adverse events (**Table 1**). The most common surgery-related complication was wound infection (5.2%) and the most common adverse event was pneumonia (4%). One patient suffered from a new neurological deficit (paraparesis) due to postoperative hematoma, which was surgically removed. Another five patients suffered from vertebral artery injury, three of them with infarction of the cerebellum without need of revision. They were all acutely treated with heparin and later with aspirin. **Table 2** shows the univariate analysis.

Influence of Clinical Admission Status and CCI/CDG

All the patients suffering postoperative complications following dorsal cervical instrumentation exhibited similar values for ASA, BMI and age. There were no significant differences regarding outcome or postoperative complications in any of the patients. Among patients categorized as high risk for AE (CCI > 5), 14.6% suffered a postoperative AE. In our univariate analysis, we found no risk factors for high rates of complications or mortality (**Table 2**). Furthermore, we conducted subgroup analysis looking at the influence of age, comparing relatively older patients (aged over >80 yrs.) with younger patients. We found no significant effect in our patient cohort ($p = 0.64$).

Influence of Patients' Comorbidities on Complications and Length of Hospital Stay

Patients with one or more of the comorbidities listed in **Table 1** did not develop a significantly higher rate of postoperative complications and presented a similar outcome (as demonstrated by length of hospital stay) as patients without any comorbidities (**Table 2**).

Influence of Operation Level, Duration of Operation, and Localization

Dorsal instrumentation took place at C1-2 level (Harms technique) in 42.5% of patients. Instrumentation for the other 57.5% of patients was subaxial (C3-7).

Operations were conducted in a single spinal level in 26.8% of patients, in two levels in 12.4% of patients, and in three or

TABLE 1 | Baseline data.

Total (*N* = 153)	**No. patients (%)**
Age (mean ± SD) (yrs.)	78 ± 7.12
Sex	
Male	93 (60.78)
Female	60 (39.21)
BMI (mean ± SD) kg/m^2	25 ± 3.54
ASA score	
1&2	51 (33.33)
3&4	102 (66.66)
Associated comorbidities	
Arterial hypertension	98 (64.05)
Coronary heart disease	30 (19.6)
Atrial fibrillation	30 (19.6)
Diabetes mellitus	34 (22.22)
Kidney disease	22 (14.37)
History of PE/DVT/COPD	24 (15.68)
Heart insufficiency	7 (4.57)
Cardiomyopathy/Valve disease	18 (11.76)
Length of stay in days (mean ± SD)	16 ± 21.44
Duration of operation in min. [q1–q3]	213 [154–266]
Instrumentation level	
1. Level	41 (26.79)
2. Levels	19 (12.41)
3. Levels and more	93 (60.78)
Localization	
Upper cervical spine	65 (42.48)
Subaxial	88 (57.51)
Pathology	
Trauma	82 (53.59)
Degenerative	46 (30.06)
Tumor	15 (9.80)
Infection	10 (6.53)
Postoperative complication	
No complications	125 (81.7)
Surgery-related complications:	
Symptomatic vertebral artery injury	5 (3.26)
Wound infection	8 (5.22)
Hematoma	1 (0.65)
Adverse events	
Pneumonia	6 (3.92)
PE/DVT	3 (1.96)
Sepsis	2 (1.3)
Death (30 day mortality)	3 (1.96)
Clavien-Dindo grading system (CDG)	
Grade II	11 (7.18)
Grade III	9 (5.88)
Grade IV	5 (3.26)
Grade V	3 (1.96)

ASA, American Society of Anesthesiology; BMI, Body Mass Index; COPD, chronic obstructive pulmonary disease; DVT, deep vein thrombosis; min., minutes; No., number; PE, pulmonary embolism; q1–q3, first quartile–third quartile; SD, standard deviation; yrs., years.

TABLE 2 | Comparison of patients without postoperative complications vs. surgery-related complications and/or adverse events.

Total (*N* = 153)	Pts. w/o complications	Pts. with surg.-rel. complications	Pts. with postoperative AEs	p1 (No compl. vs. surg.-rel.)	p2 (No compl. vs. AEs)
No. of patients	125	14	14		
Mean age (yrs.) mean ± (*SD*)	77 ± 7.3	79.6 ± 5.9	80 ± 6.4	0.304	0.141
Gender (F/M)	50/75	5/9	5/9	1.00	1.00
BMI (kg/m^2), mean ± (*SD*)	24.9 ± 3.5	23.9 ± 3.6	24.4 ± 3.7	0.317	0.665
ASA score				0.557	0.548
1 or 2	42	6	3		
3 or 4	83	8	11		
CCI score				0.132	0.071
1 or 2	57	5	4		
>3	68	9	10		
Comorbidities				0.465	1.00
Arterial hypertension	83	7	8	0.247	0.557
Coronary heart disease	24	2	4	1.00	0.481
Atrial fibrillation	22	5	3	0.147	0.717
Diabetes mellitus	24	7	3	0.016	0.735
Kidney disease	13	6	3	0.004	0.205
History of PE/DVT/COPD	19	2	3	1.00	0.465
Length of stay in days median [q1–q3]	15 [9–30]	20 [13–51]	26 [8–41]	0.182	0.981
Op duration in min., mean ± (SD)	212.3 ± 75.6	215.1 ± 57.8	217.9 ± 80.2	0.892	0.793
OP Level				0.035	0.115
1–2 level	55	1	4		
>3 levels	70	13	10		
Localization				0.262	0.092
Upper cervical spine	58	4	3		
Subaxial	67	10	11		
Pathology				0.227	0.077
Trauma	69	7	6		
Degenerative	38	5	3		
Tumor	13	0	2		
Infection	5	2	3		

AEs, adverse events; ASA, American Society of Anesthesiology; BMI, body mass index; ds, days; CCI, Charlson comorbidity index; compl., complication; COPD, chronic obstructive pulmonary disease; DVT, deep vein thrombosis; PE, pulmonary embolism; pts., patients; q1-q3, first quartile – third quartile; surg.-rel., surgery-related; w/o, without; yrs., years.

more levels in the remaining 60.8% of patients. The duration of the operation had no significant effect on complication rates.

This study shows no significant relationship between the operation level or localization and postoperative complications (**Table 2**).

Influence of Pathology

We found no greater risk of complications depending on the indication for dorsal instrumentation, especially in the tumor or trauma subgroup.

DISCUSSION

Geriatric patients are an increasingly important group in medical care (18), while comorbidities require ever better planning before surgery (8, 19). As life expectancy worldwide continues to increase, the number of older patients undergoing cervical instrumentation is also increasing, regardless of the underlying causes (2–6, 10).

The present study evaluates the early outcome of dorsal instrumentation und fixation of the cervical spine in geriatric patients, focuses on postoperative complications in this specific cohort, and investigates the influence of comorbidities on complications.

The impact of spine surgery in geriatric patients is a subject of controversy in the literature (9, 10).

In one meta-analysis including 18 studies comparing elderly (n = 1,169) and non-elderly (n = 1,699) patients who received surgical treatment for cervical spondylotic myelopathy, no significant difference in the incidence of postoperative complications was noted. In addition, the complication rate in these geriatric patients was not significant (20). Razack et al. concluded that corrective procedures for symptomatic non-traumatic cervical myelopathy in elderly patients are safe and are not associated with significant postoperative complications (3). In another study, Kobayashi et al. concluded that preoperative motor deficits, operative time, estimated blood loss, and fusion surgery with instrumentation were significant risk factors for major complications. However, preoperative comorbidities were not significantly associated with postoperative complications (21). Kiyoshi et al. have shown that neither the cervical surgical procedure nor preoperative comorbidities had a significant effect on postoperative complications in elderly patients (22). Furthermore, several other publications do not show significantly higher postoperative complication rates between older and younger patients or in relation to preoperative comorbidities (2, 3, 20–28). However, most current studies discuss cervical procedures in geriatric patients with a non-traumatic cause.

Surgery on geriatric patients has some characteristics not present in the non-geriatric population, such as comorbidities, surgical treatment, or length of stay in hospital. As a result, one study recommends not treating every impairment (29). Generally, geriatric patients with relevant comorbidities suffered more complications after surgical treatment than younger patients (13, 30, 31). In the surgical and oncological world, CCI and CDG scores are widely used to predict complications, and are therefore applied in our study (13, 32–34). Timely identification of geriatric patients and peri-procedural classification of risk, combined with a clear therapy concept, have a positive influence on the outcome (35–38).

Fu et al. describe a high correlation between the ASA score of patients undergoing spinal surgery and their postoperative morbidity and mortality (11). Other studies correlate increased morbidity following spinal surgery with comorbidity factors such as age, ASA score, BMI or DM (39, 40).

In this study, we decided to investigate the relationship between patient condition/preoperative comorbidities and postoperative complications after dorsal instrumentation. Postoperative complications were divided into operation-related complications (symptomatic vertebral artery injury, wound infection, and hematoma) and adverse events (pneumonia, pulmonary embolism, sepsis, etc.). The cohort was defined as older patients of age ≥65 years suffering from pathologies (traumatic, degenerative, tumorous, and infectious) on whom we operated between January 2013 and December 2020. Our study shows that older patients were not at significant risk of developing postoperative complications, especially operation-related complications. Patients with postoperative adverse events were generally almost 4 years older than patients without any postoperative complications. This was not statistically significant ($p = 0.14$), however. This study shows that neither sex nor other aspects of the admission status of these patients (ASA score, BMI, etc.) had a significant influence on the complication rate after cervical spine surgery. The level and localization of the operation also seem to have had no significant effect on the overall outcome.

Our hypothesis was that there is a higher potential risk when operating on geriatric patients with comorbidities, but we found that this was not true, neither for operation-related complications nor for adverse events. Furthermore, withholding surgery from older patients could have a negative effect on their quality of life due to symptom progression.

Overall, this study clearly showed that comorbidities in our older patients were not associated with significantly higher complication rates and therefore did not influence the early outcome of cervical spine surgery.

CONCLUSION

Since the overall population is clearly aging and there is a marked increase in average life expectancy, it is expected that the number of surgically treated geriatric patients will also increase in the future. It is therefore necessary to address this issue. Our data demonstrate that older patients were at no significant risk of postoperative complications. The CCI/CDG scores may identify patients at higher risk for adverse events after dorsal instrumentation and these assessments should become an essential component of stratification in this older patient population. Nonetheless, there is an associated predictor that is unlikely to be medical improved or changed. Early preoperative stratification of patients at risk may help to determine the optimal extent of postoperative monitoring and observation. This is useful for preoperative communication both with medical colleagues and with the affected patients and their families, as regards realistic needs and expectations of the therapy, especially of the neurosurgical treatment. Our recommendation meets the criteria for a level of evidence 3, based on the publication by Kaiser et al. (41).

LIMITATIONS

The present study has several limitations. Data acquisition was retrospective. Furthermore, patients were not randomized, but treated according to the expert opinion of their neurosurgeon. Additionally, the present data represent only a single center experience.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

ES: conceived, designed and performed the study, first draft of the manuscript and illustrations, and analysis and interpretation of data. SB, SR, GB, JS, LE, and HV: critical review of the manuscript. MB: analysis, acquisition, interpretation of data, and supervision. The final manuscript was critically revised and approved by all authors.

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Static Balance and Chair-Rise Performance in Neurogeriatric Patients: Promising Short Physical Performance Battery-Derived Predictors of Fear of Falling

Katharina Scholz[1*], Johanna Geritz[1], Jennifer Kudelka[1], Marten Rogalski[1], Katharina Niemann[1], Corina Maetzler[1], Julius Welzel[1], Michael Drey[2], Tino Prell[3] and Walter Maetzler[1]

[1] Department of Neurology, University Hospital Schleswig-Holstein, Kiel, Germany, [2] Department of Medicine IV, Geriatrics, University Hospital of LMU Munich, Munich, Germany, [3] Department of Geriatrics, Halle University Hospital, Halle, Germany

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Jagiellonian University Medical College, Poland

***Correspondence:**
Katharina Scholz
katharina_scholz.k@gmx.de

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Background: Fear of falling (FOF) negatively affects health-related quality of life and is common in neurogeriatric patients, however, related parameters are not well understood. This study investigated the relationship between FOF, physical performance (as assessed with the Short Physical Performance Battery and its subscores) and other aspects of sarcopenia in a sample of hospitalized neurogeriatric patients.

Methods: In 124 neurogeriatric patients, FOF was assessed with the Falls Efficacy Scale International (FES-I). Physical performance was measured using the Short Physical Performance Battery (SPPB) including walking duration, balance and five times sit-to-stand task (5xSST) subscores. Appendicular skeletal muscle mass (ASMM) was estimated with the cross-validated Sergi equation using Bioelectrical impedance analysis measures. The Depression im Alter-Skala (DIA-S) was used to assess depressive symptoms. Multiple regression models with FES-I score as outcome variable were computed using backward selection with AICc as selection criterion, including: (i) SPPB total score, ASMM/height^2, grip strength, age, gender, positive fall history, number of medications, use of a walking aid, DIA-S score and Montreal Cognitive Assessment (MoCA) score; and (ii) SPPB subscores, ASMM/height^2, grip strength, age, gender, positive fall history, number of medications, DIA-S score and MoCA score, once with and once without including use of a walking aid as independent variable.

Results: Lower SPPB total score, as well as lower SPPB balance and 5xSST subscores were associated with higher FES-I scores, but SPPB walking duration subscore was not. Moreover, DIA-S, number of medications and use of a walking aid were significantly associated with FOF.

Conclusion: Our preliminary results suggest that -if confirmed by subsequent studies- it may be worthwhile to screen patients with low SPPB balance and 5xSST subscores for FOF, and to treat especially these mobility deficits in neurogeriatric patients with FOF. Moreover, training neurogeriatric patients to use their walking aids correctly, critical evaluation of medication and treating depressive symptoms may further help reduce FOF in this highly vulnerable cohort.

Keywords: fear of falling, mobility, static balance, sit-to-stand, geriatrics, BIA, depressive symptoms

INTRODUCTION

Fear of falling (FOF) is a common and serious condition affecting 21−85% of older adults (1). FOF is also prevalent in individuals without a fall history and can predict future falls (2, 3). FOF could evoke reasonable caution in individuals with a high fall risk, but may also be a debilitating symptom that could cause disproportionate activity avoidance (2, 4–8). This may lead to a deconditioning effect on muscle strength and balance, aggravating a downward spiral towards functional decline (2, 5, 9, 10). Neurological diseases such as stroke/small vessel disease, vertigo, Parkinson's disease (PD) and polyneuropathy (PNP) have been identified as risk factors for falls (2, 11–13) with the prevalence of falls among neurological in-patients being almost twice as high as in an age-matched population (14). FOF was identified as a risk factor for future falls in neurological patients (14, 15) and is negatively correlated with health-related quality of life in patients with PD (16, 17) and stroke (18). Previous studies in community-dwelling older adults have shown that low scores in the Short Physical Performance Battery (SPPB), a composite test measuring domains of physical performance like walking (with walking duration), static balance (in standing positions) and transfer (five times sit-to-stand-to-sit task (5xSST)) (19–21), are associated with higher FOF (22–24) and may even be (in combination with self-rated disability) predictive for the development of FOF (25). Additionally, a study in patients with stroke found an association between the SPPB and fall-related self-efficacy (26) (the confidence of a person not to fall), which is related to – but not identical with FOF (27). The SPPB is a useful tool in geriatric assessments as it is predictive for falls, all-cause mortality, institutionalization and disability (19, 28–30). However, many studies on FOF in neurological patients do not include the SPPB as a physical performance measure (17, 18, 31–35), even though its use may have several advantages. Balance and lower limb strength (which is needed to successfully rise from a chair and keeping a stand-up position (36)) have been found to be associated with FOF in patients with stroke (18, 35) and PD (32, 34). Further, self-reported difficulty in rising from a chair has been previously linked to higher FOF in patients with PD (17). Adding to the importance of balance with regard to FOF, an intervention study was able to show that balance training reduces FOF in older institutionalized patients (37). Evidence on the relationship between FOF and gait speed (which is represented by walking duration in the SPPB) differs in the literature (32, 38–41). For example, a study in patients with PD found a correlation between FOF and gait speed in bivariate analysis, but not in multivariate regression analysis (32). The SPPB combines the measurement of these abilities and could therefore be useful to identify physical function parameters related to FOF. A recent study in healthy and mobility-limited community-dwelling older adults showed that the components of sarcopenia (i.e., low muscle mass, muscle strength and physical performance) independently contribute to increased FOF (23). Evidence on the relationship between muscle mass and FOF in neurological patients is lacking (17, 18, 31–35), even though neurological patients may be more likely to suffer from sarcopenia as it has recently been suggested that PD, motor neuron disease, Alzheimer's disease and sarcopenia may be part of an "extended neurodegenerative overlap syndrome" (42). Other factors associated with FOF may be the use of a walking aid (31, 43), whose incorrect use -which is frequent- may be associated with reduced stability (44), and psychological factors, such as depressive symptoms and anxiety (18, 43). This study aims to investigate the relationship between FOF and the SPPB, as well as components of sarcopenia (muscle mass and muscle strength) in a cohort of hospitalized neurogeriatric patients. This may help gain an improved understanding of FOF in this vulnerable patient cohort and propose aspects which may be studied further in longitudinal and intervention studies to evaluate factors that may be predictive of FOF or qualify as possible treatment targets.

MATERIALS AND METHODS

Study Design

The data used for this study was obtained from the prospective, explorative observational multi-center study Cognitive and Motor Interaction in the Older Population (ComOn (45)). Briefly, the ComOn study investigated motor and cognitive deficits, as well as treatment outcomes in a large geriatric cohort. For this analysis, the cross-sectional data of the neurogeriatric patients from the baseline assessment in Kiel was used. The study was approved by the ethical committee of the Medical Faculty of Kiel University, and the study was conducted according to the principles of the Declaration of Helsinki.

Patients

This study included 124 multimorbid inpatients that were recruited from September 2017 until March 2021 at their

Abbreviations: ASMM, Appendicular skeletal muscle mass; BIA, Bioelectrical impedance analysis; ComOn, Cognitive and Motor Interaction in the Older Population; DIA-S, Depression Im Alter-Skala; FES-I, Falls Efficacy Scale International; FOF, Fear of falling; MNA-SF, Mini Nutritional Assessment short-form; MoCA, Montreal Cognitive Assessment; PD, Parkinson's Disease; PNP, Polyneuropathy; SAE, Subcortical arteriosclerotic encephalopathy; SPPB, Short Physical Performance Battery; 5xSST, Five times sit-to-stand task.

admission to the neurogeriatric ward of the University Hospital Schleswig-Holstein, Campus Kiel. The patients were geriatric, aged 60 years and older and suffered from at least two chronic conditions (45–47). Additional inclusion criteria were the ability to stand without personal aid for at least ten seconds and the capability to walk at least four meters (walking aids allowed) (45). Exclusion criteria were less than six points in the Montreal Cognitive Assessment (MoCA) (45, 48, 49), clinical diagnosis of severe deficits in consciousness, two or more falls during the previous week, history of or current drug abuse (except nicotine) and (corrected) visual acuity below 60% (as assessed with a Sloan Letter Chart for three-meter distance (45, 50)). All patients received their baseline assessment during the first two days of their hospital stay.

Assessment of Body Composition

Bioelectrical impedance analysis (BIA, Akern Bia 101, SMT medical GmbH & Co. KG, Würzburg, Germany) was used to assess body composition. BIA measures the electric impedance (Z) and phase angle of an electric current going through the body, and the resistance (R) and reactance (Xc) can be calculated (51, 52). BIA was performed after a rest phase of at least ten minutes, positioning four electrodes (two each at the right arm and right leg) with the patient in a supine position (45, 52). In order to estimate the appendicular skeletal muscle mass (ASMM), we used the raw BIA measures and the cross-validated Sergi equation (36, 53):

$$\begin{aligned} \boldsymbol{ASMM\left(kg\right)} &= \boldsymbol{-3{,}964 + (0,227 \times RI) + \left(0,095 \times weight\right)} \\ &\quad \boldsymbol{+ (1,384 \times sex) + (0,064 \times Xc)} \\ RI &= \frac{height\ (cm)^2}{R\ (\Omega)},\ weight\ (kg), \\ sex: female &= 0,\ male = 1 \end{aligned}$$

We adjusted the ASMM for body size by dividing by height squared (kg/m^2) (36, 54, 55).

Physical Performance and Grip Strength Assessment

To evaluate physical performance, the Short Physical Performance Battery (SPPB) was administered. The test includes the three balance tasks (each needed to be held for ten seconds) side-by-side stand (with both feet in a parallel position, semi-tandem stand with the front inner edge of one foot touching the rear inner edge of the other foot) and tandem stand (with one foot's tip toe touching the other foot's heel), two four-meter walks at a comfortable pace (the faster was used for analysis), and a five times sit-to-stand task (5xSST) from a chair that had to be performed as fast as possible without using the arms. Time was taken with a stopwatch and each test performance was ranked depending on successful execution and time needed to complete the tasks using a zero to four scale. The SPPB total score is the sum of the three subscores (walking duration, balance, 5xSST) and can range from zero to twelve with less than nine points being indicative for physical limitation. For the walking task, the use of a walking aid was recorded, balance tasks and 5xSST were performed without a walking aid. (19–21, 56).

To measure maximum grip strength, the Jamar hydraulic hand dynamometer (AFH, Lüdge, Germany) was used. The assessment was done for both hands according to the Southampton protocol (45, 57) with the adaptation that the arms were not rested on arm chairs. The highest score of the six taken grip strength measurements (each hand three times) was used for this analysis.

Questionnaires/Screening Tests

The self-administered questionnaire Falls Efficacy Scale International (FES-I, (58)), was used to measure FOF. The patients rate their concern of falling in 16 specific activities of daily living (e.g., when reaching for something above the head or on the ground) on a scale from one (no concern) to four (maximum concern) and the total sum is then calculated.

Current depressive symptoms over the last two weeks were assessed using the Depression-im-Alter-Skala (DIA-S, (59) The questionnaire consists of ten items (e.g., "I am scared to say or do something wrong"), which the patients answer with yes or no. A maximum of ten points can be reached, a score of three points is considered marginal, scores of four or more points are considered suspicious of depressiveness.

The Mini Nutritional Assessment short-form (MNA-SF, (60, 61)) was used to assess nutritional status. It includes six items that each have two to four response categories ranked from zero to three. The items concern food intake, weight loss, mobility, psychological stress or acute disease, neuropsychological problems and Body Mass Index (BMI). A maximum of 14 points can be reached with eight to eleven points reflecting risk of malnutrition and less than or equal to seven points indicating malnourishment (61).

The MoCA (48) is a standardised neuropsychological screening test to assess cognitive function. A maximum of 30 points can be achieved, with $<$26 points suggesting a cognitive deficit (48).

Falls in the last three months were recorded in the interview as part of the geriatric screening according to Lachs et al. (62), and $\geq$1 fall (s) was considered a positive fall history. Age, gender, current medication and clinical diagnosis were derived from the medical records. Due to associations between falls and medication (e.g., antipsychotics, antidepressants, benzodiazepines) (63, 64) and potential associations between FOF and polypharmacy (43), number of medications was reported and included in the analyses.

Statistical Analysis

For patients with one ($n = 14$, completeness of 94%) or two ($n = 3$, completeness of 88%) missing responses to single items of the FES-I we used individual mean imputation (65). We calculated the within subject average of completed items, imputed this average value for the missing item(s) and calculated the sum as an imputed FES-I total score for these patients. Patients were grouped into high and low FOF according to the recommended FES-I cut-off point, with a score of $\leq$22 reflecting low FOF and $\geq$23 high FOF (58). Group differences were examined using the Mann-Whitney U-test (as the assumption of normality for the t-test was rejected for all variables according to the results of the Shapiro-Wilk test) for continuous variables and Fisher's exact test for dichotomous variables. For the Mann-Whitney U-test the rank-biserial correlation was calculated as the effect size. Spearman's rho (ρ) was calculated to evaluate correlations between FES-I score and all variables. To address the main question of the relationship among FOF, SPPB and aspects of sarcopenia, three multiple linear regression models with FES-I score as dependent variable were computed using backward selection with AICc as selection criterion. In the first model the SPPB total score, ASMM/height^2 (kg/m^2) and grip strength (kg) were initially entered as predictors and age (years), gender, positive fall history, number of medications, use of a walking aid, DIA-S score and MoCA score were included as potential confounders. In the second model the SPPB subscores (walking duration, balance, 5xSST), ASMM/height^2 (kg/m^2) and grip strength (kg) were initially included as predictors and age (years), gender, positive fall history, number of medications, DIA-S score and MoCA score were included as potential confounders. In the third model the use of a walking aid was added to the second model as independent variable. All assumptions of multiple linear regression models were examined (linear relationship, no multicollinearity evaluated with variance inflation factors, independence of observations, no autocorrelation, homoscedasticity and multivariate normality). Results were considered significant if the two-sided p-value was ≤0.05. Data was analysed using JASP Version 0.16 statistical software (66) and R (R Foundation for Statistical Computing) Version 4.1.2 (67).

RESULTS

Descriptive and Bivariate Statistics

A total of 124 patients were included in the study. Mean age was 77 years (± 6) and 66 patients (53%) were female. Most frequent primary diagnosis was PD, followed by atypical Parkinsonism, stroke, PNP and subcortical arteriosclerotic encephalopathy (SAE, **Supplementary Table 1**). Additional information on their multimorbidity profile and concomitant medication is provided in **Supplementary Tables 2** and **3**. 98 patients (79%) reported high FOF with a mean FES-I score of 36.5 (± 10.1), and 26 patients (21%) reported low FOF with a mean FES-I score of 19.2 (± 2.2).

Patients with high FOF had lower SPPB total scores ($\tilde{x} = 5.00$, IQR= 3.00 vs. $\tilde{x} = 7.00$, IQR = 2.00; rrb = −0.47, p < 0.001) and were more likely to use a walking aid (54.1 vs. 23.1%, p = 0.007). Details are provided in **Table 1**.

There was a significant inverse correlation between FES-I score and SPPB total score as well as all SPPB subscores. Significant correlations with FES-I total score were also found for DIA-S, and number of medications. Neither muscle mass nor grip strength correlated significantly with the FES-I score. Details are shown in **Table 2**.

Regression Analyses

We first determined if SPPB total score was associated with the FES-I score after correction for cofactors. Variables entered as independent variables were: SPPB total score, ASMM/height^2 (kg/m^2), grip strength (kg), age (years), gender, positive fall history, number of medications, use of a walking aid, DIA-S score and MoCA score. In the first model using backward selection, the FES-I score was associated with SPPB total score ($\beta = -0.22$, p =0.015), use of a walking aid ($\beta = 0.30$, $p = 0.001$), number of medications ($\beta = 0.16, p = 0.048$) and age ($\beta = -0.16, p = 0.047$) and additionally included DIA-S score ($\beta = 0.15$, $p = 0.066$); adjusted R^2 of the model was 0.27 ($p < 0.001$).

Next, we determined which SPPB subscores were associated with the FES-I score. Variables entered as independent variables were: SPPB subscores (walking duration, balance, 5xSST), ASMM/height, grip strength, age, gender, positive fall history, number of medications, DIA-S score and MoCA score. The FES-I score was associated with the SPPB balance ($\beta = -0.29$, $p <$ 0.001) and SPPB 5xSST ($\beta = -0.20$, $p = 0.015$) subscores, DIA-S score ($\beta = 0.17$, $p = 0.041$), and number of medications (β = 0.18, $p = 0.038$) and adjusted R^2 of the model was 0.22 (p < 0.001). When additionally correcting for the use of a walking aid, the explained variance increased (adjusted $R^2 = 0.29$, $p <$ 0.001) and the association between FES-I score and SPPB balance subscore became weaker ($\beta = -0.16$, $p = 0.077$) next to SPPB 5xSST ($\beta = -0.17, p = 0.027$) , DIA-S score ($\beta = 0.16, p = 0.049$), use of a walking aid ($\beta = 0.30, p = 0.001$), number of medications ($\beta = 0.16, p = 0.046$), and age ($\beta = -0.14, p = 0.080$). Details are shown in **Tables 3** and **4**.

DISCUSSION

This study aimed to assess the relationship between FOF and aspects of physical performance and sarcopenia in a cohort of hospitalized neurogeriatric patients. Our main findings were that: (i) higher FOF was associated with decreased physical performance, especially with; (ii) decreased static balance; and (iii) decreased chair-rise performance. Moreover, number of medications, depressive symptoms and use of a walking aid were also associated with FOF, and the associations of FOF with static balance is weakened when considering use of a walking aid, although the physical task itself was performed without a walking aid.

Similar to studies in community-dwelling older adults (1, 22–24, 43), low physical performance was associated with higher FOF in our study cohort of hospitalized neurogeriatric patients. A study in patients with stroke found comparable results. The authors described an association between physical performance (also measured with the SPPB) and fall-related self-efficacy (26). A recent two-year longitudinal study in community-dwelling older adults demonstrated that by using two criteria: self-reported mobility disability and less than eight points in the SPPB total score, they were able to identify 82% of people at risk of developing FOF (25). Taken together, poor physical performance (measured with the SPPB) is strongly associated with, and may even be predictive for, FOF in different cohorts including neurogeriatric patients. If confirmed by subsequent studies, FOF should be taken into consideration for diagnostics and treatment routines in neurological patients with low SPPB total scores. As the SPPB is frequently used as part of the comprehensive

TABLE 1 | Patients' characteristics and group comparisons.

	Entire cohort *N* = 124	FES-I low (≤ 22 points) *N* = 26			FES-I high (≥ 23 points) *N* = 98			*p*-values		
		Female *N* = 12	Male *N* = 14	Both genders *N* = 26	Female *N* = 54	Male *N* = 44	Both genders *N* = 98			
	x; IQR (x ± SD)	x; IQR (x ± SD)	x; IQR (x ± SD)	x; IQR (x ± SD)	x; IQR (x ± SD)	x; IQR (x ± SD)	x; IQR (x ± SD)	F [a]	M [b]	All [c]
Age (years)°	78.0; 7.0 (77.2 ± 6.0)	79.0; 2.5 (79.1 ± 2.6)	77.0; 5.5 (77.0 ± 6.4)	78.0; 4.5 (78.0 ± 5.0)	78.0; 8.8 (76.8 ± 6.2)	77.0; 5.0 (77.3 ± 6.2)	77.5; 7.0 (77.0 ± 6.2)	0.237	0.799	0.466
BMI (kg/m^2)°	26.1; 5.8 (27.0 ± 5.3)	23.2; 5.4 (23.8 ± 3.6)	25.0; 3.9 (25.7 ± 3.4)	24.3; 4.9 (24.8 ± 3.6)	27.2; 5.0 (28.2 ± 6.1)	26.3; 6.7(26.8 ± 4.9)	26.8; 5.9 (27.5 ± 5.6)	0.009*	0.500	0.014*
MoCA (score)°	22.0; 6.0 (21.5 ± 4.0)	21.0; 6.3 (20.9 ± 5.1)	22.0; 6.5 (21.4 ± 4.3)	22.0; 6.8 (21.2 ± 4.6)	21.5; 5.0 (21.2 ± 3.8)	22.0; 5.3 (22.1 ± 3.9)	22.0; 5.8 (21.6 ± 3.9)	1.000	0.642	0.784
Number of diagnoses°	11.0; 7.0 (11.5 ± 5.3)	10.0; 5.3 (11.1 ± 6.2)	9.5; 5.8 (10.7 ± 4.9)	10.0; 5.8 (10.9 ± 5.4)	12.0; 6.5 (12.3 ± 5.3)	10.5; 8.0 (10.8 ± 5.4)	11.5; 7.0 (11.6 ± 5.4)	0.233	0.792	0.301
Number of medications°	7.5; 6.0 (7.3 ± 3.8)	5.5; 5.5 (6.2 ± 3.8)	6.5; 4.0 (6.4 ± 4.0)	6.0; 4.8 (6.3 ± 3.8)	8.0; 6.0 (8.0 ± 4.0)	7.0; 5.0 (6.9 ± 3.6)	8.0; 5.0 (7.5 ± 3.8)	0.179	0.535	0.154
ASMM/height (kg/m^2)°	6.6; 1.6 (6.9 ± 1.2)	5.7; 1.1 (5.8 ± 0.6)	7.2; 1.2 (7.3 ± 0.8)	6.6; 1.5 (6.6 ± 1.1)	6.2; 0.9 (6.5 ± 1.0)	7.4; 1.6 (7.5 ± 1.3)	6.6; 1.8 (6.9 ± 1.3)	0.028*	0.660	0.359
Grip strength (kg)°	22.0; 14.0 (25.1 ± 10.7)	20.0; 6.3 (19.9 ± 7.2)	31.5; 17.5 (33.3 ± 10.9)	25.0; 11.8 (27.1 ± 11.4)	18.0; 5.8 (17.9 ± 5.4)	33.5; 13.1 (32.7 ± 9.5)	21.5; 14.0 (24.5 ± 10.5)	0.182	0.949	0.193
SPPB (score)°	6.0; 3.0 (5.7 ± 2.2)	7.0; 2.0 (7.0 ± 1.5)	7.5; 2.0 (7.1 ± 1.8)	7.0; 2.0 (7.0 ± 1.6)	5.0; 3.8 (5.0 ± 2.0)	6.0; 2.3 (5.7 ± 2.2)	5.0; 3.0 (5.3 ± 2.1)	0.003*	0.038*	<0.001*
FES-I (score)°	30.0; 19.3 (32.9 ± 11.5)	20.0; 2.8 (19.4 ± 2.3)	19.5; 3.8 (19.1 ± 2.1)	20.0; 3.8 (19.2 ± 2.2)	37.0; 15.9 (37.3 ± 9.3)	32.5; 15.5 (35.6 ± 11.1)	34.0; 16.9 (36.5 ± 10.1)	<0.001*	<0.001*	<0.001*
DIA-S (score)°	2.0; 4.0 (2.8 ± 2.5)	2.0; 2.8 (2.5 ± 2.2)	1.0; 2.0 (1.9 ± 2.8)	1.5; 3.0 (2.2 ± 2.5)	3.0; 4.0 (3.4 ± 2.7)	2.0; 2.0 (2.4 ± 2.2)	2.5; 4.0 (3.0 ± 2.5)	0.301	0.125	0.077
Positive fall history (%)+	61 (49.2)	5 (41.7)	6 (42.9)	11 (42.3)	22 (40.7)	28 (63.6)	50 (51.0)	1.000	0.218	0.510
Walking aid (%)+	59 (47.6)	4 (33.3)	2 (14.3)	6 (23.1)	30 (55.6)	23 (52.3)	53 (54.1)	0.210	0.015*	0.007*
MNA-SF (score)°	12.0; 3.0 (11.3 ± 2.3)	11.0; 3.5 (10.9 ± 2.0)	12.0; 4.0 (11.2 ± 2.7)	11.5; 4.0 (11.1 ± 2.4)	12.0; 2.0 (11.6 ± 2.2)	12.0; 3.8 (11.2 ± 2.5)	12.0; 3.0 (11.4 ± 2.3)	0.291	0.873	0.553

Results are displayed as median; interquartile range (mean ± standard deviation) except for walking aid and positive fall history (displayed in total number and percentage). ASMM, appendicular skeletal muscle mass; BMI, body mass index; DIA-S, depression im alter-skala; FES-I, falls efficacy scale international; MNA-SF, mini nutritional assessment short-form; MoCA, montreal cognitive assessment; SPPB, short physical performance battery. °Mann-Whitney-U Test; +Fisher's exact test.

[a] *FES-I high compared to FES-i low (females only).*

[b] *$p < 0.05$ FES-I high compared to FES-i low (males only).*

[c] *FES-I high compared to FES-I low (entire cohort); *$p < 0.05$.*

TABLE 2 | Spearman correlations with FES-I score.

	Spearman correlations with FES-I score	*p*-values
ASMM/height (kg/m^2)	−0.02	0.799
Grip strength (kg)	−0.12	0.195
SPPB total score	−0.37	< 0.001*
SPPB walking duration subscore	−0.21	0.020*
SPPB 5xSST subscore	−0.27	0.003*
SPPB balance subscore	−0.35	< 0.001*
Number of medications	0.25	0.006*
DIA-S score	0.29	0.001*

*ASMM, appendicular skeletal muscle mass; DIA-S, depression im alter-skala; FES-I, falls efficacy scale international; SPPB, short physical performance battery; 5xSST, five times sit-to-stand task, *p<0.05.*

TABLE 3 | Multiple Regression Analyses including SPPB total score with FES-I score as dependent variable.

	Model I			
	b (95% CI)		β	p
SPPB total score	−1.17	(−2.12, −0.23)	−0.22	0.015*
DIA-S score	0.69	(−0.05, 1.42)	0.15	0.066
Walking aid	6.81	(2.73, 10.88)	0.30	0.001*
Number of medications	0.48	(0.00, 0.96)	0.16	0.048*
Age	−0.31	(−0.61, −0.00)	−0.16	0.047*

*ASMM, appendicular skeletal muscle mass; DIA-S, depression im alter-skala; FES-I, falls efficacy scale international; MoCA, montreal cognitive assessment; SPPB, short physical performance battery. Dichotome variables: gender (1 = female), walking aid (1 = yes), positive fall history (1 = yes). Variables entered as independent variables: SPPB total score, ASMM/height^2 (kg/m^2), grip strength (kg), age (years), gender, positive fall history, number of medications, use of a walking aid, DIA-S score and MoCA score. Model I Statistics: $F(5, 118) = 10.23$ ($p < .001$), Adjusted $R^2 = 0.27$. *$p < 0.05$.*

geriatric assessment this may help identify patients with FOF in a clinical setting.

To understand which specific aspects of physical performance drive the relationship with FOF, walking duration, static balance and chair-rise performance were considered separately. As the use of a walking aid may have several underlying factors (balance confidence, balance ability, muscle strength, disease severity) which may influence the results, the analysis was performed twice, once with and once without including walking aid as independent variable. When the use of a walking aid was not considered, chair-rise performance and static balance ultimately showed a significant association with FOF. When including walking aid in the analysis the association between SPPB balance subscore and FOF was weakened. This may be because many patients with poor balance and FOF use a walking aid or because use of a walking aid may reflect low balance confidence and therefore may be associated with FOF. Our results support previous findings of an association between balance and FOF in patients with PD and stroke as well as in community-dwelling older adults (1, 32, 35). In contrast to other tools (e.g., the frequently used Berg Balance Scale (BBS) (32, 35, 68) that assesses balance more granularly) the SPPB balance tasks focus only on the assessment of static balance (dynamic balance aspects are measured merely indirectly within the walking and the 5xSST tasks). Although -again- no causality can be drawn from our results, our and previous studies' results suggest that improving balance may be an essential factor in the treatment portfolio against FOF also in this neurogeriatric cohort, as already shown for institutionalized older people with FOF (37).

The 5xSST can measure lower limb strength (36), and there are already studies in patients with stroke and PD available that demonstrate a relationship between the lower limb muscle strength and FOF (18, 34). Moreover, a study on patients with PD showed that self-reported difficulties in rising from a chair was significantly associated with FOF (17). Our analysis therefore confirms a widely recognized association in a patient cohort with overall advanced disease stages and existing multimorbidity, and also supports the hypothesis that in patients with FOF, particular attention must be paid to maintaining and improving muscle strength in the lower extremities in the context of self-directed exercise, allied health therapy and pharmacological management. Interestingly, muscle mass as assessed with BIA was not significantly associated with FOF in our analyses. This is in contrast to a study investigating the association between the individual components of sarcopenia and FOF in 26 healthy and 22 mobility-limited community-dwelling older adults that found low muscle mass to contribute to an increase of FOF (23). This discrepancy may be due to study population differences and different methods used to estimate muscle mass or FOF. Although these differences certainly need to be investigated in more detail, it may be inferred from the current results (and also from other studies and trials, e.g., (69)) that the focus in the treatment of FOF should be on strength training, and not (only) on muscle building *per se*, also in this cohort.

Also in contrast to a previous study in older adults (40), walking duration was not associated with FOF in multivariate analysis, but was only correlated in bivariate analysis. What is the most appropriate explanation for the lack of association between the SPPB walking duration subscore and FOF? Our patients were asked to walk at a comfortable pace, but it cannot be ruled out that some of them were extrinsically motivated by the test situation to walk faster than their usual pace. A previous study found that adults fearful of falling did walk slower than those who were not fearful, but similarly to the control group they were physically able to accelerate their gait speed when asked to do so (39). In line with this observation, studies in PD patients found an association between self-rated walking disability and FOF, but not between gait speed and FOF (32, 33). Additionally, a study in patients with PD found a significant difference in the time needed to perform the two turns during the Timed-up-go (TUG) including the stand-to-sit movement test between individuals with and without FOF, but not in the gait speed (38). Therefore, concerning FOF, this study also highlights the importance of the capability to perform transitions and does not see gait speed *per se* as relevantly predictive of this symptom. Another reason for the lack of significant association between SPPB walking duration subscore and FOF could be

TABLE 4 | Multiple regression analyses including SPPB subscores with FES-I score as dependent variable (with and without including the use of a walking aid as independent variable).

	Model II⁺				Model III°			
	b (95% CI)		β	p	b (95% CI)		β	p
SPPB 5xSST subscore	−3.27	(−5.90, −0.64)	−0.20	0.015*	−2.90	(−5.41, −0.33)	−0.17	0.027*
SPPB balance subscore	−2.57	(−3.99, −1.15)	−0.29	<0.001*	−1.42	(−3.00, 0.16)	−0.16	0.077
Walking aid					6.85	(2.76, 10.94)	0.30	0.001*
DIA-S score	0.79	(0.03, 1.54)	0.17	0.041*	0.73	(0.003, 1.46)	0.16	0.049*
Number of medications	0.53	(0.03, 1.02)	0.18	0.038*	0.49	(0.01, 0.96)	0.16	0.046*
Age					−0.27	(−0.57, 0.03)	−0.14	0.080

*ASMM, appendicular skeletal muscle mass; DIA-S, depression im alter-skala; FES-I, falls efficacy scale international; MoCA, montreal cognitive assessment; SPPB, short physical performance battery; 5xSST, five times sit-to-stand task. Dichotome variables: gender (1 = female), walking aid (1 = yes), positive fall history (1 = yes). ⁺Variables entered as independent variables: SPPB 5xSST subscore, SPPB balance subscore, SPPB walking duration subscore, ASMM/height^2 (kg/m^2), grip strength (kg), age (years), gender, positive fall history, number of medications, DIA-S score and MoCA score. °Variables entered as independent variables: SPPB 5xSST subscore, SPPB balance subscore, SPPB walking duration subscore, ASMM/height^2 (kg/m^2), grip strength (kg), age (years), gender, positive fall history, number of medications, use of a walking aid, DIA-S score and MoCA score. Model II Statistics: $F(4, 119) = 9.81$ ($p < 0.001$), Adjusted $R^2 = 0.22$. Model III: $F(6, 117) = 9.20$ ($p < 0.001$), Adjusted $R^2 = 0.29$ *$p < 0.05$.*

the simplicity of the walking condition (i.e., short distance of four meters, flat ward floor with no disturbances, presence of the examiner). A previous study found no significant difference in walking speed among individuals with and without FOF on flat ground. However, on an elevated walkway, walking speed of those with FOF decreased disproportionately, suggesting that walking speed of those individuals is only deteriorated under challenging conditions (41). In line with this idea, a systematic review pointed out the existing heterogeneity in gait speed measurement protocols (e.g., concerning the distance), which decreases comparability of studies. However, the four meter distance is the most frequently used distance to assess gait speed in older adults (10). Whatever the reasons are for this result, it seems likely overall that simple walking tasks can do little to define individuals with FOF.

The lack of association between grip strength and FOF that we observed in our analyses was already found in studies in older adults (70, 71). Therefore, it can be assumed with a high degree of confidence that measuring force at the upper extremities, which very likely contribute little to our mobility in space, may also not contribute relevantly to the detection and prediction of FOF.

Also interesting and in line with previous studies (32, 34), we did not find a significant association between previous falls and FOF, highlighting once again that FOF could also appear as a fall-independent condition.

Studies have already indicated that FOF is associated with walking aid use in community-dwelling older adults and adults with stroke (31, 43). In our analyses, the use of walking aids contributed the most to FOF of all determinants, even after including physical function parameters. There may be several reasons for this. For once, walking aid use may reflect poor balance confidence and/or low balance ability and may therefore be associated with FOF. Previous evidence has shown that use of a walking aid is an independent risk factor for falls (12) and a recent study revealed that walking aids are frequently used incorrectly, which was associated with reduced stability (44). The use of walking aids may be associated with FOF not only because they are used by patients with impaired physical function, but also because they reduce stability when used improperly, which may lead to an increase in FOF. Taken together, educating patients on the proper use of their walking aids and work with them to select the most suitable walking aid may have potential to reduce FOF. However, future studies are needed to further investigate the relationship between FOF and walking aid use.

Controversial evidence exists on the relationship between age and FOF. The studies that found an independent relationship described a positive association between age and FOF (2, 43). Contrarily, in our study cohort, younger age was associated with higher FOF in the first model and showed a trend toward significance in the third model. It may be hypothesized that younger patients on the neurogeriatric ward have a higher disease burden or have only recently received their diagnosis and haven't developed coping mechanisms yet. However, our findings differ in our models and are probably not representative of the general neurogeriatric cohort.

We also found a significant association between depressive symptoms and FOF (in all models, but the first one). A systematic review including studies on community-dwelling older adults found (although only weak) evidence on the relationship between depressive symptoms or depression and FOF (43), and a study in patients with stroke found an association between anxiety and FOF, but not depressive symptoms and FOF (18). A recent study in patients with PD showed that while depression predicted perceived consequences of falling, anxiety predicted fear-related activity avoidance (17). Depressive symptoms and FOF may be associated, because low self-efficacy is a symptom of depression and may be associated with low fall-efficacy, which is again related to FOF. Although studies' results vary, we assume that depressive symptoms and anxiety may play a role in the vicious cycle of FOF and activity avoidance and that treatment of FOF requires a holistic concept that must include also psychological components.

In our analysis, also the number of medications was associated with FOF. A higher number of medications may increase the risk of adverse drug events (e.g., hypotension, dizziness) (43, 63). The effect observed in our cohort may have been driven by specific drugs (e.g., antipsychotics, antidepressants, benzodiazepines) that have been linked to an increased risk of falling (63, 64). In our clinical practice we have indeed seen some patients who have reported a reduction in FOF after discontinuing antidepressants (e.g., citalopram). However, analyzing the relationship between specific medication and FOF is beyond the scope of this study and certainly needs larger cohort sizes, to be able to investigate the hen-egg problem as well.

Several limitations need to be addressed. First, due to the cross-sectional study design, we cannot draw conclusions regarding the causality of relationships. Second, this is a heterogeneous study cohort representing geriatric patients with predominating neurological disabilities with acute onsets and chronic disease courses (13), thus we cannot draw definite conclusions for patients with specific diseases and also cannot adjust the analyses for disease-related confounders (e.g., freezing in patients with PD). Third, we did not include measures of physical activity and anxiety, and we had to rely on self-reported retrospective falls assessment. Finally, possible influencing factors on the BIA measures (e.g., former dehydration, fluid and nutrition intake and body temperature) cannot be excluded with certainty. Although we have addressed these aspects in our assessment to the best of our ability, some variation in these parameters cannot be ruled out due to data collection in a clinical setting.

In conclusion, in geriatric patients with predominating neurological disabilities admitted to a University hospital, our preliminary results suggest that the SPPB, one of the most commonly used mobility assessment tasks in geriatric medicine, is associated with FOF. As a novel finding, the balance and 5xSST subscores of the SPPB contributed most to this effect. If confirmed by subsequent studies, it may thus be worthwhile to screen patients with low SPPB balance and 5xSST subscores for the presence of FOF and it may even be possible to predict the development of FOF. Although it is difficult to interpret the results from this cross-sectional study in terms of therapeutic effect, the following aspects may still be considered for future therapeutic studies and possibly also for clinical application: It may be beneficial to focus on (static) balance and muscle strength training especially of the lower limbs in neurogeriatric patients with FOF. Training patients to use their walking aids correctly, critical evaluation of medication especially in case of existing polypharmacy, and addressing mental aspects such as depressive symptoms might further help reduce FOF in this highly vulnerable cohort.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Commitee of the medical faculty of the Christian-Albrechts-University of Kiel. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KS, JG, and WM were responsible for the conception and design of the study, as well as the analysis and interpretation of data. KS was responsible for drafting the manuscript. JG and WM made substantial contribution to the revision of the manuscript. TP and JW made substantial contributions to methodologies and revision of the manuscript. CM, JG, JW, and JK were responsible for the implementation of the database and organization of data and revised the manuscript critically. MR and KN were substantially involved in the acquisition of data and revised the manuscript critically. MD made substantial contributions to the revision of the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2022.904364/full#supplementary-material

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The Value of Cognitive and Physical Function Tests in Predicting Falls in Older Adults: A Prospective Study

*Rong Zhou[1], Jiayu Li[1] and Meiling Chen[2]**

[1] The Second School of Clinical Medicine, Zhejiang Chinese Medical University, Hangzhou, China, [2] School of Humanities and Management, Zhejiang Chinese Medical University, Hangzhou, China

Introduction: Previous studies suggested that physical and cognitive function can be indicators to assess the risk of falls in the elderly. Various tests are widely used in geriatric clinical studies as assessment tools of physical and cognitive function. However, large sample studies comparing the fall predictive value of these tests are still sparse. This study was conducted to investigate the value of cognitive and physical function tests in predicting the risk of subsequent falls in the elderly, with the overarching goal of providing more evidence on fall-risk assessment.

Methods: The current study was based on the data of respondents aged 60 and above from the China Health and Retirement Longitudinal Study (CHARLS). Data from the 2015 CHARLS national survey were used as the baseline data, and the fall data in 2018 were used as the follow-up data. Physical function tests included balance, walking speed, the five times sit-to-stand test (FTSST), and grip strength. The value of cognitive and physical function tests in predicting falls was evaluated by logistic regression analysis and receiver operating characteristic (ROC) curves.

Results: The incidence of falls among the 4,857 subjects included in this study was 20.86%. Results showed that cognition (OR = 0.83, 95% CI: 0.70–0.98), the FTSST (OR = 3.51, 95% CI: 1.66–7.46), and grip strength (OR = 1.02, 95% CI: 1.01–1.03) were independent predictors of falls in the full sample after adjusting for various confounders. Notably, the above tests showed better predictive value for falls for the oldest-old ($\geq$ 80 years) subjects.

Conclusion: Overall, results showed that grip strength, the FTSST, and cognition tests are simple and practicable tools for identifying individuals at higher risk of falls in the community. Moreover, the fall predictive performance of physical and cognitive function tests was age-dependent, with a higher predictive value in older adults aged 80 and above.

Keywords: balance, cognition, fall risk assessment, grip strength, older adults, walking speed, the five times sit-to-stand test

Edited by:
Maw Pin Tan,
University of Malaya, Malaysia

Reviewed by:
I. G. P. Suka Aryana,
Udayana University, Indonesia
Tien K. Khoo,
Griffith University, Australia

****Correspondence:***
Meiling Chen
chenmeiling920@zcmu.edu.cn

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INTRODUCTION

Falls are common among the elderly. It is reported that the annual incidence of accidental falls among older individuals is 28–35%, and the incidence of falls increases with age (1). Falls can lead to pain, fracture, disability, decreased ability to perform activities of daily living, and even death (2–5). With the irreversible trend of global population aging, the prevalence of falls and fall-related costs of older adults are increasing annually (6). Therefore, it is of great significance to carry out a fall risk assessment for the elderly, with the ultimate goal of preventing the occurrence of fall events.

Declines in physical and cognitive function in older adults tend to be associated with an increased likelihood of adverse health events (7). Many studies have revealed that impairments in domains of physical and cognitive function are strong risk factors for falls among the elderly (8–11). In addition, recent studies have demonstrated a strong correlation between physical and cognitive function in aging (12), with a combination of physical and cognitive function deficits being more likely to result in adverse outcomes, including falls, than physical or cognitive deficits alone (13).

A previous study proposed that performance-based measures may be more sensitive than self-reported measures in assessing physical and cognitive function (14). Given that balance, walking speed, and muscle strength are important indicators that reflect physical function (8), they have been commonly used in geriatric clinical studies. The five times sit-to-stand test (FTSST) and grip strength are two simple tools used to rapidly assess muscle strength. In addition, there is a wide range of cognitive screening tools in the clinic, among which the Mini-Mental State Examination (MMSE) is the most widely used (15). Notably, the above tests can be easily implemented and are suitable for use among the elderly in the community.

Numerous studies have shown that objective evaluation of physical and cognitive function is of great significance in predicting falls (16, 17). For instance, grip strength was proved to be the most significantly independent risk factor of falls in a recent study (18). The FTSST was also significantly associated with falls (19), and another study demonstrated that lower limb power assessed based on the FTSST is more predictive of falls than strength in older adults (20). Additionally, timed up and go test (TUGT) has been shown to have a higher predictive value of both falls and repeated falls compared with walking speed and grip strength (21). However, there are still few studies that have compared the value of both physical and cognitive function tests in predicting falls based on the same large sample and stable research methods (22). Moreover, the results on the fall predictive value of multiple function tests in previous studies have been quite inconsistent. Therefore, further research is still needed to better evaluate the fall predictive value of common tests in different aging stages.

In older adults aged 80 and above, the annual incidence of falls has increased to about 50% with increased difficulty in completing all the tests (23). Notably, physical performance is considered a strong predictor of mortality and disability in this age cohort (24). Based on this, subjects included were divided into two subgroups according to age: the young elderly (aged 60–79 years) and the oldest-old (aged $\geq$ 80 years). The value of the five tests in predicting falls was, respectively, analyzed in the two groups. This study aimed at investigating the fall prediction value of physical and cognitive function tests that are commonly used in geriatric clinical studies based on representative data from a nationwide study, with the overall goal of providing more insights into establishing a more accurate predictor of falls for this particular population.

MATERIALS AND METHODS

Study Design and Participants

The data used in the current study was acquired from the Chinese Health and Retirement Longitudinal Survey (CHARLS). CHARLS is a nationally representative longitudinal survey conducted among middle-aged and older adults in China by Peking University. The survey includes assessments of basic demographics, health status, physical measurement, utilization of medical services, and socioeconomic status through one-on-one interviews based on a structured questionnaire. The clinical assessment of physical and cognitive function was carried out in the participants' homes by interviewers recruited in advance. Centralized training and regular assessment were conducted for interviewers to ensure the authenticity and effectiveness of the collected data. By 2018, the survey had collected data from a total of 19,000 respondents in 12,400 households (25).

In the current study, the demographic data, lifestyle and health status data, grip strength, balance, walking speed, the FTSST, and cognition data were taken from the 2015 data. The subsequent fall data were obtained from the 2018 data as the outcome variable.

Participants aged 60 and older were selected for inclusion in this study. The exclusion criteria were as follows: (1) missing demographic, lifestyle behaviors and health status data; (2) aged $<$ 60; (3) missing subsequent fall data in 2018; and (4) missing data for the five tests. Finally, a total of 4,857 individuals were included. **Figure 1** shows the detailed exclusion process.

Study Variables

Fall

In the CHARLS survey, participants were asked to answer "yes" or "no" to the question "Have you fallen in the last 2 years?" The participants included in this study were divided into the falls group and the no falls group according to their answers.

Cognition

Cognitive function was quantified in the CHARLS questionnaire with a full score of 21, including telephone interviews for cognitive status-10 (TICS-10), visual-spatial ability test, and episodic memory. TICS-10 is a reliable and valid method for MMSE, with a total score of 10 points. Participants were asked to answer the year, season, month, date, and the day of the week at that time, one point would be given for each correct answer. Then, participants needed to calculate 100 minus 7 for five consecutive times, with one point for each correct calculation. With regard to the visual-spatial ability, participants were asked to draw the picture provided, with one point being given for

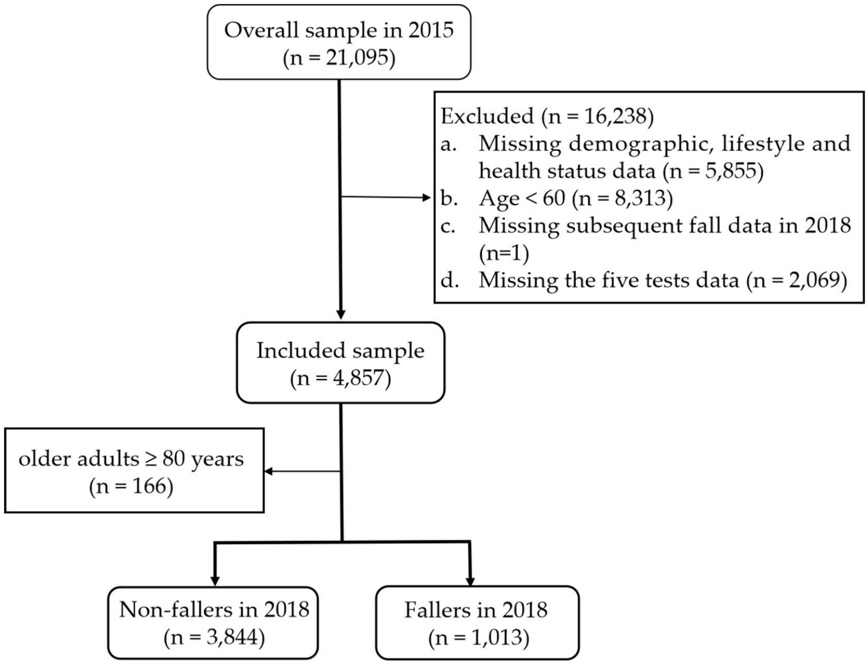

FIGURE 1 | Flow-chart showing the process of enrolling participants in the analysis.

successfully drawing. Episodic memory was assessed through immediate and delayed words recall with a total score of 10. A list consisting of 10 words was provided by the interviewer, and the participants would be given one point for each correct word recall. The scores of the above tests were added to the total cognition score (26).

Balance

The balance test required participants to stand with the heel of one foot in front of the other, touching the toes of the other foot for 30/60 s (30 s for 70 years old or above and 60 s for less than 70 years old) without moving their feet. The result is either recorded as "pass" or "fail."

Walking Speed

In the walking speed test, participants were asked to walk along a 2.5-m long line twice, and the average time of the two times was recorded.

Grip Strength

Grip strength was measured by a Yuejian™ WL-1000 dynamometer (Nantong Yuejian Physical Measurement Instrument Co., Ltd., Nantong, China). After the demonstration, the participants clenched the dynamometer as hard as they could, held it for a few seconds, and then released it. Each hand was tested twice, and the mean value of grip strengths (in kilograms) was recorded.

Five Times Sit-to-Stand Test

In the FTSST, participants were asked to stand up straight and then sit as fast as possible on a standard-height (43 cm) chair without armrests, five times without stopping or pushing with their arms. The result was recorded as either "pass" or "fail."

Controlled Variables

We selected the following covariates as potential risk factors for falls based on the relevant literature: (1) Demographics: including age, gender, marital status, and education level. Marital status was divided into two groups: "married with spouse present" group and "without a spouse present" group (including participants who were separated/divorced/widowed/never married/cohabitated/married but not living with spouse temporarily); (2) Behavior and lifestyle: smoking status was classified into "yes" or "no" according to the answer; sleep status included the night sleep time and whether a nap was usually taken (27); (3) Health status: CHARLS questionnaire investigated 14 chronic diseases. According to the answers to "Have you been diagnosed with [the chronic disease] by a doctor?," participants were divided into two groups, one with chronic diseases (one chronic disease or more), and the other without. Disability variables included physical disabilities, intellectual disability, vision problems, hearing problems, and a speech impediment. In addition, the CES-D scale was applied to evaluate depression with a total score of 30. Scores $\geq$ 10 indicated the presence of obvious symptoms of depression (28, 29); (4) Fall history: participants were asked to answer "yes" or "no" to the question "Have you fallen since your last visit?"

Statistical Analyses

The data in DTA format was obtained from the CHARLS database. Statistical analyses were performed using STATA MP

17.0 and SPSS 26.0. The above risk factors were included as covariates during the univariate analysis of falls, and the categorical variables were analyzed through chi-squared test. If the continuous variables conformed to a normal distribution or approximate normal distribution, the independent samples *t*-test was used; otherwise, a non-parametric rank-sum test of two independent samples was used. The associations among cognition, balance, walking speed, grip strength, FTSST, and falls were evaluated by stepwise forward logistic regression models, controlling for confounding factors. The receiver operating characteristic (ROC) curve were generated to determine the predictive value of the five tests. To explore the predictive value in different age cohorts, the above analysis was first conducted in the full sample and then in older adults aged ≥ 80 years. A two-tailed *p*-value < 0.05 was considered statistically significant.

RESULTS

Among the 4,857 subjects enrolled in this study, 2,667 (54.91%) were men and 2,190 (45.09%) were women. The age of the subjects ranged from 60 to 102 years, with a mean age of 67.16 ± 5.78. Results showed that 1,013 (20.86%) people had fallen in the previous 2 years.

According to the follow-up time, respectively published in both data sets, the mean duration between the two assessment points for participants included in this study was 35.98 ± 0.74 months, with the shortest of 31 months, and the longest of 38 months.

General Characteristics of the Subjects

The baseline characteristics of the falls group and the no falls group were shown in **Table 1**. Results showed that gender was significantly associated with falls (χ^2 = 51.64, $p < 0.001$) with a higher risk of falls in females than in males. Increased age was significantly associated with a higher possibility of falls (χ^2 = 4.55, $p < 0.001$). Older adults with lower educational level were more likely to suffer from falls (χ^2 = 23.25, $p < 0.001$). And older adults who did not have a spouse present had a higher risk of falls (χ^2 = 13.80, $p < 0.001$).

In addition, there were statistically significant differences in smoking status (χ^2 = 10.68, p = 0.001), physical disabilities (χ^2 = 28.38, $p < 0.001$), intellectual disability (χ^2 = 14.28, $p < 0.001$), vision problems (χ^2 = 6.65, p = 0.01), hearing problems (χ^2 = 8.97, p = 0.003), night sleep duration (χ^2 = 45.28, $p < 0.001$), nap duration (χ^2 = 10.88, p = 0.012), chronic diseases (χ^2 = 10.40, $p < 0.001$), depression (χ^2 = 15.25, $p < 0.001$), and fall history (χ^2 = 244.35, $p < 0.001$) between the falls group and the no falls group. However, there was no significant difference with regard to speech impediment.

Characteristics of the Five Tests

The results of the five function tests were compared between the two groups of older adults. **Table 2** shows that there were significant differences in balance (χ^2 = 22.90, $p < 0.001$), grip strength (t = –4.40, $p < 0.001$), and cognition score (t = –6.19, $p < 0.001$) between the falls group and the no falls group. In addition, the difference in the FTSST was statistically significant (χ^2 = 4.04, p = 0.044).

Correlations Between the Variables

Before binary logistic regression, the correlations between the variables were tested. According to the Pearson's correlation test, the left-hand grip strength was significantly associated with the right hand, and thus we used the right-hand grip strength to represent the individual grip strength.

Associations Between the Five Tests and Falls in the Full Sample

To further evaluate the associations between the above tests and falls, cognition, balance, walking speed, FTSST, and grip strength were added to five independent binary logistics models. **Table 3** shows that cognition, grip strength, and FTSST were independent risk factors of falls after adjusting for confounding factors (including gender, age, marital status, education level, physical disabilities, intellectual disability, night sleep duration, depression, chronic disease, and history of falls). Participants with higher cognitive scores had a lower probability of falls compared to participants with lower cognitive scores (OR = 0.83, 95% CI: 0.70–0.98, p = 0.02). Moreover, older adults with lower grip strength were more likely to fall (OR = 1.02, 95% CI: 1.01–1.03, $p < 0.001$), and failing in FTSST was associated with a higher possibility of falls (OR = 3.51, 95% CI: 1.66–7.46, p = 0.001).

ROC curves were plotted to analyze the predictive value of the five tests for falls in the full sample (**Figure 2**). **Table 4** displays the AUC of the five tests in the full sample.

The Predictive Value of the Five Tests in Older Adults Aged ≥ 80 Years

Older adults aged 80 and above showed a higher incidence of falls and increased difficulty in completing all the tests. Based on this, the value of the five tests in predicting falls was, respectively analyzed in older adults aged ≥ 80 years. According to the ROC curve, the five tests showed better predictive value for falls in older adults aged 80 and above (**Figure 3** and **Table 5**). Among these tests, cognition had the highest predictive value (AUC = 0.73, 95% CI: 0.65–0.79). The corresponding sensitivity and specificity values for cognition were 72.92 and 72.03%, respectively.

DISCUSSION

Population aging has led to the advent of a tremendous challenge: falls are not only the leading cause of injury and death among the elderly, but also pose a serious global health issue. Many previous studies have analyzed the predictive value of various function tests in falls (13, 17, 18, 21), but the results obtained in different studies were not consistent. The current study was conducted to compare the value of five physical and cognitive function tests in predicting falls based on a nationally representative survey. In this population-based study involving older adults, we evaluated the value of five clinically important function tests in predicting falls in different age cohorts.

TABLE 1 | Comparison of general characteristics between the falls and no falls group (n = 4,857).

Variables	Total	Fall		χ^2/t	*P*-value
		Yes	No		
Gender, *n* (%)				51.64	<0.001***
Male	2,667 (54.91)	455 (17.06)	2,212 (82.94)		
Female	2,190 (45.09)	558 (25.48)	1,632 (74.52)		
Age		67.90 ± 6.06	66.97 ± 5.69	4.55	<0.001***
Marital status, *n* (%)				13.80	<0.001***
Married with spouse present	3,933 (80.98)	779 (19.81)	3,154 (80.19)		
Without a spouse present	924 (19.02)	234 (25.32)	690 (74.68)		
Education, *n* (%)				23.25	<0.001***
Illiteracy	1,102 (22.69)	285 (25.86)	817 (74.14)		
Primary school or below	2,573 (52.98)	512 (19.90)	2,061 (80.10)		
Middle school	784 (16.14)	147 (18.75)	637 (81.25)		
High school or above	398 (8.19)	69 (17.34)	329 (82.66)		
Smoking, *n* (%)				10.68	0.001**
Yes	1,762 (36.28)	323 (18.33)	1,439 (81.67)		
No	3,095 (63.72)	690 (22.29)	2,405 (77.71)		
Physical disabilities, *n* (%)				28.38	<0.001***
Yes	350 (7.21)	112 (32.00)	238 (68.00)		
No	4,507 (92.79)	901 (19.99)	3,606 (80.01)		
Intellectual disability, *n* (%)				14.28	<0.001***
Yes	331 (6.81)	96 (29.00)	235 (71.00)		
No	4,526 (93.19)	917 (20.26)	3,609 (79.74)		
Vision problems, *n* (%)				6.65	0.01*
Yes	724 (14.91)	177 (24.45)	547 (75.55)		
No	4,133 (85.09)	836 (20.23)	3,297 (79.77)		
Hearing problems, *n* (%)				8.97	0.003**
Yes	1,055 (21.72)	255 (24.17)	800 (75.83)		
No	3,802 (78.28)	758 (19.94)	3,044 (80.06)		
Speech impediment, *n* (%)				1.27	0.26
Yes	35 (0.72)	10 (28.57)	25 (71.43)		
No	4,822 (99.28)	1,003 (20.80)	3,819 (79.20)		
Night sleep duration (in hours), *n* (%)				45.28	<0.001***
<6	1,519 (31.27)	404 (26.60)	1,115 (73.40)		
6∼8	2,892 (59.54)	519 (17.95)	2,373 (82.05)		
> 8	446 (9.18)	90 (20.18)	356 (79.82)		
Napduration (in minutes), *n* (%)				10.88	0.012*
0	1,879 (38.69)	427 (22.72)	1,452 (77.28)		
<30	337 (6.94)	77 (22.85)	260 (77.15)		
30∼60	1,631 (33.58)	329 (20.17)	1,302 (79.83)		
> 60	1,010 (20.79)	180 (17.82)	830 (82.18)		
Chronic diseases, *n* (%)				10.40	<0.001***
No	1,099 (22.63)	191 (17.38)	908 (82.62)		
Yes	3,758 (77.37)	822 (21.87)	2,936 (78.13)		
CES-D score, *n* (%)				15.25	<0.001***
0–9	959 (19.74)	156 (16.27)	803 (83.73)		
10–30	3,898 (80.26)	857 (21.99)	3,041 (78.01)		
History of falls, *n* (%)				244.35	<0.001***
Yes	887 (18.26)	356 (40.14)	531 (59.86)		
No	3,970 (81.74)	657 (16.55)	3,313 (83.45)		

**p < 0.05, **p < 0.01, ***p < 0.001.*

China is facing the severe challenge of aging, and the high incidence of falls among older adults cannot be ignored. A recent study has found that the median annual incidence of falls among the elderly in China was 18% (30). Chu et al. demonstrated in their study that the prevalence of falls of the Chinese elderly were 19.3% (31). Consistently, the incidence of falls found in this study was 20.86%. In addition, previous studies have reported many risk factors for falls, including age, gender, history of falls, cognitive impairment, balance, chronic disease, and other factors (32–37). Results obtained in this study indicated that gender,

TABLE 2 | Comparison of the five function tests between the falls and no falls group in the full sample (*n* = 4,857).

Variables	Total	Fall		χ ²/t	*P*-value
		Yes	No		
Balance, *n* (%)				22.90	<0.001*
Pass	3,876 (79.80)	754 (19.45)	3,122 (80.55)		
Fail	981 (20.20)	259 (26.40)	722 (73.60)		
Walking speed (in seconds)		3.96 ± 15.69	3.41 ± 5.32	1.83	0.067
FTSST, *n* (%)				4.04	0.044*
Pass	4,826 (99.36)	1,002 (20.76)	3,824 (79.24)		
Fail	31 (0.64)	11 (35.48)	20 (64.52)		
Grip strength (kg)	27.85 ± 9.69	25.63 ± 9.33	29.20 ± 25.37	–4.40	<0.001***
Cognition		11.01 ± 3.94	11.82 ± 3.66	–6.19	<0.001***

**p* < 0.05, ***p* < 0.01, ****p* < 0.001.*

TABLE 3 | Binary logistic regression models for falls in the full sample (*n* = 4,857).

	Model 1 (cognition)	*P*	Model 2 (balance)	*P*	Model 3 (walking speed)	*P*	Model 4 (FTSST)	*P*	Model 5 (grip strength)	*P*
	OR (95%CI)		OR (95%CI)		OR (95%CI)		OR (95%CI)		OR (95%CI)	
Gender	1.46 (1.25–1.71)	<0.001	1.45 (1.24–1.69)	<0.001	1.47 (1.26–1.71)	<0.001	1.48 (1.27–1.73)	<0.001	1.19 (1.00–1.42)	0.05
Age	1.01 (1.01–1.02)	<0.001	1.01 (1.01–1.02)	<0.001	1.01 (1.01–1.02)	<0.001	1.00 (0.99–1.01)	0.456	1.01 (1.00–1.01)	0.018
Marital status	1.35 (1.14–1.59)	<0.001	1.37 (1.15–1.62)	<0.001	1.36 (1.15–1.61)	<0.001	1.26 (1.05–1.50)	0.011	1.27 (1.07–1.51)	0.006
Education		0.191		0.227		0.222		0.383		0.32
Illiteracy (ref)										
Primary school or below	1.23 (0.90–1.67)	0.20	1.09 (0.82–1.46)	0.546	1.08 (0.81–1.45)	0.599	0.99 (0.73–1.33)	0.924	1.10 (0.82–1.50)	0.542
Middle School	1.33 (1.01–1.74)	0.04	1.26 (0.96–1.63)	0.092	1.25 (0.96–1.62)	0.1	1.14 (0.87–1.50)	0.344	1.23 (0.94–1.61)	0.128
High school or above	1.21 (0.89–1.64)	0.23	1.19 (0.88–1.61)	0.272	1.18 (0.87–1.60)	0.282	1.07 (0.78–1.46)	0.675	1.12 (0.82–1.52)	0.476
Physical disabilities	0.62 (0.48–0.80)	<0.001	0.62 (0.49–0.80)	<0.001	0.62 (0.48–0.80)	<0.001	0.61 (0.47–0.78)	<0.001	0.65 (0.51–0.84)	0.001
Intellectual disability	0.78 (0.60–1.01)	0.06	0.77 (0.59–1.01)	0.056	0.77 (0.59–1.00)	0.046	0.76 (0.58–0.99)	0.038	0.78 (0.60–1.02)	0.071
Night sleep duration (in hours)		0.011		0.008		0.009		0.008		0.011
<6 (ref)										
6˜8	1.02 (0.79–1.32)	0.87	1.04 (0.81–1.33)	0.773	1.04 (0.81–1.33)	0.777	0.95 (0.74–1.24)	0.72	0.97 (0.75–1.25)	0.799
>8	1.36 (1.07–1.72)	0.01	1.39 (1.09–1.77)	0.007	1.39 (1.09–1.76)	0.008	1.27 (0.99–1.62)	0.062	1.27 (0.99–1.62)	0.057
CES–D score	1.27 (1.04–1.54)	0.02	1.27 (1.04–1.54)	0.018	1.26 (1.0–1.54)	0.019	1.26 (1.04–1.53)	0.021	1.24 (1.02–1.51)	0.03
Chronic diseases	1.15 (0.96–1.38)	0.13	1.15 (0.96–1.38)	0.124	1.15 (0.96–1.38)	0.126	1.14 (0.95–1.37)	0.16	1.13 (0.94–1.35)	0.204
History of falls	0.34 (0.29–0.40)	<0.001	0.34 (0.29–0.40)	<0.001	0.34 (0.29–0.40)	<0.001	0.34 (0.29–0.40)	<0.001	0.34 (0.29–0.40)	<0.001
Tests	0.83 (0.70–0.98)	0.02*	0.88 (0.74–1.05)	0.152	1.00 (0.99–1.00)	0.2	3.51 (1.66–7.46)	0.001**	1.02 (1.01–1.03)	<0.001***

**p* < 0.05, ***p* < 0.01, ****p* < 0.001. OR, odds ratio; 95% CI, 95% confidence interval. Adjusted covariates: gender, age, marital status, education, physical disabilities, intellectual disability, night sleep duration, depression, chronic disease, and history of falls.*

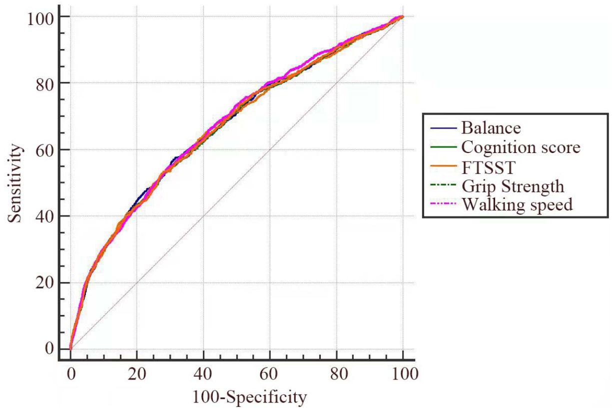

FIGURE 2 | ROC curves of the five tests in the full sample (*n* = 4,857).

TABLE 4 | The AUC of the five tests in the full sample (*n* = 4,857).

Tests	AUC	95% CI	Sensitivity (%)	Specificity (%)	Youden index (%)	*p*
Grip strength	0.67	0.66–0.68	54.39	70.94	25.33	<0.001***
FTSST	0.66	0.65–0.68	52.42	72.79	25.21	<0.001***
Cognition	0.66	0.65–0.68	49.75	75.03	24.78	<0.001***
Balance	0.67	0.65–0.68	56.96	69.09	26.05	<0.001***
Walking speed	0.66	0.65–0.68	53.31	72.03	25.34	<0.001***

****p* < 0.001. AUC, Area Under the Curve.*

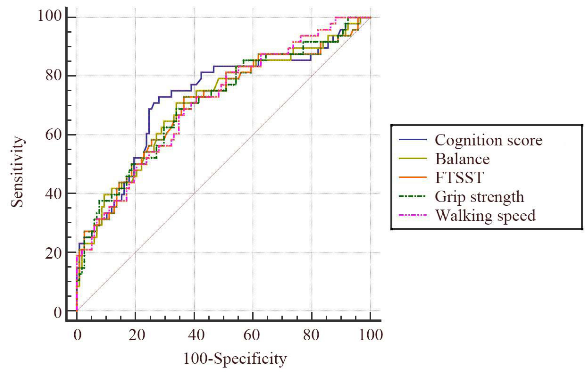

FIGURE 3 | ROC curves of the five tests in older adults ≥ 80 years (*n* = 166).

TABLE 5 | The AUC of the five tests in older adults ≥ 80 years (*n* = 166).

Tests	AUC	95% CI	Sensitivity (%)	Specificity (%)	Youden index (%)	*p*
Grip strength	0.71	0.63–0.78	68.75	66.10	34.85	<0.001***
Cognition	0.73	0.65–0.79	72.92	72.03	44.95	<0.001***
Balance	0.71	0.64–0.78	70.83	66.10	36.94	<0.001***
Walking speed	0.71	0.63–0.78	68.75	63.56	32.31	<0.001***
FTSST	0.71	0.63–0.77	72.92	63.56	36.48	<0.001***

****p* < 0.001. AUC, Area Under the Curve.*

age, marital status, education level, smoking, history of falls, disabilities, sleep duration, depression, and chronic diseases were significantly associated with falls, and balance instability, muscle weakness, as well as cognitive impairment in the five tests were independent risk factors of falls.

In the full sample analysis, poorer performance in the FTSST, cognition, and grip strength were significantly associated with an increased risk of falls after adjusting for various confounding factors, which was consistent with findings reported in previous studies (38–42). It is widely believed that a decline in cognitive function leads to various physiological and functional impairments involving gait (43, 44), balance (45), reaction time, and muscle strength (46), which increases the risk of falls. However, compared to physical function, age-related declines in cognitive function are generally not detected until much later (47), especially in the pre-dementia stage including mild cognitive impairment (MCI). Our results showed that cognition was a sensitive and specific index in predicting falls in the elderly. Collectively, our findings suggested that early identification of older adults with cognitive impairment may be an important strategy for reducing the risk of falls.

Given that the included subjects had a wide age distribution, we further evaluated the predictive value of the five tests in different age cohorts. The oldest-old (≥ 80 years) cohort is the most rapidly growing age group globally (48), and physical performance is considered as a strong predictor of mortality and disability in this group (24). Therefore, considering the further decline in physical function, fall prediction tools with higher accuracy are urgently needed for this cohort. Previous studies have evaluated the fall prediction value of different physical function tests, such as the Berg balance scale, Timed Up and Go test, and Tinetti balance scale (49, 50). However, for people in their 80s, especially when applied to large-scale fall risk screening in the community, the best tool should be simple and time-saving, taking into account its sensitivity and specificity. In the current study, the five tests showed better predictive value for falls in the oldest-old cohort. These tests require little space and do not need special equipment. Therefore, clinicians can easily use them to identify individuals at high risk of falls as they can easily be understood and executed by the elderly.

There is a strong association between physical and cognitive impairment, which was described as the "common cause" theory of aging in previous studies (47). Taylor et al. (46) proposed that the extent of cognitive impairment in the elderly may be quantified by monitoring their physical condition. Martin et al. (13) pointed out that the impact of physical deficits on falls can be amplified by cognitive impairment. Alcazar et al. (51) demonstrated a greater correlation between the sit-to-stand muscle strength tests and other risk factors (including physical and cognitive function) than the traditional FTSST in assessing muscle strength in the elderly, which may contribute to a more ideal tool for identifying the risk of falls in the elderly. Furthermore, Phirom et al. (52) proposed that simultaneous physical and cognitive training contributed to reducing the incidence of falls in seniors effectively. Thus, combining physical and cognitive impairments as a predictor may be helpful in fall-risk assessment, which is worth investigating in future studies.

There are several strengths of this study. First, we enrolled a large number of subjects (n = 4,857). The large sample size and the high quality of samples account for the representativeness of the study. Second, on the basis of evaluating the fall prediction values of different physical function tests, we also pay special attention to the impact of environmental factors and cognitive function on falls. The value of both physical and cognitive function tests in predicting falls were evaluated in this study based on the same large sample and stable research methods. It should be noted that the occurrence of falls results from the complex interaction between internal and external factors. It is expected that our findings will supplement the available evidence on the fall-risk assessment by providing data on appropriately large numbers of subjects of different age groups after adjusting for various potential confounding variables.

However, this study also had some limitations. First, we explored limited tests due to the shortage of data. Balance, walking speed, FTSST, and grip strength are only four among many physical function tests associated with falls. In addition, the evaluation of cognitive impairment in this study was based on questionnaire indicators in CHARLS. Since no other cognitive function evaluation scale was adopted, it may lead to evaluation bias in cognitive impairment and further affect the sensitivity and specificity of our results. Moreover, the study was conducted based on CHARLS data, thus, interpretation and promotion of our results should also cautiously consider the homogeneous ethnic background of the study population. Also, respondents in the CHARLS were expected to be able to answer the questions of the interviewers in line with the actual situation, which may lead to participant selection bias. As the data were mainly based on the respondents' self-reports, the possibility of recall bias and self-selection bias cannot be completely excluded in this study. Finally, although we confirmed the predictive value of physical and cognitive function tests as independent predictors of falls, they showed a relatively low diagnostic significance (AUC $<$ 0.7) in the full sample. Therefore, more efforts should be made to further explore how to improve the accuracy by combined prediction.

CONCLUSION

In this study, nationally representative data were used to evaluate the value of five common physical and cognitive function tests in predicting the risk of subsequent falls in older adults, adding to evidence of the association of physical and cognitive deficits with falls. Results showed that grip strength, FTSST, and cognition tests may be simple and practicable tools for fall risk assessment in the community. Moreover, the five tests had better predictive value for falls in people aged 80 and older. Correspondingly, relevant strategies and measures should be put forward to identify individuals, especially the oldest-old, at high risk of falls in large-scale community screening.

DATA AVAILABILITY STATEMENT

The datasets for this study can be found in online repositories. The name of the repository and accession number can be found at: The China Health and Retirement Longitudinal Study (CHARLS), accessible on http://charls.pku.edu.cn/en. The current study is a secondary analysis of public data of CHARLS.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Biomedical Ethics Review Committee of Peking University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

RZ contributed to the conceptualization and drafted the original draft preparation. JL conducted the data analysis. RZ, JL, and MC revised the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2022.900488/full#supplementary-material

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EDITED BY
Tzvi Dwolatzky,
Technion Israel Institute
of Technology, Israel

REVIEWED BY
Irma Ruslina Defi,
Padjadjaran University, Indonesia
Paolo Fabbietti,
National Institute of Science
and Health for Aging (IRCCS), Italy

*CORRESPONDENCE
Yukihide Nishimura
ynishi@iwate-med.ac.jp

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Characteristics of falls occurring during rehabilitation in an acute care hospital in older and non-older patients: A retrospective cohort study

Tokio Kinoshita[1], Yukihide Nishimura[2]*, Yasunori Umemoto[1], Shinji Kawasaki[1], Yoshinori Yasuoka[1], Kohei Minami[1], Yumi Koike[1] and Fumihiro Tajima[1]

[1]Department of Rehabilitation Medicine, Wakayama Medical University, Wakayama, Japan,
[2]Department of Rehabilitation Medicine, Iwate Medical University, Morioka, Japan

Introduction: Although falls are often reported in hospitals and are common in older individuals, no reports on falls during rehabilitation exist. This study evaluated patients with falls occurring during rehabilitation and identified the characteristics of older and non-older patients.

Materials and methods: Our study retrospectively analyzed reports of falls occurring during rehabilitation at a university hospital from April 1, 2020 to March 31, 2022. The survey items included the number of falls in the hospital as a whole and during rehabilitation, age, gender, mankin Scale (mRS) before admission and at the time of fall, functional independence measure (FIM) at admission, patient communication status at the time of fall, and whether a therapist was near the patient. Patients aged $\geq$ 65 were considered older; aged $\leq$ 64, non-older; and those with the same age, gender, and clinical department, randomly selected as non-falling patients.

Results: Thirty-five falls occurred during rehabilitation (14 in the non-older and 21 in the older patients), significantly lower than the 945 for the entire hospital, without any significant difference between non-older and older patients. No significant differences in mRS before admission and FIM at admission were noted for both groups in comparison with the non-falling patient group. Furthermore, gender, mRS, FIM, good communication status, and presence of therapist near the patient were similar between non-older and older patients (non-older 71.4%, older 52.4%). Most falls were minor adverse events that did not require additional treatment.

Conclusion: The rate of falls during rehabilitation was much lower than that during hospitalization, and many falls had minimal impact on the patient. It was also difficult to predict falls in daily life and communication situations, and there was no difference in characteristics between the older and non-older groups. Since more than half of the falls occurred during training with the therapist, it is necessary to reconsider the training content.

KEYWORDS

incident, accident, patient safety, inpatients, rehabilitation

Introduction

According to the World Health Organization's definition, a fall is "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level" (1). Falls cause varying degrees of injury, loss of confidence, and reluctance to move. Furthermore, patients who fall during hospitalization have longer average lengths of stay and may incur additional costs than those who do not (2). Older adults often have several risk factors that increase the likelihood of falls, including impaired sensory and motor function, impaired integration of these systems (3), adverse drug events, and musculoskeletal disorders such as gait dysfunction and balance problems (4). Additionally, older patients in geriatric or rehabilitation wards have a higher risk of falls than that in other age groups (5, 6). Hospital falls are the most common safety incidents affecting older individuals, frequently causing family complaints, including civil claims. Therefore, an important medical safety measure includes understanding the characteristics of patients who experience falls and taking steps to prevent them. Preventive measures in hospitals include patient education, clinician education, environmental adaptation, use of assistive devices, exercise, scrutiny of medications, optimal nutritional guidance, cognitive impairment management, measures to mitigate disability due to falls, and development of leadership systems (7–11).

While falls in stroke patients admitted to rehabilitation wards and in older patients admitted to rehabilitation facilities are reported (12–14), no detailed investigations of falls that occur during actual rehabilitation practices exist. The authors have experienced adverse event (AE)s during rehabilitation that resulted in femur fractures, requiring additional surgery and prolonging hospital stays (15), and are keenly aware of the need to develop fall prevention strategies.

This study evaluated falls occurring during rehabilitation and obtained detailed information to improve risk management strategies for future rehabilitation care and identify characteristics of older and non-older patients.

Materials and methods

Study setting

As of 2022, Wakayama Medical University hospital has 760 general beds (including ten Intensive Care Unit beds) and 40 psychiatric beds, serving 27 clinical departments and 28 central medical treatment sections. Rehabilitation begins upon request from the physicians in various departments to the department of rehabilitation. Physiatrists examine inpatients prior to rehabilitation and evaluate their diagnosis, disease state, and physical condition. Registered and skilled therapists then commence exercise therapy. Thus, rehabilitation therapies are performed based on a thorough clinical examination and in accordance with each patient's condition (16, 17).

Study design

In this retrospective cohort study, we analyzed AE reports submitted by the Department of Rehabilitation Medicine to the Medical Safety Promotion Department at our hospital between April 2020 and March 2022.

Data collection methods and procedures

At our hospital, all staff are required to report an AE to their corresponding risk manager. An AE during rehabilitation includes any instance that has caused or may have caused further physical or psychological injury to the patient (15).

The survey items were the number and contents of adverse events during the survey period, number of falls in the entire hospital and during rehabilitation, the age of fall patients, gender, modified Rankin Scale (mRS) at admission and time of fall, functional independence measure (FIM) at the time of admission, good communication rate of the patient at the time of the fall, presence or absence of a nearby therapist, and main clinical department. In addition, patients with matching age, gender, and department, who had not experienced a fall, were randomly selected for comparison as non-falling patients, and the same data were collected. The mRS (defines six levels of disability) and FIM (basic indicator of the severity of disability) were evaluated as indicators of Activities of Daily Living (ADL) (18–22). The FIM consists of 18 items, with a motor subscale (13 items) and cognition subscale (5 items), each of which is assessed using a 7-point ordinal scale.

The degree of impact the AE had on the patient was determined by the Medical Safety Promotion Department (15). According to the National Coordination Council for Medication Error Reporting and Prevention index (23), impacts of AEs are categorized into nine levels, as follows: category A (no error); categories B to D (error but no harm); categories E to H (error and harm), and category I (error and death). For AEs in categories A to D, no additional treatment is required. Specifically, category B refers to an error occurring but not reaching the patient (an "error of omission" does reach the patient). While category C pertains to an error occurred that reaches the patient but does not cause harm, category D is an error that reaches the patient and requires monitoring to confirm that it did not harm the patient and/or required intervention to preclude harm. For AEs in category E, minor treatment is required; however, for those in category F, intensive treatments are required and/or extension of hospital stay is needed. If permanent disability and sequelae with no significant or with significant functional or cosmetic problems develop, severe AEs are defined as G or H, respectively. Categories A to D that do not require additional treatment are classified as minor AEs (15).

Statistical analysis

Data were grouped by age $\geq$ 65 years and $\leq$ 64 years, defined as older in the author's country (24). The values of the variables are given as numbers, mean $\pm$ standard deviation (SD), and median (75th–25th percentiles), where applicable. The older and non-older and fall and non-fall groups were compared using the unpaired t-test for age and time from hospitalization and surgery to fall occurrence; the Mann–Whitney U test was used to evaluate the mRS and FIM; the χ^2-test was used to evaluate the incidence of falls and gender differences, good communication rate of the patient, and whether a therapist was present at the time of the fall; and the Fisher's exact test explored the main clinical departments of fallen patients. Differences were considered statistically significant at $p < 0.05$, and statistical evaluations were performed using the Graph Pad Prism 6 software (Graph Pad Software Inc, San Diego, California).

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the relevant ethics review committee (No. 3529). No additional risks were posed to patients during the data collection and analysis, and all related information was protected. Additionally, information concerning this study was posted on the university website, and patients or their families and relatives were given the opportunity to opt-out. The ethics review committee waived the requirement for patients' written informed consent due to the retrospective nature of the study.

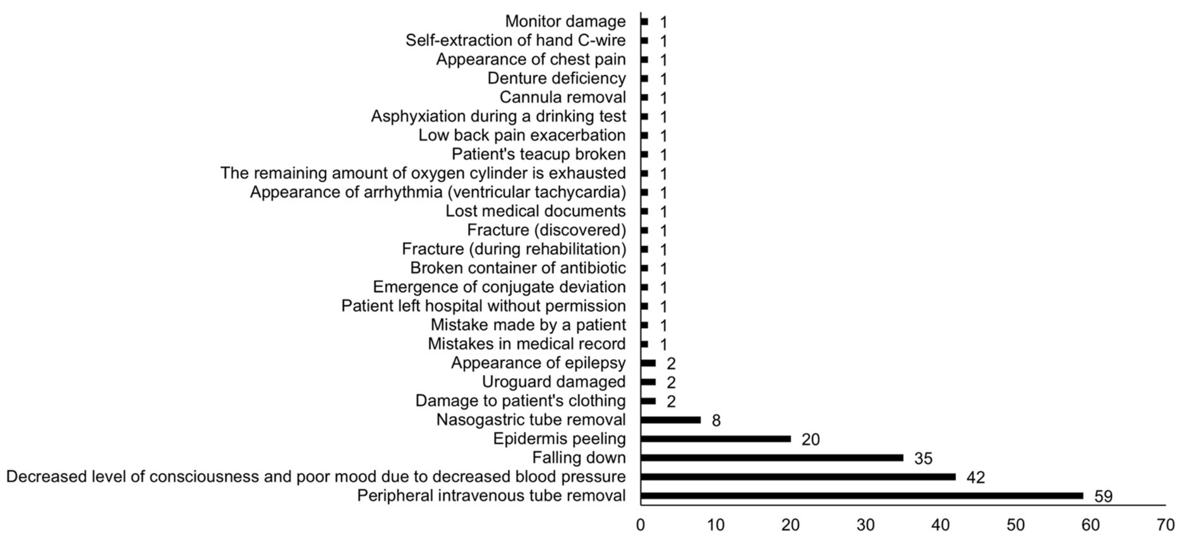

FIGURE 1
Adverse events that occurred during rehabilitation.

TABLE 1 Number of falls occurring during hospitalization and rehabilitation.

	Number of falls	*p*-value
During hospitalization total (n = 46050)[a]	945 (2.05%)[c]	<0.0001[e]
During rehabilitation (n = 13177)[b]	35 (0.27%)[d]	0.0555[f]
Non-older (n = 3406)[b]	14 (0.41%)[d]	
Older (n = 9771)[b]	21 (0.21%)[d]	

[a]Is total number of hospitalized. [b]Is number of patients referred to department of rehabilitation. [c]Is number of falls/total number of hospitalized × 100. [d]Is number of falls/number of patients referred to department of rehabilitation × 100. [e]Is compares total inpatients to total falls during rehabilitation. [f]Is comparison between non-older and older patients.

Results

In the 2 years from April 2020, 46,050 patients were admitted to our hospital, of which 13,177 were rehabilitated. All AEs and occurrences during rehabilitation are shown in Figure 1. Of the 188 AEs that occurred during the 2-year period, falls were the third most common, following peripheral intravenous tube removal, and decreased level of consciousness and poor mood due to decreased blood pressure. Table 1 shows the number of falls that occurred during hospitalization and rehabilitation. The number of falls in the entire hospital was 945 and during rehabilitation was 35 (14 and 21 in the non-older and older groups, respectively), and the fall rate during rehabilitation was significantly lower (p < 0.0001) than that during hospitalization. While the incidence of falls during rehabilitation was 0.21 and 0.41% in the older and non-older patients, respectively, in older patients, it was about half that in the non-older patients; however, the difference was not significant (p = 0.0555).

Table 2 shows the characteristics of the patients who fell grouped by age and matched with non-fall patients. There were no significant differences in mRS before admission and FIM at admission in both the non-older and older groups compared to the non-falling patients group. Furthermore, a comparison of non-older and older patients who fell showed no significant differences in mRS before admission, FIM at admission, days from admission to fall occurrence, days from surgery to fall occurrence, or mRS at fall.

Table 3 shows the details of the fall, patient's communication status at the time of the fall, and whether the therapist was with the patient. Ten of 14 (71.4%) of the non-older and 11 of 21 (52.4%) of older patients fell despite good communication; however, there was no significant difference between the two (p = 0.2598). In addition, 10 of 14 (71.4%) non-older and 11 of 21 (52.4%) older patients fell even though the therapist

TABLE 2 Characteristics of non-older and older adults who fell during rehabilitation.

	Non-older (≦64)				Older (≧65)			
	Total fall patients (n = 35)	Fall patients (n = 14)	Not-fall patients (n = 14)	*p*-value	Fall patients (n = 21)	Not-fall patients (n = 21)	*p*-value	Non-older vs. older
Age (years)	65.0 ± 16.8	49.6 ± 16.3	49.8 ± 16.4	0.9821	72.1 ± 5.7	72.1 ± 5.8	0.9790	p < 0.0001
Sex (female/male)	15/20	4/10	4/10	1	11/10	11/10	1	p = 0.1632
Pre-admission mRS (median IQR)	1 (0–2)	1 (0–2.75)	1 (0–2.5)	0.6252	1 (0–2)	1 (0–2)	>0.9999	p = 0.7397
FIM at admission (median IQR)	79 (46–115.5)	74 (39.0–99.25)	92 (48.25–120)	0.4265	93 (52–125)	98 (58–115)	0.9950	p = 0.3196
Motor FIM	47 (18.0–82.5)	41.5 (13–66.5)	64.5 (14.75–85)	0.3058	58 (23–90	55 (23–80)	0.9353	p = 0.2035
Cognition FIM	33 (25–35)	33 (24.75–34.75)	34.5 (24.25–36)	0.4459	31 (25–35)	34 (28–35)	0.4843	p = 0.8576
Days from hospitalization to occurrence	32.8 ± 31.5	39.4 ± 40.4			28.4 ± 23.2			p = 0.3216
Days from surgery to occurrence	26.1 ± 31.1	41.0 ± 47.3 (n = 7)			17.4 ± 8.7 (n = 12)			p = 0.1178
mRS at AE occurrence (median IQR)	4 (4–4)	4 (4–4)			4 (3–4)			p = 0.5785

mRS, modified Rankin Scale; IQR, 75th–25th percentiles; FIM, functional independence measure; AE, adverse event. The not-fall group was randomly selected from a group of patients matched by age, sex, and primary department.

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TABLE 3 About the communication ability of the patient at the time of the fall and details of the fall situation.

Non-older ($n = 14$)	**Older ($n = 21$)**
Good communication ($n = 10$)	Good communication ($n = 11$)
The therapist was near the patient ($n = 8$)	*The therapist was near the patient ($n = 5$)*
During stand-up training 1	During sitting training 1
During walking training 5	During walking training 4
Wheelchair-driven 1	*The therapist was not near the patient ($n = 6$)*
During transfer from bed to wheelchair 1	During stand-up training 1
The therapist was not near the patient ($n = 2$)	During walking training 1
During stand-up training alone 1	During walking alone 2
Legs touched the desk when moving 1	Legs touched the desk when moving 1
	Falling when doing exercises other than instructions 1
Poor communication ($n = 4$)	Poor communication ($n = 10$)
The therapist was near the patient ($n = 2$)	*The therapist was near the patient ($n = 6$)*
During walking training 1	During walking training 5
Falling out of a wheelchair 1	When standing from a wheelchair 1
The therapist was not near the patient ($n = 2$)	*The therapist was not near the patient ($n = 4$)*
During standing training 1	Resting in the sitting position 1
While climbing stairs alone 1	Standing up alone 2
	Falling out of a wheelchair 1

There was no significant difference between the two groups regarding the orientation status of non-older and older patients who fell and whether the therapist was near the patient. $p = 0.2598$ for both.

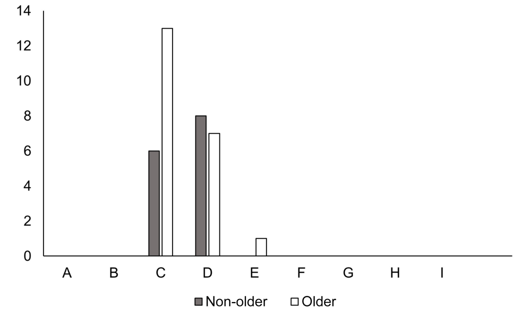

FIGURE 2
Impact of falls on patients. The x-axis is classification by National Coordination Council for Medication Error Reporting and Prevention index (reference 23), and the y-axis is number of falls.

was nearby (assisting), with no significant difference between the two ($p = 0.2598$). Furthermore, falls in both groups most commonly occurred while walking.

The impact of falls on non-older patients was in categories C and D, where all fall patients did not require additional treatment. However, even in older patients, 20 out of 21 were in category C or D, with only one in category E in which a fall occurred during walking training while accompanied by a therapist and a wound was sutured due to an eyelid laceration (**Figure 2**). In the non-older group, more patients in the main departments of neurosurgery (28.6%), orthopedic surgery (14.3%), and rehabilitation (14.3%) had falls, while older patients also had more patient falls in neurosurgery (28.6%), orthopedic surgery (23.8%), and rehabilitation medicine (9.5%; **Table 4**). There was no significant difference in the main clinical departments of fallen patients between the non-older and older.

Discussion

In this study, the number of falls that occurred during rehabilitation was significantly lower than that during hospitalization and being older did not increase the number of falls. Furthermore, the ADL status before illness and at admission for both non-older and older patients was not related to the occurrence of falls. In addition, older patients with poor communication were not more likely to fall. This is the first report to investigate the characteristics related to patients who fall between non-older and older patients occurring during rehabilitation in an acute care hospital.

The risk of falls and injury increases with age and falls in older individuals are more likely to occur in association with social, behavioral, and physical risk factors, such as reduced physical fitness; impaired vision, balance, and gait; and multiple medications as well as physical environmental risk factors such as poor lighting and slippery floors (25, 26). People ≥ 65 years are at a high risk of falls, with 30% > 65 and 50% > 80 falling at least once a year (27). However, there was no significant difference in the incidence of falls in this study, and the actual incidence was 0.21% in older patients, lower than 0.41% in non-older patients. Lee et al. (13) reported that fall patients had a significantly lower total FIM score on admission than that of non-fall patients, and that patients with a low cognition FIM on admission had a higher risk of falls. Patients with Mini Mental State Examination (MMSE) scores < 28/30 had a nearly threefold increased risk of falls compared to control patients with 30/30 scores, indicating a relationship between cognitive ability and falls (28). Thirty-two patients who were unable to communicate their basic needs (21.7%) were almost twice as likely to fall during hospitalization as those who were able to communicate (29). Furthermore, Teasell et al. (30) reported that the group of patients who fell had significantly lower scores on the Berg Balance Scale and FIM than those from the non-fall group. Additionally, the number of falls significantly increased with lower FIM in the patients who fell. Pils et al. (31) also reported that being older, gender (higher fall rates in men), and MMSE scores were associated with falls during hospitalization for rehabilitation after femur fracture. In our study, there were no significant differences in mRS, motor FIM,

TABLE 4 Main clinical departments of fallen patients.

	Total patients (n = 35)	Non-older (n = 14)	Older (n = 21)	p-value
Neurosurgery	10 (28.6%)	4 (28.6%)	6 (28.6%)	> 0.9999
Orthopedic surgery	7 (20.0%)	2 (14.3%)	5 (23.8%)	0.6760
Rehabilitation	4 (11.4%)	2 (14.3%)	2 (9.5%)	> 0.9999
Diabetes, endocrine, and metabolic medicine	2 (5.7%)	1 (7.1%)	1 (4.8%)	> 0.9999
Gastrointestinal, endocrine, and pediatric surgery	2 (5.7%)	1 (7.1%)	1 (4.8%)	> 0.9999
Neuropsychiatry	2 (5.7%)	1 (7.1%)	1 (4.8%)	> 0.9999
Cardiovascular medicine	1 (2.9%)	1 (7.1%)	0 (0%)	0.4000
Rheumatology and clinical immunology	1 (2.9%)	1 (7.1%)	0 (0%)	0.4000
Pediatrics	1 (2.9%)	1 (7.1%)	0 (0%)	0.4000
Emergency medicine	1 (2.9%)	0 (0%)	1 (4.8%)	0.4400
Cardiovascular, respiratory, and breast surgery	1 (2.9%)	0 (0%)	1 (4.8%)	0.4400
Plastic and reconstructive surgery	1 (2.9%)	0 (0%)	1 (4.8%)	0.4400
Nephrology (artificial dialysis)	1 (2.9%)	0 (0%)	1 (4.8%)	0.4400
Otolaryngology	1 (2.9%)	0 (0%)	1 (4.8%)	0.4400

cognition FIM before admission in the two groups, or in the ratio of mRS and good communication at the time of fall. Furthermore, there were no significant differences in either the older or non-older patients when compared to the matched non-fall group. Significantly, the incidence of falls during acute rehabilitation was not related to ADL performance or degree of communication as previously reported.

Schwendimann et al. (32) investigated 3,842 fall patients out of 34,972 inpatients, of which 2,552 (66.4%) were intact and 1,142 (29.7%) had minor injuries such as pain, bruise, blood type, and laceration. Additionally, 148 (3.9%) reported serious AEs such as fractures and intracranial hemorrhage. Of the 1,472 patients admitted to the rehabilitation center, 140 fell during their stay; 90% did not suffer harm, while 8/10 who did suffer harm had minor contusions, lacerations, or abrasions, and 2/10 suffered fractures (13). Saverino et al. (33) also reported 40/320 post-acute orthopedic and neurologic inpatients fell during hospitalization, with one sustaining a rib fracture; however, the falls otherwise had minor effects. The results of our study support previous findings that most falls do not have serious consequences, as 34/35 total falls were minor AEs that did not require additional treatment. However, follow-up studies of older adults who fell show that even non-injurious falls are associated with subsequent decline in basic and instrumental ADLs. Additionally, two or more non-injurious falls are associated with decreased social activity, and at least one injurious fall is associated with decreased physical activity (34). Therefore, attention to fall prevention is necessary regardless of the degree to which a fall affects the patient.

In this study, falls were more common in neurosurgical patients in both groups. In a one-year survey of falls in acute care hospitals (35), 826 of 49,059 inpatients experienced falls, with the most common primary diseases being neurological 214 (26%), gastroenterological 145 (18%), pediatrics 57 (7%), respiratory 51 (6%), cardiac 41 (5%), otolaryngology 40 (5%), orthopedics 33 (4%), and others 245 (30%). Eileen et al. (36) reported 3.38 falls per 1,000 patients per day in an academic hospital with 1,300 beds, with the highest rate of falls in neurology and internal medicine at 6.12. Stroke patients have a higher risk of experiencing falls due to multiple intrinsic risk factors, including impaired consciousness, cognitive impairment, ADL impairment, and depressive symptoms (37, 38). However, it is difficult to generalize as the disease severity of patients, severity of the disease to be treated at the study facility, number of patients accepted, and presence or absence of rehabilitation are unknown, more attention to fall prevention during rehabilitation for both older and non-older patients with cerebrovascular disorders should be paid, as in previous reports.

In previous studies, more than 80% falls in hospitals were not witnessed, and most falls occurred in situations where no one was nearby (9, 39). However, more than half of the falls during this study occurred in situations where the therapist was nearby (assisting) both the older and non-older groups. Patients offered rehabilitation in this hospital often have multiple serious motor, cognitive, and ADL impairments, and require a high amount of assistance. The difference in results as compared to previous studies may be related to the fact that the falls occurred during rehabilitation therapy sessions and that therefore the severity of the patient's disability was different.

This study has the limitation of being a single-site, retrospective cohort study, which affects generalizations. Thus, it is important to conduct a larger, multi-site study in the future.

Conclusion

The rate of falls during rehabilitation was significantly lower than that during hospitalization, and many falls had minimal impact on the patient. It was also difficult to predict falls by ADL and communication status, and there appeared to be no difference in characteristics between the older and non-older groups who experienced falls. However, since more than half of falls occur during training with a therapist near the patient, it is necessary to scrutinize the patient's disability status and training content.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Review Committee of Wakayama Medical University. Written informed consent from the participants or their legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TK and YN conceptualized and designed the study, drafted, reviewed, and revised the manuscript. YU, YK, SK, YY, and KM designed the data collection instruments, collected data, performed the initial analyses, reviewed, and revised the manuscript. FT designed the data collection instruments, coordinated and supervised data collection, and critically reviewed the manuscript. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Tzvi Dwolatzky,
Technion Israel Institute of Technology, Israel

REVIEWED BY
Hangue Park,
Texas A&M University, United States
Ilaria Bortone,
National Research Council (CNR), Italy

*CORRESPONDENCE
Jianhuang Wu
jh.wu@siat.ac.cn
Jing Tao
taojing01@163.com

†These authors have contributed equally to this work

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Automated assessment of balance: A neural network approach based on large-scale balance function data

Jingsong Wu[1,2†], Yang Li[3,4†], Lianhua Yin[1], Youze He[1], Tiecheng Wu[2], Chendong Ruan[1], Xidian Li[1], Jianhuang Wu[3,4*] and Jing Tao[1,2*]

[1]College of Rehabilitation Medicine, Fujian University of Traditional Chinese Medicine, Fuzhou, China, [2]Fujian Collaborative Innovation Center for Rehabilitation Technology, Fuzhou, China, [3]Shenzhen Institutes of Advanced Technology, Chinese Academy of Science, Shenzhen, China, [4]University of Chinese Academy of Sciences, Beijing, China

Balance impairment (BI) is an important cause of falls in the elderly. However, the existing balance estimation system needs to measure a large number of items to obtain the balance score and balance level, which is less efficient and redundant. In this context, we aim at building a model to automatically predict the balance ability, so that the early screening of large-scale physical examination data can be carried out quickly and accurately. We collected and sorted out 17,541 samples, each with 61-dimensional features and two labels. Moreover, using this data a lightweight artificial neural network model was trained to accurately predict the balance score and balance level. On the premise of ensuring high prediction accuracy, we reduced the input feature dimension of the model from 61 to 13 dimensions through the recursive feature elimination (RFE) algorithm, which makes the evaluation process more streamlined with fewer measurement items. The proposed balance prediction method was evaluated on the test set, in which the determination coefficient (R2) of balance score reaches 92.2%. In the classification task of balance level, the metrics of accuracy, area under the curve (AUC), and F1 score reached 90.5, 97.0, and 90.6%, respectively. Compared with other competitive machine learning models, our method performed best in predicting balance capabilities, which is especially suitable for large-scale physical examination.

KEYWORDS

neural networks, machine learning, feature selection, balance, automated assessment

Introduction

Balance ability refers to the ability to maintain a stable posture immediately and autonomously when a person's center of gravity deviates (1, 2). The problem of falls has become a global public health issue because it greatly increases the risk of injury and even death among middle-aged and elderly people (1–6). Studies have found that balance impairment (BI) is a key factor in causing people to fall (7, 8). With the aging of the international society, it is particularly important to conduct early assessment and screening of the balance ability of middle-aged and elderly patients.

The research of balance ability has always been the focus of some scholars (9–16). Many studies have achieved satisfactory results by using machine learning or deep learning methods to solve the problem of balance prediction and falling (see Supplementary Table 3). Yeh et al. (9) developed a virtual reality (VR) balance rehabilitation training system for patients and used the support vector machine (SVM) algorithm to train a machine learning model on data collected from 48 patients and 36 normal people. Khandoker et al. (10) proved the effectiveness of wavelet-based and multi-scale analysis in the assessment of balance disorders in the elderly. Begg et al. (11) collected the minimum foot clearance (MFC) data from 30 young people and 28 old people and analyzed the difference in a dynamic balance between young and elderly. Moreover, as early as 1993, Holzreiter and Köhle (16) used neural networks to analyze healthy and pathological gaits to explain balance assessment.

In addition to the gait perspective, Liu and Cheng (13) started from the center of gravity and used the SVM algorithm to train a fall detection model. Their accuracy rate is as high as 98.4%. Similarly, Bao et al. (14) trained the 1–5 PT (physical therapist) level evaluation model and compared it with the actual PT level of physical therapy, and their classification accuracy reached 82%. Different from the above method, Nait et al. (15) used wearable sensors to obtain daily data of 296 elderly people and combined the convolutional neural network with long-term and short-term memory to build a network model, which can effectively assess the risk of falls based on wearable sensor data. Pickle et al. (17) used a dynamic non–linear autoregressive neural network to train motion data collected from five able-bodied individuals and five individuals with Parkinson's disease walking on a non-steady-state locomotor circuit comprising stairs, ramps, and changes of direction. They found that estimating segment contributions to angular momentum from mechanical signals (linear acceleration, angular velocity) from a sparse set of body segments is a feasible method for assessing coordination of balance. Dubois et al. (18) used the Microsoft Kinect sensor to collect the balance of 84 participants in 8 balanced tasks. Using the clustering algorithm to analyze the experimental data, they found that the prediction results of standing on the foam pad are the most accurate.

A large amount of literature and reviews on gait and balance ability (9–18) has discussed the role and importance of gait and balance ability in falls (19), but few papers study how to optimize balance test items and quickly measure balance function. At present, balance test system is the commonly used tool for quickly measuring and evaluating the balance ability of subjects, such as German Bismarck Super Balance (GBSB) (20, 21) and Biodex Balance System (22). The GBSB system uses three-dimensional force measurement to eliminate the interference factor of the individual's weight on the force plate, which can obtain more accurate measurement data. There are four actions measured by the GBSB system, namely (1) stand on feet with eyes open (FEO); (2) stand on feet with eyes closed (FEC); (3) stand on one foot with eyes open (OFEO); (4) stand on one foot with eyes closed (OFEC). Each set of actions includes 12 test items as shown in Supplementary Table 2. In addition, each action should be kept for a while to collect enough test data. For each subject, it takes at least 90 sec to measure the four sets of actions. At the same time, taking into account the understanding and execution efficiency of instructions for the elderly, when they performing the balance test, the data collection time will be extended, which brings inconvenience to large-scale physical examinations and BI screening. In addition, in order to obtain a comprehensive balance function result, balance assessment requires the measurement of a large number of metrics. Specifically, GBSB system needs to measure at least 61 metrics of the subject to calculate the balance score (20, 21). However, there is massive redundancy in these metrics.

In recent years, artificial intelligence has been applied in various fields of medical data processing (23, 24). Using machine learning algorithms to mine potential information in data has become one of the promising tools for solving medical problems (25–31). In this work, we aim at building a balance assessment model based on the data-driven machine learning techniques. After analyzing the collected data set, we will propose an artificial neural network (ANN) model based on machine learning to predict balance capabilities. Finally, the proposed model is able to quickly and automatically evaluate new subjects, which can simplify the measurement metrics and ensure high accuracy.

Methodology

Overview

The overall process of balance prediction is shown in Supplementary Figure 1. Subjects need to stand in different positions on the GBSB platform for data collection, such as bipedal and single-foot tests with eyes open or closed. Then the system will automatically measure the four sets of items. After that, we clean and preprocess the collected data to facilitate subsequent training and prediction using neural networks. We used BS and BL as the ground truth for regression and classification tasks. A lightweight artificial neural network model was proposed to accurately predict the balance ability of new test examples.

Data collection and preprocessing

The dataset was obtained from the Second Affiliated Hospital of Fujian University of Traditional Chinese Medicine, China. This dataset was used for retrospective analysis, and a total of 17,541 subjects aged 12–80 years entered the analysis with medical examination data. This dataset does not show any personal privacy other than medical information. The study was approved by the Medical Ethics Committee of the Second Affiliated Hospital of Fujian University of Traditional Chinese Medicine, China (No. SPHFJP-K2019059-02).

The features consist of 48 common measurement features of four specific actions and 13 other features. The equipment used for data collection is the GBSB system. The subjects were required to stand on the instrument in different postures to do four sets of actions according to the instructions, including FEO, FEC, OFEO, and OFEC. The durations were 30, 30, 20, and 10 sec, respectively. This protocol is set according to the GBSB system, through which we obtain various measurement data of the subjects. The details of test were shown in Supplementary Figure 2.

This dataset collected a total of 17,541 subjects, each with 61-dimensional features and two labels, where the 61 features represent measurement items, and two labels collectively represent the balance ability: Balance Score (0–100) and Balance Level (high, medium, low), which are used as ground truth for regression tasks and classification tasks, respectively. The Balance Score is measured by GBSB system, and then the doctor evaluates the Balance Level according to the Balance Score and the physical condition of the subjects.

As shown in Supplementary Figure 3, the whole 61-dimensional features include 48 common measurement features of four sets of actions and 13 other individual features. Each set of actions includes 12 test items. Supplementary Table 2 shows the value range of 48 common measurement features and four sets of actions.

Eighty percentage of the data is used as the training set, 10% of the data is used as the validation set, the remaining 10% are test set. We performed a 10-fold cross-validation. Since there are missing values in the dataset, which will affect the prediction performance of the model on the balance ability. Firstly, we calculated the median of all samples to deal with the missing values. Because the proportion of missing data is relatively small (account 5% of all), the median is a good way to fit the original data distribution. Regarding the problem of inconsistent feature dimensions, since the original data conforms to the Gaussian distribution, we have carried out the following standardization processing, so that the mean of the data is 0 and the variance is 1.

$$z = \frac{x - \mu}{\sigma}. \tag{1}$$

Where x is the original value, z is the standardized value, μ means the average of all samples, and σ represents the standard deviation of x.

The proposed ANN model

Due to the high accuracy and strong robustness of the neural network algorithm, we designed a model based on a deep neural network to predict the balance ability. To make the neural network model fit the data better, generally, the common methods prefer to increase the depth and width of the network. However, this will increase the number of network parameters exponentially, making the computational complexity of the model greater. Through a large number of experiments, we find that when the number of hidden layers of the neural network is set to five, the accuracy and complexity of the model can be effectively balanced. Supplementary Figure 4 shows the proposed neural network structure. The entire network contains an input layer, five hidden layers, and an output layer. In each middle-hidden layer, the number of neurons is set as 128, 64, 32, 16, and 8 respectively. The dimension of the input layer matches the number of features of the data, while the output layer represents the prediction result of the neural network. We implemented regression and classification tasks using the proposed model. In the classification task, the output layer dimension is the number of categories, which indicates the high, medium, or low level of predicted balance ability. While in the regression task, the output layer has only one dimension, namely the balance score.

Notably, the three important components of a neural network are weights, bias term, and activation function. It is those weight parameters that are constantly updated during the learning process of the network that make the neurons between adjacent layers fully connected. The strength of the connection between neurons is determined by the value of weight. Furthermore, bias is a crucial parameter of the model to ensure that the output value calculated by the input cannot be activated casually. Typically, the activation function acts as a non-linear mapping, which can limit the output amplitude of the neuron within a certain range. The structure of one neuron is shown in the dotted box in Supplementary Figure 4. Given the input feature data $x_i (i = 0, 1, \ldots n)$, the output S is calculated as follows:

$$S = \max\{0, \left(w_0 x_0 + w_1 x_1 + \ldots + w_n x_n + \mathrm{b}\right)\}, \tag{2}$$

where the weight parameter $w_i (i = 0, 1, \ldots n)$ represents the connection strength between neurons. It should be noted that the activation function is set in our experiment as the ReLU function, which not only promotes the non-linear representation of features but also makes the neurons have sparseness that further improves the fitting ability of the model.

The purpose of training the model is to obtain the model parameters that minimize the cost function. The cost function (15) we define is as follows:

$$\mathrm{J}\left(\mathrm{w}, \mathrm{b}\right) = \frac{1}{\mathrm{m}} \sum_{i=1}^{m} \mathrm{L}\left(\hat{y}_i, y_i\right) + \frac{\lambda}{2\mathrm{m}} \|\mathrm{W}\|_2^2. \tag{3}$$

Where m is the total number of samples, $\hat{y}_i$ and y_i represent the predicted value and true value of the i-th sample respectively and L means cross-entropy loss function. The $\frac{\lambda}{2m}\|W\|_2^2$ is an L2-regularization term used to penalize complex models. And the item λ is a hyperparameter that controls the degree of penalty. In the process of model parameter updating, we use the Adam optimizer to perform gradient descent and back-propagation.

Experiments

Experimental settings and metrics

The experimental environment is a Windows 10 system with python 3.6. The neural network model framework used in the experiment is based on scikit-learn library with version 0.24, an efficient tool for data mining which built on numpy, scipy, and matplotlib. In the process of training the neural network, the batchsize is set to 200. The optimizer used for weight update is Adam, and its constant learning rate is initialized to 0.001.

We use common evaluation metrics to evaluate classification and regression models, namely: Accuracy (Acc), Recall (Re), Precision (Pr), F1-score (F1), and coefficient of determination (R^2) score. These evaluation metrics range from 0 to 1. The larger the value, the better the model effect. These formulas are as follows:

$$\mathrm{Acc} = \frac{\mathrm{TP}+\mathrm{TN}}{\mathrm{TP}+\mathrm{TN}+\mathrm{FN}+\mathrm{FP}'} \tag{4}$$

$$\mathrm{Pr} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FP}'} \tag{5}$$

$$\mathrm{Re} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}'} \tag{6}$$

$$\mathrm{F1} = \frac{\mathrm{TP}(2\mathrm{TP}+\mathrm{FP}+\mathrm{FN})}{2(\mathrm{TP}+\mathrm{FN})(\mathrm{TP}+\mathrm{FP})}. \tag{7}$$

$$\mathrm{R}^2(\mathrm{y},\hat{\mathrm{y}}) = 1 - \frac{\sum_{i=1}^{n}(\mathrm{y_i}-\hat{\mathrm{y}}_i)^2}{\sum_{i=1}^{n}(\mathrm{y_i}-\bar{\mathrm{y}})^2}. \tag{8}$$

Where $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$. The $\hat{y}_i$ and y_i represent the predicted value and true value of the i-th sample. TP, TN, FP, and FN represent true positive, true negative, false positive, and false negative, respectively.

Feature selection

Since the data contains irrelevant feature attributes, it will interfere with the prediction of new data. In order to reduce the input feature dimension of the model and improve the robustness of the algorithm, we adopted a recursive feature elimination (RFE) algorithm to filter the 61-dimensional features. As shown in Figure 1, the flow of feature selection algorithm included recursive feature elimination, neural network training, and classification.

Results

In this study, we used a physical examination database from the clinic, which contains the physical examination data of 17,541 subjects. The descriptive statistics about the subjects is shown in Supplementary Table 1. Among all subjects, the middle-aged and elderly (aged between 41 and 80) accounted for 68.17%. Further, among the people with low and medium balance ability, the middle-aged and elderly (aged between 41 and 80) accounted for 78.36%, indicating that the target population of our proposed method is more suitable for the middle-aged and elderly.

A total of 61 balance indicators were measured and entered into analysis. Based on the features selected by the RFE algorithm, we compared the accuracy of different machine learning models on the test dataset. As shown in Supplementary Table 4, these competitive machine learning algorithms include Decision Tree, Random Forest, K-Neighbors, Linear Regression, Extra Tree, and Support Vector Machine. Compared with other methods, our proposed neural network model performs best regardless of the input feature dimension. Typically, when the feature is 61-dimensional, the coefficient of determination of our model is the highest, reaching 97.8%, while the feature is reduced to 13 dimensions, our model is still the best, with the coefficient of determination reaching 92.2%. Figure 2 further shows the trend of different methods in the case of reduced feature dimensions. It can be seen from Figure 2 that our neural network model can still maintain a high coefficient of determination even when the feature dimension drops sharply, indicating that our method is more robust and stable.

By weighing the feature dimension and model accuracy, that is to make the measurement time of subject as low as possible while keeping the coefficient of determination as high as possible, we finally chose #F = 13 as the final filtered feature. The selected 13-dimensional features are shown in Table 1. Taking the selected 13 features as the input of the proposed neural network model, the true and predicted balance score of samples on the test set are shown in Supplementary Figure 5. In order to show more intuitively, we only drew 100 samples. We can see from the resulting graph that the predicted balance score is basically the same as the true value, which shows the accuracy of the model from an intuitive effect.

As shown in Table 2, compared with other machine learning models like Decision Tree (32), Linear Discriminant Analysis (LDA) (34), K-Neighbors (36), Logistic (38), Naive Bayes (40), and Support Vector Machines (SVM) (42), our method has the highest accuracy, recall, precision, and F1-score evaluation metrics, reaching 90.5, 90.8, 90.5, and 90.6%, respectively.

From the perspective of clinical balance assessment procedures, compared with traditional measurement methods, the proposed method has the following advantages, namely

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Input: Original 61 features, set $X = \{X_1, X_2, \ldots X_{61}\}$
Output: Selected 13 features rank list, S.

Step 1: Set S= { }
Step 2: Repeat step 3-8 until X is not empty
Step 3: Train the base model using X
Step 4: Compute the weight vector $W = \sum_{i=1}^{n} \beta_i x_i y_i$, where n=61, i is the number of feature, β is lagrangian multiplier, x is feature vector for sample and y is label of sample.
Step 5: Compute the ranking criteria, $\mathrm{Rank} = W^2$
Step 6: Rank the features as in sorted manner. $\mathrm{New}_{\mathrm{Rank}} = \mathrm{sort}(\mathrm{Rank})$
Step 7: Update the feature rank list. Update $S = S + X(\mathrm{New}_{\mathrm{Rank}})$
Step 8: Eliminate the feature with smallest rank. Update $X = X - X(\mathrm{New}_{\mathrm{Rank}})$
Step 9: End

FIGURE 1
Feature selection algorithm.

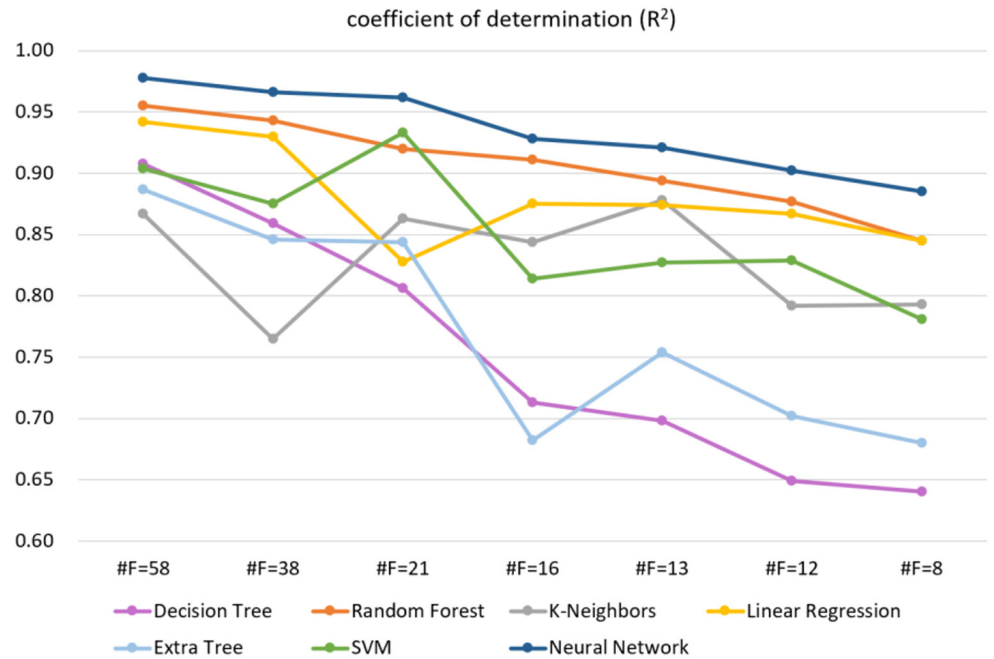

FIGURE 2
The trend of different methods in the case of reduced feature dimensions, where #F indicates the number of feature dimensions. The higher the R^2, the better the model effect. The label used on the regression task is balance score (0–100).

(1) fewer measurement metrics, (2) less measurement time. Our method only needs to measure 13 metrics to evaluate the balance ability, which takes only 40 sec (55% less time than GBSB's 90 sec). For the evaluation accuracy, the determination coefficient R^2 of our method reached 92.2%, and the classification accuracy rate reached 90.5%, both of which met the clinical requirements.

Discussions

In this work, we propose the method to assess the balance ability efficiently and accurately, which can predict the risk of falling. To obtain the balance score and balance level, we implemented regression and classification tasks on the data set respectively by designing and training a neural network model.

TABLE 1 The selected 13 features.

#	Features	Units	Description	Range	Mean
1	TLS FEC	mm	Total trajectory length of shaking, eyes closed with feet	43.1–2,065.2	266.3
2	TLS OFEC	mm	Total trajectory length of shaking, eyes closed with one foot	26.6–3,799.1	506.2
3	PA OFEC	mm^2	Peripheral area, eyes closed with on one foot	5.2–57,102.7	2469.2
4	TLPA FEC	-	Track length per unit area, eyes closed with feet	0.1–27.2	2.0
5	TLPA OFEC	-	Track length per unit area, eyes closed with on one foot	0.0–6.2	0.3
6	Y-D FEC	mm	Y-axis mean center displacement, eyes closed with feet	−68.5–84.1	27.7
7	Y-D OFEC	mm	Y-axis mean center displacement, eyes closed with one foot	−120.4–127.1	13.9
8	AS-X FEC	mm/s	Average speed in the X-direction, eyes closed with feet	0.6–65.9	32.1
9	AS-X OFEC	mm/s	Average speed in the X-direction, eyes closed with one foot	0.7–259.3	182.6
10	AS-Y FEC	mm/s	Average speed in the Y-direction, eyes closed with feet	1.2–60.0	30.2
11	AS-Y OFEC	mm/s	Average speed in the Y-direction, eyes closed with one foot	2.1–240.8	48.9
12	LT-X OFEC	mm	Length of track in the X-direction, eyes closed with one foot	7.1–2,593.1	1,008.7
13	LT-Y FEC	mm	Length of track in the Y-direction, eyes closed with feet	36.7–1,800.8	947.1

TABLE 2 Classification results (%) with evaluation metrics of different methods on 13-dimensional features.

Single method	Acc	Pr	Re	F1	Ensemble method	Acc	Pr	Re	F1
Decision tree (32)	78.4	78.4	78.4	78.4	BDT (33)	84.7	85.0	84.7	84.8
LDA (34)	78.6	78.9	78.6	78.4	RF (35)	84.0	84.4	84.0	84.1
K-neighbors (36)	80.8	81.3	80.8	80.9	ET (37)	78.9	72.7	72.7	72.7
Logistic (38)	80.9	80.9	80.9	80.8	SGBoost (39)	87.3	87.5	87.3	87.3
Naive bayes (40)	60.1	79.0	60.1	53.4	AdaBoost (41)	83.1	83.6	83.1	83.2
SVM (42)	83.5	83.9	83.5	83.6	Voting (43)	86.7	86.9	86.7	86.7
Ours	90.5	90.8	90.5	90.6	Ours	90.5	90.8	90.5	90.6

The label used on the classification task is the balance level (high, medium, low). Acc, accuracy; Pr, precision; Re, recall; F1, F1-score.

Generally, the fitting ability of neural networks increases as the number of layers deepens, but the training time and complexity of the model also increase. We weighed these two aspects and designed a neural network with five hidden layers. To prevent the model from overfitting, we added an L2 regular term to the cost function to prevent the weight parameter from being too large, which is conducive to improving the generalization ability and robustness of the neural network.

It is known that the data and features determine the upper limit of machine learning, while models and algorithms only approach the upper limit. Therefore, feature selection helps to discover the output results that we are interested in. We filtered the 61-dimensional features based on the RFE algorithm. As shown in Table 2, the accuracy of different models on the test set decreases as the feature dimensions decrease. Specifically, when the feature dimension was reduced from 61 to 38, which was reduced nearly by half, but the accuracy of the model remained almost unchanged, indicating that the original data contained feature attributes that were not related to balance ability. It is worth noting that when the feature dimension of our model is reduced from 61 to 13, the accuracy rate drops from 97.8 to 92.2%. The feature dimension is reduced by 78.7%, however, the model accuracy is only reduced by 5.7%. The above situation illustrates our proposed neural network can maintain high accuracy even when the feature dimension is drastically reduced, suggesting that the original data is redundant and our model is robust.

In order to get the level of balance ability, a comprehensive study of different methods on classification task has been undertaken. There are three categories for the level of balance ability in the data set, namely: high, medium, and low. For the prediction of the balance level, we changed the output layer dimension of the proposed neural network to 3 to perform the classification task. The input to the network is the selected 13-dimensional features in Table 1. As shown in Table 2, compared with other machine learning models like Decision Tree (32), Linear Discriminant Analysis (LDA) (34), K-Neighbors (36), Logistic [(38)], Naive Bayes (40), and Support Vector Machines (SVM) (42), our method has the highest accuracy, recall, precision, and F1-score evaluation metrics, reaching 90.5, 90.8,

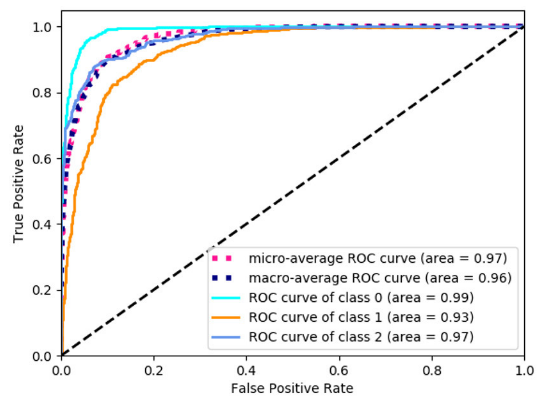

FIGURE 3
The area under the curve (AUC) value of each balance level. The class 0, 1, and 2 correspond to low, medium and high balance levels respectively.

90.5, and 90.6%, respectively. For the balance level, we count the area under the curve (AUC) value of each category, as shown in Figure 3. Class 0, 1, and 2 correspond to low, medium, and high balance levels respectively, and their AUC values reach 99, 93, and 97%, which shows the neural network model trained by 13-dimensional features has high accuracy and low redundancy.

In machine learning, every single algorithm has different characteristics and application range. To absorb the advantages of different models, integration technology is usually used to combine multiple algorithms for improving the accuracy of the model. There are three methods of integration: bagging, boosting, and voting.

Bagging

The bagging algorithm separates the training data set into multiple subsets by random sampling with a return. Then each subset trains a weak model. Finally, the weight of each weak model is averaged by combining strategies to obtain a strong model. The models using the bagging method include Bagged Decision Tree (BDT) (33), Random Forest (RF) (35), and Extra Tree (ET) (37). As shown in Table 2, their accuracy reaches 84.7, 84.0, and 78.9% respectively. As can be seen from Figure 4, except for Extra Tree, there are significant improvements in the bagging models.

Boosting

The boosting algorithm first trains the data set according to the initialized weight *D*1 to obtain a weak model and then the weak model updates the weight *D*1 according to the error to obtain the weight *D*2. In the second round, *D*2 is used to train the data, and so on. The main idea of boosting is to train multiple models and form a sequence. Each model in the sequence corrects the errors of the previous one and finally merges all weak models to obtain a strong model. The models that use boosting include AdaBoost (41) and SGBoost (39), and their accuracy reaches 83.1 and 87.3%, respectively, which is better than the overall effect of the bagging algorithm.

Voting

The voting algorithm (43) creates two or more models, uses voting to package the algorithm, and then calculates the average prediction of each sub-model. The voting algorithm shown in Table 2 is a strong classifier obtained by voting on three single models including a decision tree classifier, a support vector machine, and a logistic regression model.

Compared with ensemble techniques, the accuracy of our method is about 3% higher than the second-place SGBoost method, which proves the neural network model we proposed can obtain the best performance whether dealing with regression tasks or classification tasks. The main reason for this is that our neural network model can approximate any non–linear function, skip the model analysis and directly mine the relationship among the data. In addition, the neural network fully considers the influence of characteristic factors, while other machine learning models are relatively fixed. Moreover, the neural network allows outliers in the training data, which has strong robustness and fault tolerance to noise. The above discussion illustrates the fact that our method can effectively extract different dimensions of features to better fit and predict the balance ability.

Limitations

Although the proposed method shows good performance, there are still some aspects that can be further explored in the future. The first is limited adaptability. Since the data collected is local balance data, the prediction model may not apply to other regions. In this case, prediction models in other regions require additional training on local data sets to generate new models. Secondly, there is room for improvement in the accuracy of our automated assessment because of the noise in raw data. We can also optimize the model through grid search and random search to further improve accuracy.

Conclusions

In this work, we proposed an artificial neural network model to train large-scale physical examination data, so that the model can efficiently and accurately predict the balance score and balance level, which is beneficial for the early screening and

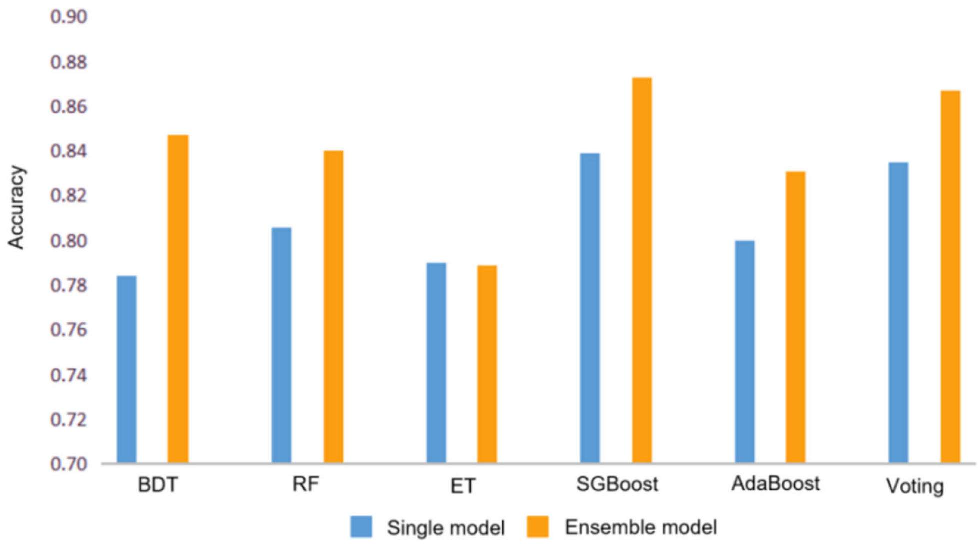

FIGURE 4
Accuracy comparison between single model and ensemble model. Where BDT, RF, and ET represent Bagged Decision Tree, Random Forest and Extra Tree respectively.

prevention of falls in the middle-aged and elderly. Compared with other competitive machine learning models, our method performed best in predicting balance capabilities, where the determination coefficient of balance score reaches 92.2%. In the classification task of balance level, the metrics of accuracy, precision, recall, and F1 score reached 90.5, 90.8, 90.5, and 90.6% respectively. The proposed method greatly reduces the dimensionality of the input features, indicating that for the prediction of balance ability, only two actions with 13 items need to be measured to get the result, which greatly reduces the workload.

Data availability statement

The raw data supporting the conclusions of this article will be made available from the corresponding author upon reasonable request.

Ethics statement

The studies involving human participants were reviewed and approved by Medical Ethics Committee of The Second Affiliated Hospital of Fujian University of Traditional Chinese Medicine. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

JiaW and JT secured the fundings and conceived the original idea and designed the study. JinW and LY prepared the ethical reviews application. JinW, LY, YH, TW, CR, and XL were responsible for the data collection and collation. YL did the data modeling and analysis. JinW wrote the manuscript. All authors contributed to further development of this manuscript and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.882811/full#supplementary-material

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Tzvi Dwolatzky,
Technion – Israel Institute of Technology, Israel

REVIEWED BY
Wei Jiang,
Guangdong Provincial Hospital of Chinese Medicine, China
Meng Ding,
Shandong Normal University, China

*CORRESPONDENCE
Linxuan Guo
gemmaice@hotmail.com

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The effect of Baduanjin on the balancing ability of older adults: A systematic review and meta-analysis

Linxuan Guo*, Zhihao Liu and Wenxue Yuan

School of Kinesiology and Health Promotion, Dalian University of Technology, Dalian, China

Purpose: To systematically evaluate the effect of Baduanjin on the balancing ability of older adults.

Methods: The systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Six electronic databases were searched for eligible studies. Data synthesis and statistical analysis using a random effects model were performed with Review Manager 5.4. Random-effects weights were used to pool the effect sizes. Publication bias was assessed by funnel plot.

Results: A total of 17 RCTs involving 1,267 patients were identified. The meta-analysis showed that the Baduanjin group was significantly superior to the control group in balancing performance measured by Berg balance scale [mean difference (MD) 4.82; 95% confidence interval (CI) 3.40 to 6.24, $P < 0.00001$], Timed Up and Go (MD −2.21, 95% CI −2.69 to −1.74, $P < 0.00001$) and Eye Closed One Leg Standing Balance (MD 2.01, 95% CI 0.79 to 3.23, $P < 0.00001$) tests.

Conclusion: Baduanjin can effectively affect the balancing ability of older adults. More high-quality evidence-based studies are required to confirm these findings.

Systematic review registration: [https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=293183], identifier [CRD42021293183].

KEYWORDS

older adults, Baduanjin, balancing ability, meta-analysis, randomized control trial

Introduction

The ability to balance generally declines with age because of reduced muscle strength, bone loss, and cognitive decline. Thus, older adults have a high risk for falling than other age groups. Falls can cause soft tissue injury, bone fractures and psychological trauma, leading to disability or even death (1, 2). Falls due to the decline in balance can impact older persons' life expectancy as well as their quality of life (QOL) and place a greater burden on their family and society in terms of medical costs (3). According to the seventh National Census in China in 2020, 13.5% of the population was aged ≥ 65 years (4), a higher percentage than in previous censuses, indicating that population of China is aging. Methods to enhance the balancing ability of older adults and prevent accidental falls are regard to effectively affect their wellbeing and QOL.

Qigong exercise has been an essential component of traditional Chinese medical care for more than 2000 years (5). Baduanjin, a light-to-moderate intensity Qigong practice, is distinguished by its therapeutic effects for health promotion (6). It emphasizes calm, deep breathing, physical stretches, and mental attention while emphasizing the mind-body connection (7). Baduanjin has been shown to increase the limb strength of middle-aged and older adults and to improve their joint flexibility and balancing ability (5, 6). Baduanjin has also been used to treat patients with osteoporosis and Parkinson's disease, effectively improving their balancing and limb movement abilities (7, 8).

Although there is some systematic analysis suggesting that Baduanjin can improve the balancing ability of older persons (9), Assessment of Multiple Systematic Reviews 2.0 (AMSTAR 2.0) found that the research was of low methodological quality and evaluated to have highly heterogeneous populations. Moreover, the previous research did not include relevant studies from outside China. The present study was designed to comply with the requirements of AMSTAR 2.0 (10), using strict inclusion and exclusion criteria, to provide more rigorous evidence to systematically analyze the effect of Baduanjin exercises on the balancing ability of older adults.

Methods

The study protocol for this systematic review and meta-analysis was registered on PROSPERO (International Prospective Register of Systematic Review) with the register number (CRD42021293183) and complied with the PRISMA guidelines.

Eligibility criteria

The Population, Intervention, Comparison, Outcome and Study (PICOS) framework was used to determine the inclusion criteria for studies and the following selection criteria were applied: (P) Participants: the elderly aged ≥ 60 years, with no restrictions on gender, race, nationality, or living environment; (I) Intervention: studies with Baduanjin as the main exercise intervention in the experimental group, including intervention process, duration, frequency, and the training length ≥ 4 weeks; (C) Comparator: the control group who have no exercise habit or performed some simple daily activity; (O) Outcome: the scores of Berg Balance Scale (BBS), Timed Up and Go (TUG), and Eye Closed One Leg Standing Balance (ECLSB) tests; (S) Study design: randomized controlled trials (RCT). Studies were excluded if (1) not written in Chinese or English; (2) full texts unavailable; (3) repeated publications; (4) missing original research data or no way to obtain them; or (5) the drop-out rate over 20%.

Information sources and search strategy

Electronic databases, including PubMed, Web of Science, The Cochrane Library, China National Knowledge Infrastructure (CNKI), WanFang Data, and SinoMed, were searched through November 2021 to identify RCTs assessing the effect of Baduanjin on the balancing ability of older adults. Keywords used for searching included ("Baduanjin" OR "Ba Duan Jin" OR "Ba-Duan-Jin" OR "eight section brocades") AND ("postural balance" OR "musculoskeletal equilibrium" OR "accidental falls" OR "fall") AND ("elderly" OR "old man") AND ("RCT" OR "controlled trial" OR "randomized clinical trial"). The search strategy is illustrated in **Supplementary material**.

Data collection process

Studies identified by the online search were independently screened by two researchers, based on the pre-determined inclusion and exclusion criteria, with discrepancies resolved by consensus or consulting a third researcher. Data extracted from these studies included the research objective, sample size, intervention measures, control measures, intervention frequency, intervention duration, outcome indicators, and evaluation of bias risk.

Statistical analysis

Data synthesis and statistical analysis using a random effects model were performed with Review Manager (version 5.4) available from Cochrane. The mean difference (MD) was adopted as the effect index, with each effect quantity including its point estimate and 95% confidence interval (CI). The statistical heterogeneity among research results was evaluated by χ^2 tests, with a test level of $\alpha = 0.1$, which is combined with I^2 to quantitatively assess the extent of heterogeneity ($I^2 < 25\%$ means low heterogeneity; $25\% < I^2 < 50\%$ means medile heterogeneity; $I^2 > 50\%$ means high heterogeneity). Sensitivity analysis was performed to detect the dependency of the overall heterogeneity on a particular study. To identify the probable sources of heterogeneity, subgroup analyses were conducted according to the health status of the participants (healthy elderly vs. frail/transitional elderly) of the included studies. Also, to explore whether total exercise amount impacts the effect of Baduanjin practice, the stratified subgroup analysis was carried out to explore the dose-response relationship for the included studies. Given that the majority of studies did not discuss the intensity of Baduanjin exercises and that all Baduanjin practice followed the same movement paradigms, the study assumed that the intensity of Baduanjin workouts in every study was, by default, consistent. On the basis of total exercise amount, the included studies were classified into three subgroups: small exercise group (SE = exercise time less than 1999 min), medium exercise group (ME = exercise time between 2000 and 3999 min), and large exercise group (LE = exercise amount of 4000–5999 min). The total exercise amount was calculated by duration of weeks, sessions per week and time per session (take the median if it is a range) as listed in **Table 1**.

Results

Search selection

One hundred seventy-four studies were initially identified from the electronic databases. Of these, 89 were duplicate studies and excluded. A total of 85 studies were screened for titles and abstracts, and 38 were excluded. After the first stage of screening, 47 studies were selected for full-text screening. Of these, 30 articles that failed to meet the PICOS framework were excluded. As a result, 17 studies were included in the meta-analysis. The flowchart of the process of screening and study selection was illustrated in **Figure 1**.

Quality assessment

The quality of the included studies was assessed using the Cochrane Handbook for Systematic Reviews of Interventions. The included studies that recorded inadequate information about the methods used for allocation concealment were rated as unclear or high risk. The subjects and personnel were not blinded due to the particularity of the intervention approaches, which made the relevant trials result in high risk in the performance bias. One trial detailed the method of blinding of assessors and were rated as low risk (17). Two studies rated as high risk had abscission data that was not used in their analyses, while they noted the drop-out rate of participant in the trials (14, 15). The remaining studies with all data included in the final analysis were classified as low risk. An overview of the results of the risk of bias analysis for the included studies was shown in **Figure 2**.

Study characteristics

The characteristics of 17 RCTs included in the current meta-analysis were presented in **Table 1**. These studies were published between 2011 and 2021. All the participants in the study were older adults $\geq$ 60 years old, the vast majority of whom were recruited from communities or hospitals. The Baduanjin intervention in some studies were combined with other exercise, but the movement paradigm of Baduanjin in the studies included was basically consistent.

Berg Balance Scale

Nine studies reported scores of BBS, with significant heterogeneity among these studies ($\chi^2 = 50.76$, df = 8; $P < 0.00001$, $I^2 = 84\%$). Results from the sensitivity analysis showed that the exclusion of any single study did not influence the heterogeneity and mean difference (MD) among studies with the parameter of BBS. The analysis using a random effect model showed that BBS scores were significantly higher in Baduanjin than in control groups (MD = 4.82, 95% CI 3.40 to 6.24, $P < 0.00001$; **Figure 3**).

Timed Up and Go

Eight studies reported TUG scores, with significant heterogeneity among these studies ($\chi^2 = 20.49$, df = 7, $P = 0.005$, $I^2 = 66\%$). Results from the sensitivity analysis showed that the exclusion of any single study did not influence the heterogeneity and MD among studies with the parameter of TUG. The analysis by a random effect model showed that TUG test scores were better in Baduanjin than in control groups (MD = −2.21, 95% CI −2.69 to −1.74, $P < 0.00001$; **Figure 4**).

Eye Closed One Leg Standing Balance

Seven studies reported ECLSB scores, with significant heterogeneity among these studies ($\chi^2 = 515.30$, $P < 0.00001$, $I^2 = 99\%$). After the sensitivity analysis, it was speculated that the data of Zhang et al.'s study (15) was the main source of heterogeneity. Accordingly, the analysis was reperformed after the data of this study was excluded. The analysis by a random effect model showed that ECLSB test scores were better in Baduanjin than in control groups (MD = 2.01, 95% CI 0.79 to 3.23, $P < 0.00001$; **Figure 5**).

TABLE 1 Characteristics of the included studies.

Author	Participant description				Intervention protocols		Control group/Condition	Outcomes
	Sample size	Age (years) (Mean ± SD)	Female (BDJ/Con)	Source of participants	BDJ	Duration, sessions with supervision per week, time per session		
Shi et al. (11)	64/65	67.89 ± 4.63/67.48 ± 4.52	31/30	Outpatient	BDJ and balance Ex	8 weeks, 4, 64 min	Balance Ex	①
Zhang et al. (12)	38/40	67.84 ± 4.94/68.13 ± 4.67	38/37	Community	BDJ and resistance Ex	12 weeks, 5, 60–90 min	Educational program	②
Zhao (13)	17/17	65.82 ± 3.88/64.35 ± 3.62	–	Community	BDJ	12 weeks, 3, 60 min	No treatment	③
Li et al. (14)	36/35	65.2 ± 3.6/65.7 ± 3.7	–	Community	BDJ	24 weeks, 5, 60 min	Educational program	①
Zhang et al. (15)	42/41	66.68 ± 2.53/66.59 ± 2.73	16/15	Outpatient	BDJ and balance Ex	12 weeks, 7, 34 min	Balance Ex	③
Zhou et al. (16)	20/20	72.67 ± 9.56/73.25 ± 8.54	12/11	Community	BDJ	8 weeks, 5, 40 min	Educational program	① ②
Gao et al. (17)	34/34	79.79 ± 4.18/78.88 ± 4.66	26/28	Nursing home	BDJ	12 weeks, 5, 30 min	No treatment	②
Song et al. (18)	60/60	67.5 ± 3.5/68.2 ± 3.3	28/24	Outpatient	BDJ and balance Ex	8 weeks, 5, 35 min	Balance Ex	①
Wang et al. (19)	42/42	66.40 ± 4.90/66.60 ± 4.70	20/18	Inpatients	BDJ	12 weeks, 5, 30 min	Walking	①
Kuang (20)	41/41	68.68 ± 3.22/70.33 ± 3.34	–	Outpatient	BDJ	12 weeks, 7, 120 min	Medical treatment	①
Li et al. (21)	44/44	65.1 ± 5.1/65.1 ± 5.1	31/29	Outpatient	BDJ	24 weeks, 7, 30–40 min	No treatment	① ② ③
Wu et al. (22)	60/60	70.63 ± 4.52/70.55 ± 4.26	42/42	Community	BDJ	4 weeks, 7, 120 min	No treatment	① ②
Chen et al. (23)	20/20	64.10 ± 2.64/63.00 ± 3.00	8/12	Community	BDJ	12 weeks, 6, 30 min	No treatment	③
Hou (24)	20/20	60–69	–	Community	BDJ	12 weeks, 5, 60–70 min	No treatment	② ③
Liu (25)	7/8	82.14 ± 1.68/84.15 ± 2.95	–	Outpatient	BDJ	12 weeks, 5, 60 min	No treatment	②
He et al. (26)	40/40	63.4 ± 1.5/62.2 ± 2.1	40/40	Women veterans	BDJ	20 weeks, 7, 45 min	No treatment	③
Liu et al. (27)	47/48	≥ 60	38/37	Community	BDJ	12 weeks, 7, 30–40 min	Walking	② ③

BDJ, Ba Duan Jin; Con, control condition/group; Ex, exercise; ①, BBS; ②, TUG; ③, ECLSB.

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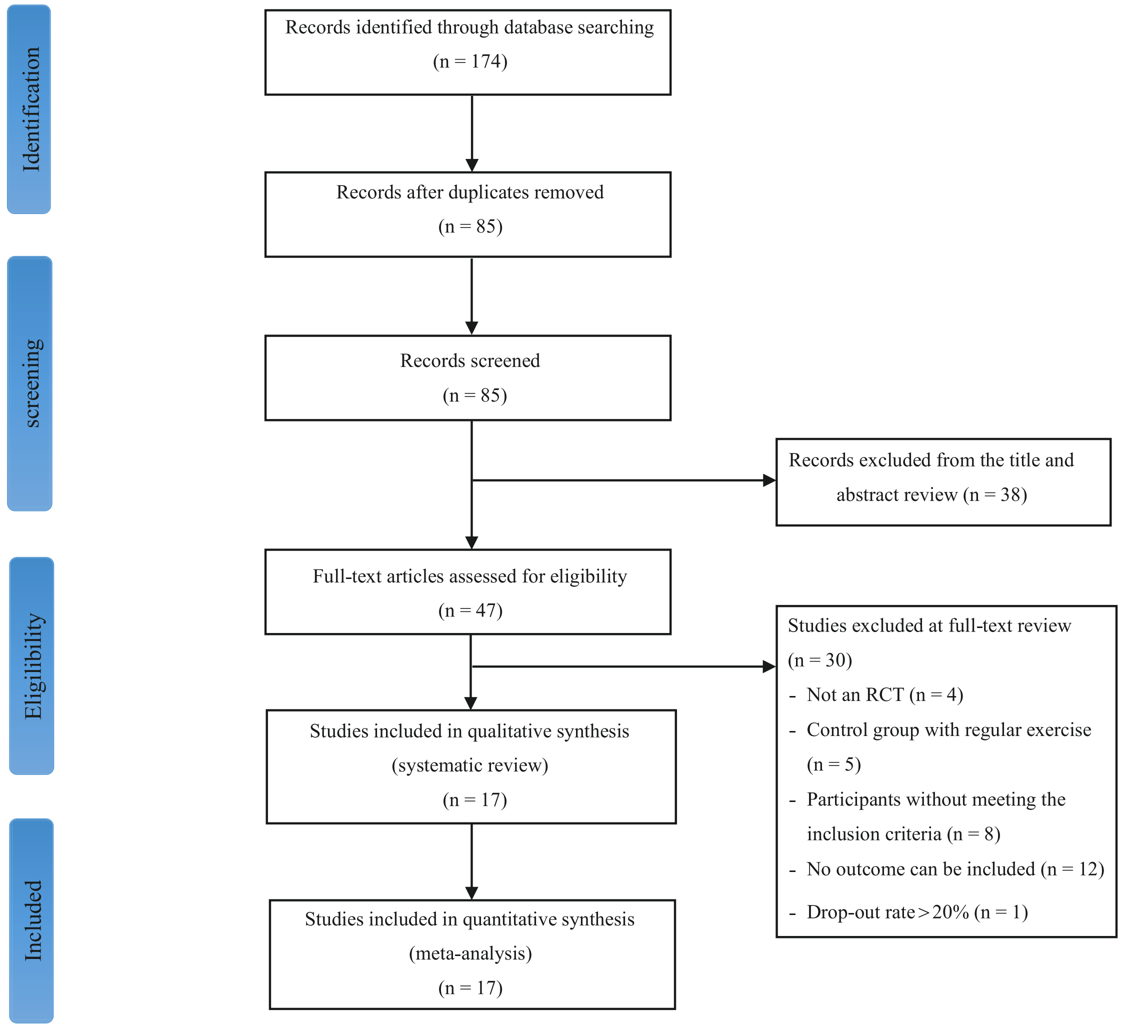

FIGURE 1
Flowchart of the process of screening and study selection.

Subgroup analysis

Health status of the participants

Due to the large heterogeneity among the included studies, as well as the differences in health status among study subjects, the RCTs that included BBS, TUG, and ECLSB scores were analyzed separately according to the health status of study subjects. The studies of healthy older subjects showed moderate heterogeneity (BBS: I^2 = 47%; TUG: I^2 = 49%; ECLSB: I^2 = 41%). The analyses showed that BBS scores were better in Baduanjin groups than in control groups for both healthy (MD = 3.85, 95% CI 2.48 to 5.22, P < 0.00001) and frail/transitional (MD = 5.53, 95% CI 3.46 to 7.61, P < 0.00001) older adults. And the time reduction on the standing and walking test after the intervention was better in Baduanjin groups than in control groups of both healthy (MD = −2.00, 95% CI −2.50 to −1.49, P < 0.00001) and frail/transitional (MD = −2.92, 95% CI −3.44 to −2.40, P < 0.00001) older subjects. In addition, ECLSB scores were also significantly better in Baduanjin groups than in control groups of both healthy (MD = 2.40, 95% CI 1.84 to 2.97, P < 0.00001) and frail/transitional (MD = 1.48, 95% CI −0.51 to 3.47, P < 0.00001) older persons. High degree of heterogeneity was shown in the studies including the frail/transitional older subjects. All the above results were presented in Figures 6–10.

Total exercise amount

The results of subgroup analysis in different total exercise amounts are shown in Figures 9–11. The Baduanjin group had significant improvement than control group in BBS [SE: MD = 2.85, 95% CI (1.60, 4.11), P < 0.000 01; ME: MD = 4.62, 95% CI (2.30, 6.94), P < 0.000 1; LE: MD = 6.76, 95% CI (4.57, 8.96), P < 0.000 01], TUG [SE: MD = −2.74, 95% CI (−4.26, −1.21), P = 0.000 4; ME: MD = −1.31, 95% CI (−1.90, −0.72),

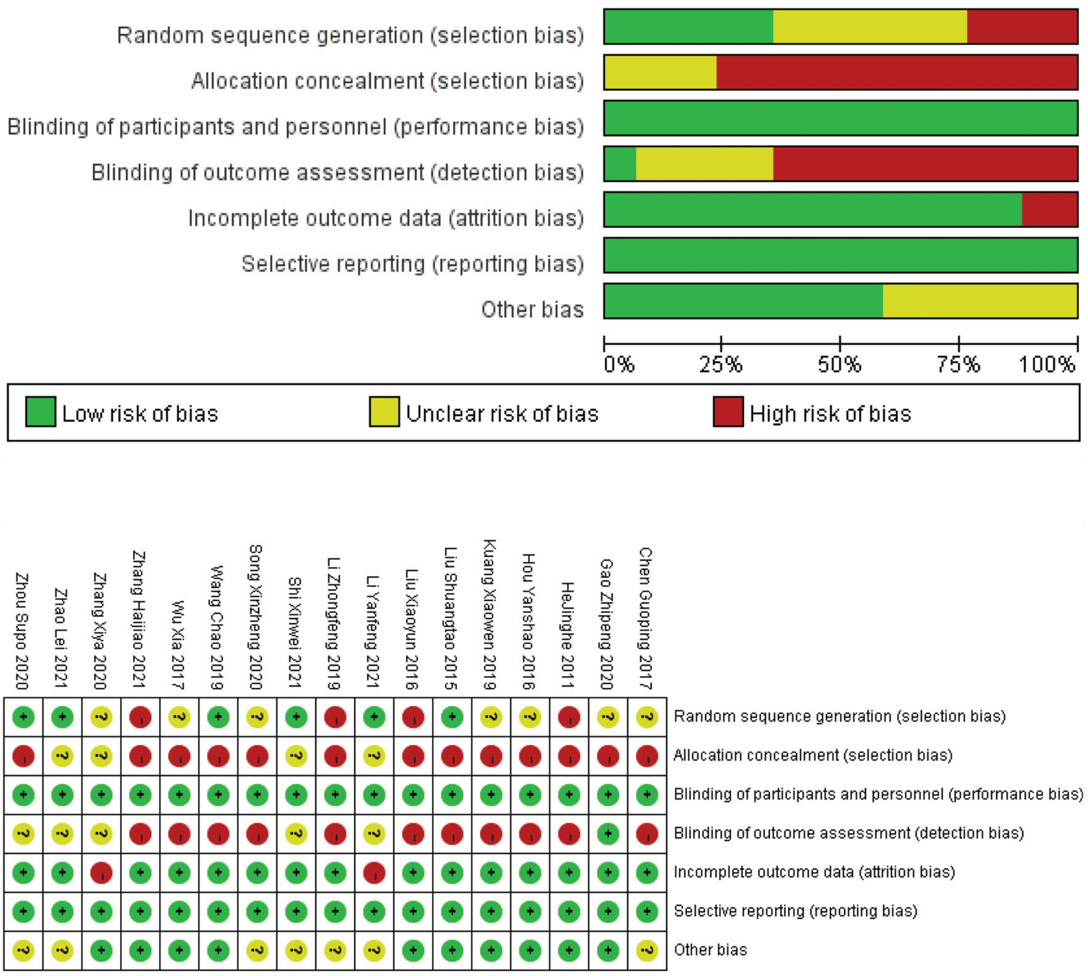

FIGURE 2
Risk of bias graph and summary.

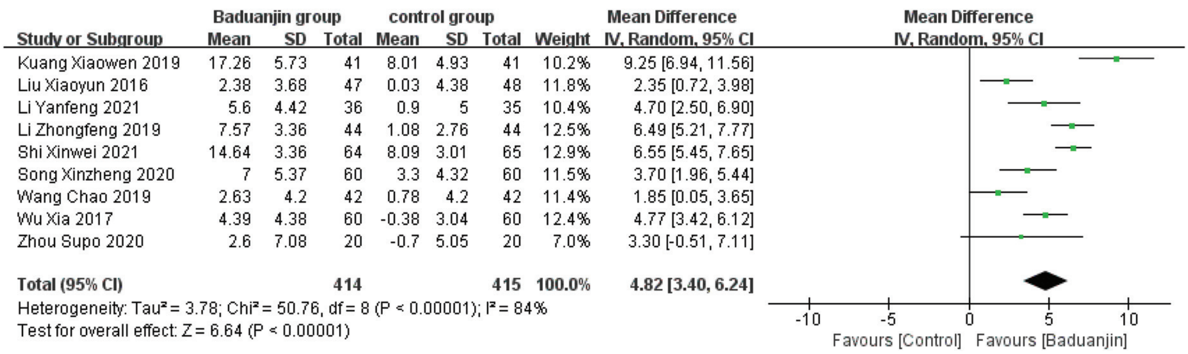

FIGURE 3
Forest plot of the meta-analysis of BBS. CI, confidence interval; SD, standard deviation.

$P < 0.000$ 1; LE: MD = −2.66, 95% CI (−3.12, −2.20), $P < 0.000$ 01] and ECLSB [ME: MD = 2.32, 95% CI (1.54, 3.10), $P < 0.000$ 1; LE: MD = 2.51, 95% CI (2.06, −2.97), $P < 0.000$ 01]. For the parameter of BBS, the subgroup pool effect size increased with the increase of total exercise amount, and there was the significant difference between SE and LE as shown in **Figure 9**.

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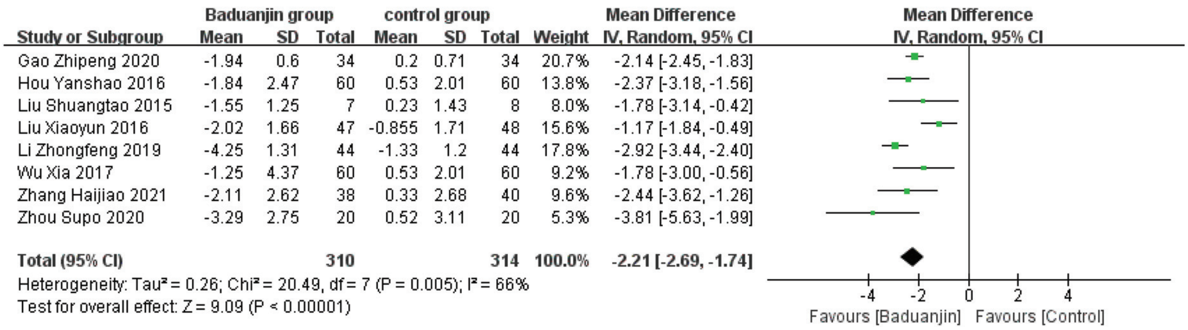

FIGURE 4
Forest plot of the meta-analysis of TUG. The green squares and horizontal lines indicate the study-specific mean difference and 95% CIs. The size of the green area reflects the study-specific statistical weight. The black diamonds represent the mean difference and 95% CIs of each subgroup and the overall population.

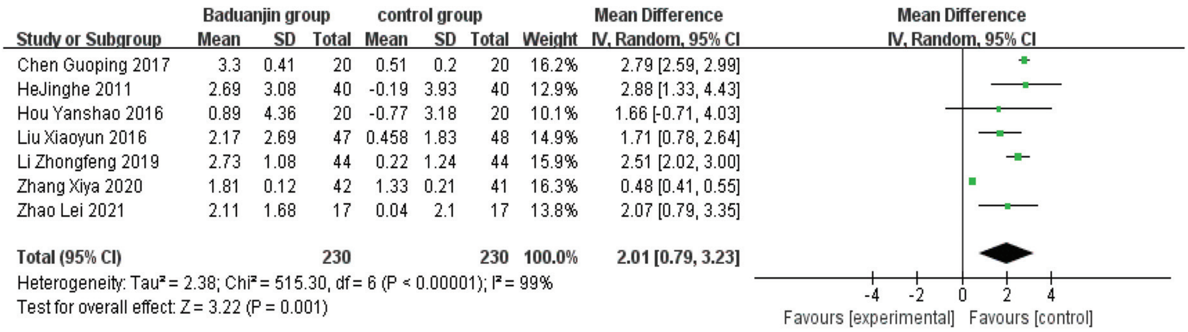

FIGURE 5
Forest plot of the meta-analysis of ECLSB. CI, confidence interval; SD, standard deviation.

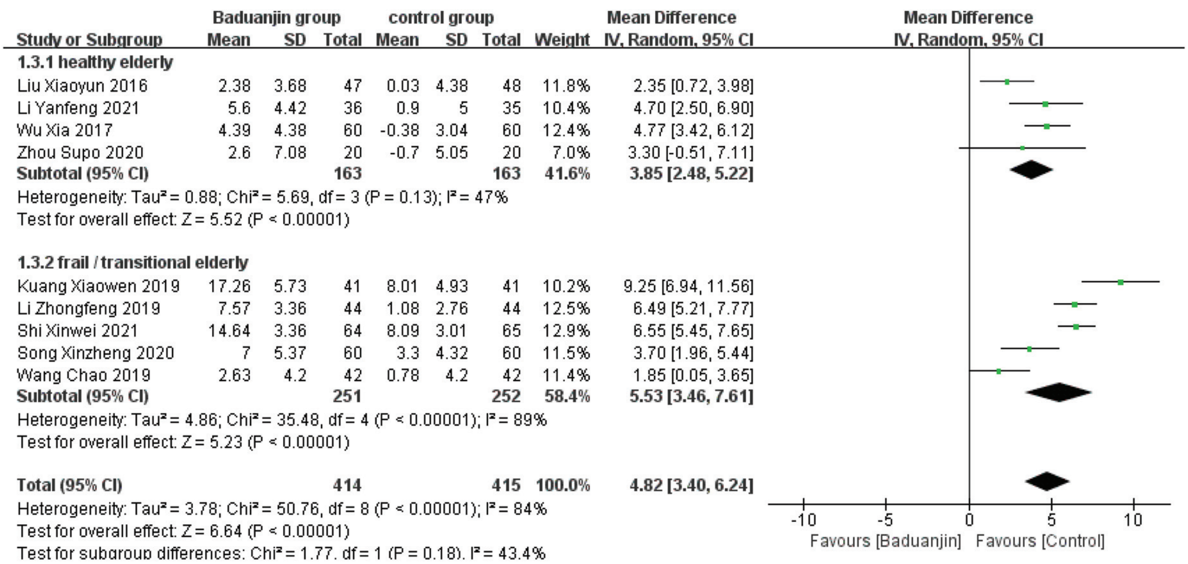

FIGURE 6
Forest plot of the subgroup analysis of BBS for the different health status. CI, confidence interval; SD, standard deviation.

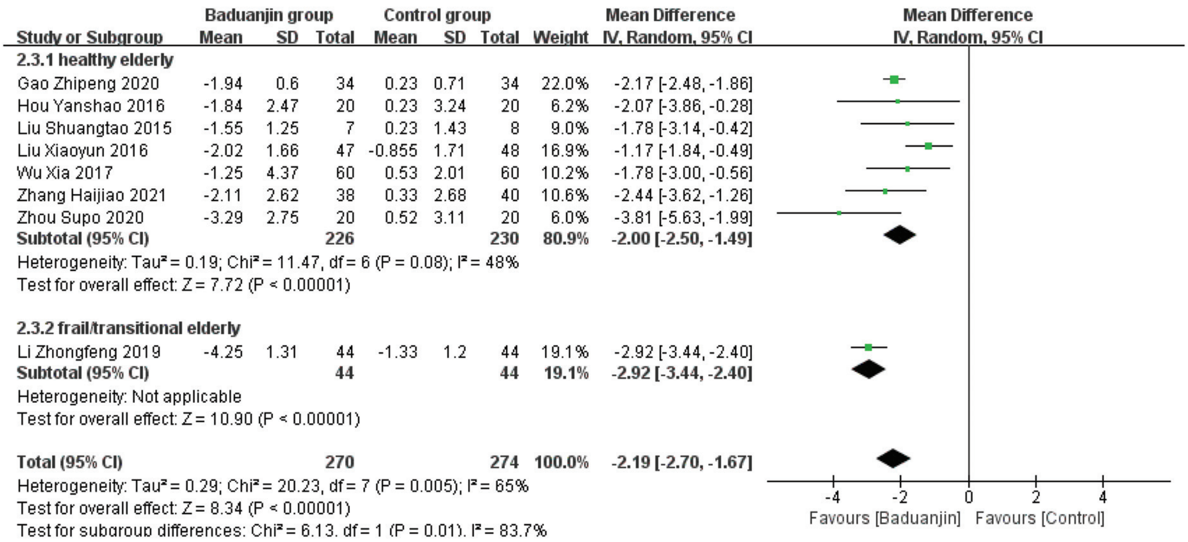

FIGURE 7
Forest plot of the subgroup analysis of TUG for the different health status. CI, confidence interval; SD, standard deviation.

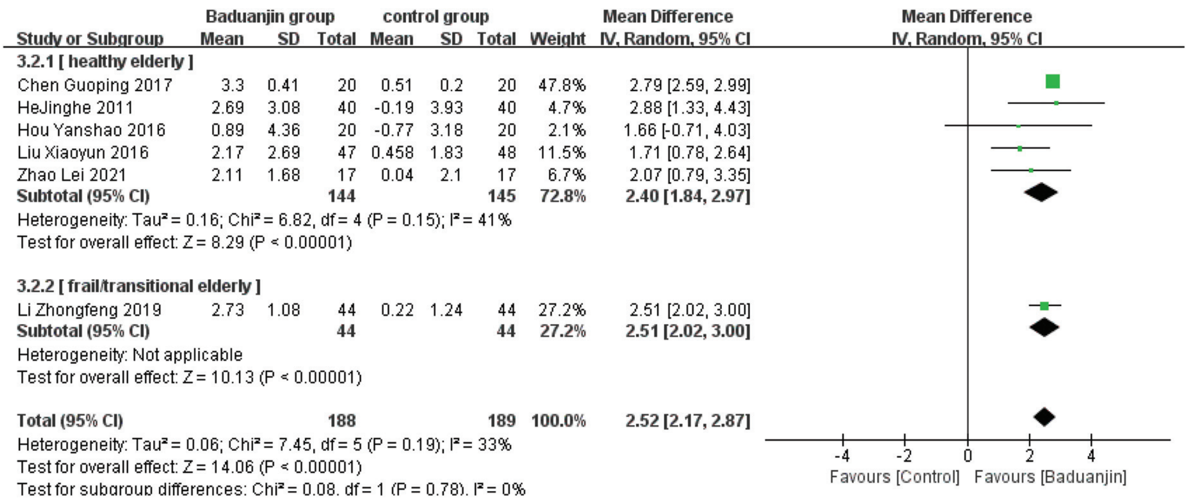

FIGURE 8
Forest plot of the subgroup analysis of ECLSB for the different health status. CI, confidence interval; SD, standard deviation.

Publication bias

Funnel plots showed that the distribution of research points on the BBS, TUG, and ECLSB indices were generally symmetrical (**Figures 12A–C**), suggesting that there was little likelihood of publication bias.

Discussion

Aging is associated with a decline of balancing ability caused by reductions in cognitive and motor function, increasing the likelihood of falls and associated injuries (28). Falls are one of the major cause affecting the QOL in the elderly. Muscle strength and balance are crucial elements of overall health, which help older adults lower their risk of falling. Practicing Baduanjin can increase flexibility and stability, as well as improving muscle strength and proprioception of the lower limbs (29).

As the outcome indicator for this systematic analysis, the measurement of BBS, TUG, and ECLSB is not complicated to conduct. BBS can systematically and quantitatively evaluate the balancing ability through a series of tests. TUG assesses the balancing ability of subjects in their daily activities by measuring the time required to sit up and walk. ECLSB measures vestibular function, hip flexion

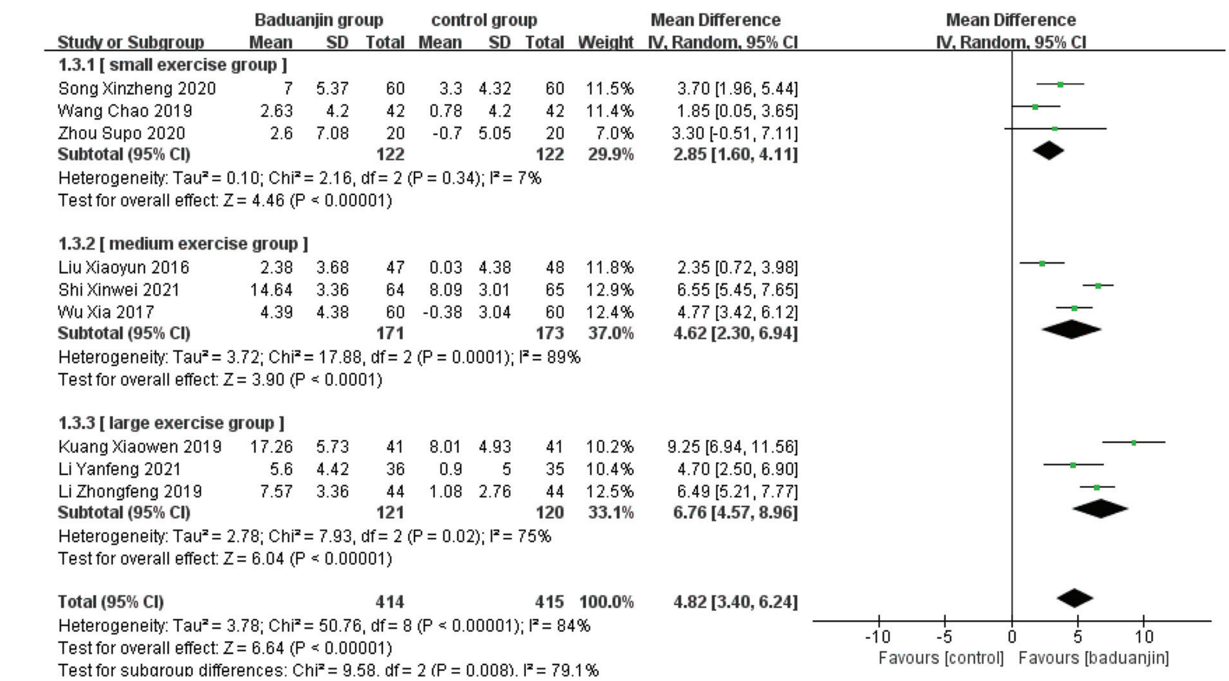

FIGURE 9
Forest plot of the subgroup analysis of BBS for the total exercise amount. CI, confidence interval; SD, standard deviation.

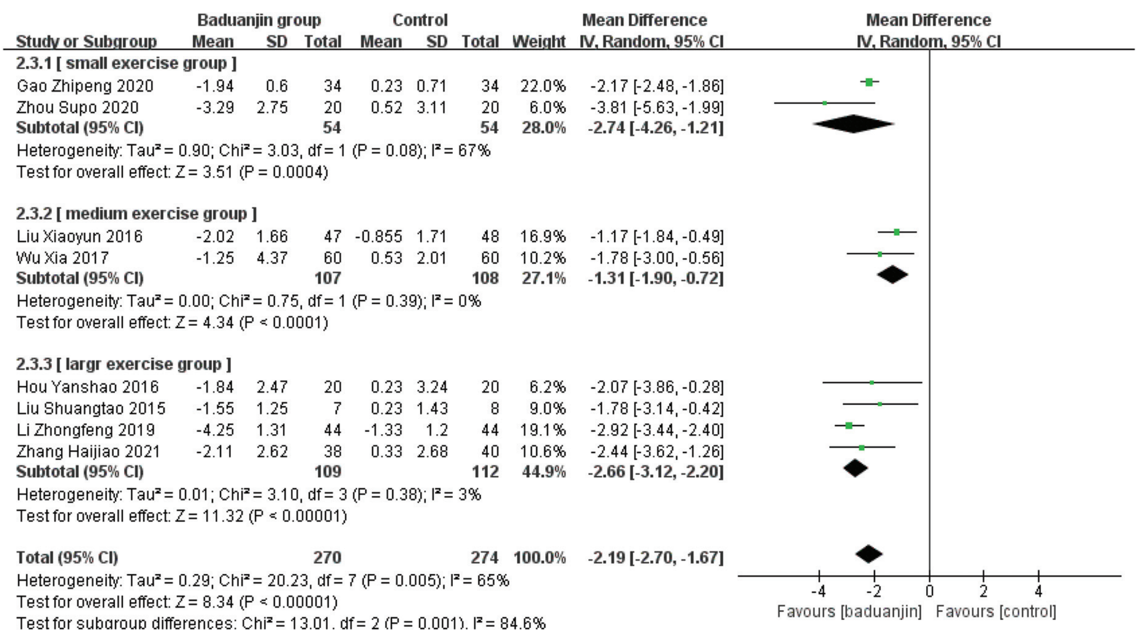

FIGURE 10
Forest plot of the subgroup analysis of TUG for the total exercise amount. CI, confidence interval; SD, standard deviation.

and extension muscle strength, with the subject's vision blocked. BBS and TUG were shown to have good reliability and validity in previous research (30, 31). Comparatively, the evaluation standard for ECLSB is easily affected by external factors (32). Systematic evaluation of these three indicators in the present meta-analysis demonstrates that

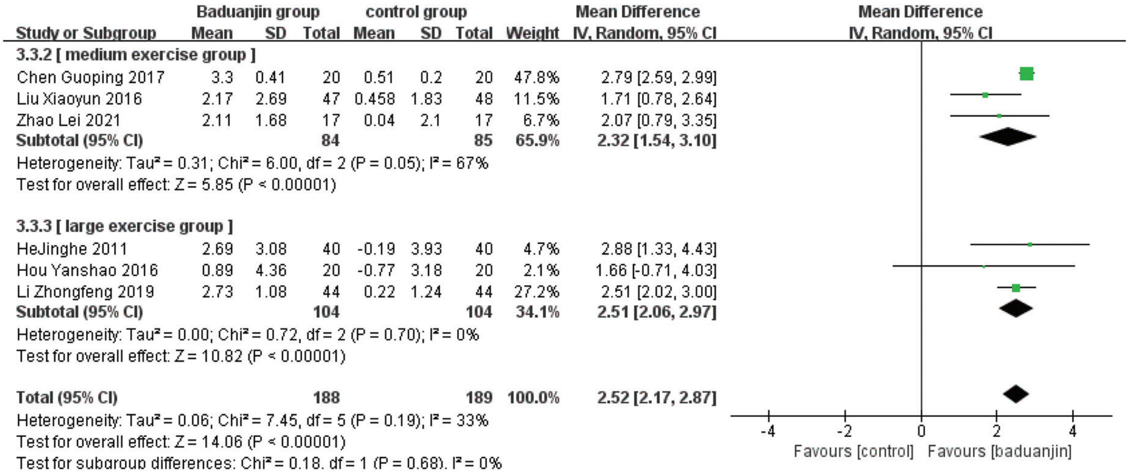

FIGURE 11
Forest plot of the subgroup analysis of ECLSB for the total exercise amount. CI, confidence interval; SD, standard deviation.

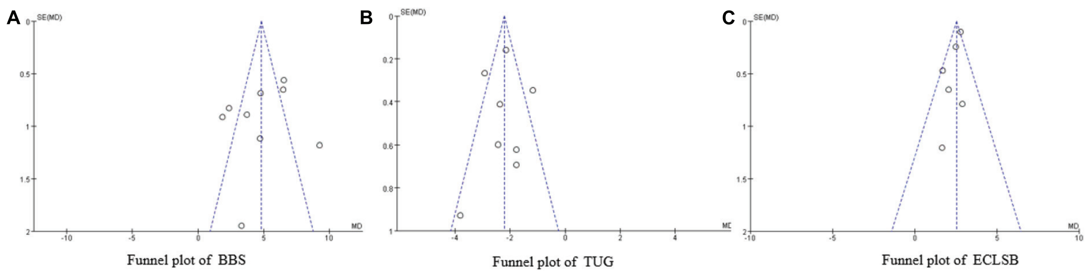

FIGURE 12
Funnel plots of BBS **(A)**, TUG **(B)** and ECLSB **(C)**. SE, standard error; MD, mean difference.

Baduanjin can effectively impact the balancing ability of older adults.

Physical flexibility and balance are strongly correlated, and increasing physical flexibility can enhance body coordination and balance, both of which are important factors in preventing falls (33). With regards to Baduanjin movements, it involves flexion and extension of the knee and ankles joints, internal and external rotation of the arms while keeping them flexed. Baduanjin exercise has been found to significantly enhance body flexibility in previous research (34).

In addition, some studies have examined how Baduanjin training affects the muscular strength in the lower limbs. Baduanjin's persistent half-squat position will present constant challenges to the body's balance and postural stability from the standpoint of its own movements. In particular, the feet must be level with the ground and cannot straddle the shoulder-width limit (similar to the oval area) (35). Some studies have demonstrated that Baduanjin exercise can significantly enhance spatial gait parameters such as stride length, walking speed, and stride frequency, which are also closely related to lower limb muscle strength and balance (36). After Baduanjin exercise, the vastus medialis muscle was found elevated, whereas the vastus lateralis muscle did not change significantly, by measuring the root mean square, integrated and average electromyogram (37). It's possible that the 16-week intervention period in the research is not long enough.

As for the impact by the factor of training duration, this meta-analysis also revealed that the improvement of balancing ability is positively related to total exercise amount. Following the subgroup analysis based on total exercise amount, the heterogeneity with the subgroup is reduced, and it is basically shown that the larger the exercise amount, the stronger the effect of intervention. Such result was consistent with another study on another popular Chinese traditional exercise—Tai Chi (38). In this meta-analysis, it was shown that the improvement in the Baduanjin group's BBS test followed the total exercise amount increased. But such a trend was not occurred in TUG and ECLSB. This outcome could be caused by the two factors. Firstly, the number of studies included in the analysis is relatively small, and the participant characteristics and intervention techniques used in each research varied from one another. In some studies, Baduanjin intervention was combined with other exercises such as balance or resistance exercise, while in some research older participants with specific medical issues, like stroke patients, were recruited. Secondly, when calculating the amount of exercise, it is defaulted that Baduanjin's intensity is universal. The included research, however, may cover inconsistent approaches to execute Baduanjin's intervention, such as instruction technique, movement modification, supervision process, etc., so the intensity could be altered. Although Baduanjin has a unified motion pattern when compared to various school of Taichi, the standard and quality of the movement completion could undoubtedly have an impact on the intensity of Baduanjin.

Baduanjin with low-to-moderate intensity is comparatively easy to learn and practice, making it ideal for improving balance in older persons. Besides the studies included based on the selecting criteria, the effect of Baduanjin on balancing ability of the elderly with varied health conditions has also been proved by numerous studies. In chronic stroke patients, Baduanjin is beneficial at enhancing balance, leg muscle strength, and flexibility. Additionally, Baduanjin can reduce the risk and frequency of falls in Parkinson's disease patients by strengthening the lower extremities and enhancing balance (39).

Subgroup analysis according to the health status showed that Baduanjin was advantageous for all the older participants. The indicator of BBS and TUG differed significantly between healthy and frail/transitional older subjects. It was found that the heterogeneity was obviously lower for the subgroup of healthy older subjects than the whole, indicating that one of heterogeneity source could be related to the variations in the participants' health status. In this study, the frail symptoms or diseases varied and only a small number of research examined frail or transitional older people. Thus, it was difficult to further evaluate and analyze each parameter because the pooled data on this subgroup had considerable heterogeneity and bias.

Limitation

Some limitations should be acknowledged. Firstly, there may be omissions of research because only the databases of PubMed, Web of Science, The Cochrane Library, CNKI, Wan Fang, and SinoMed were searched owing to the limited conditions. Of the 17 selected studies, only one was from a study published outside China. Thus, the findings may not be generalizable to other nations and ethnicities. Secondly, the papers of poor quality were included, which had the lack of description of the blind and random distribution methods, the absence of analysis on the gender variable, and/or the failure to indicate whether subjects were missing or not in some trails. Thirdly, because of large heterogeneity across the included studies, only the random-effect model could be used, which had an impact on the findings.

Conclusion

The current meta-analysis demonstrates that Baduanjin can enhance older adults' ability to balance and that the effect of the intervention may vary depending on the participants' health condition. In addition to further exploring the influencing factors of gender, age, and health status, more investigations are needed to determine the effects of Baduanjin on older adults from different cultures and ethnic groups.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

LG conceptualized and designed the study, coordinated and supervised data collection, and critically reviewed and revised the manuscript. ZL and WY collected data and wrote and revised the articles. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2022.995577/full#supplementary-material

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EDITED BY
Tzvi Dwolatzky,
Technion Israel Institute of Technology, Israel

REVIEWED BY
Vahid Rashedi,
University of Social Welfare and Rehabilitation Sciences, Iran
Jaquelini Betta Canever,
Federal University of Santa Catarina, Brazil

*CORRESPONDENCE
Xiaorong Ding
✉ 1442935193@qq.com

[†]These authors have contributed equally to this work and share first authorship

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Risk factors for falls among community-dwelling older adults: A systematic review and meta-analysis

Ying Li[1†], Lingyu Hou[2†], Hanping Zhao[1], Rongrong Xie[3], Yue Yi[4] and Xiaorong Ding[2*]

[1]School of Nursing, Weifang University of Science and Technology, Weifang, Shandong, China, [2]Nursing Department, Peking University Shenzhen Hospital, Shenzhen, China, [3]Wuxi Mental Health Center, Wuxi, Jiangsu, China, [4]Department of Neurology, Shandong Guoxin Senior Care Group Laiwu Central Hospital, Jinan, China

Background and objective: The prevalence of falls among older adults living in the community is ∼30% each year. The impacts of falls are not only confined to the individual but also affect families and the community. Injury from a fall also imposes a heavy financial burden on patients and their families. Currently, there are different reports on the risk factors for falls among older adults in the community. A retrospective analysis was used in this study to identify risk factors for falls in community-dwelling older adults. This research aimed to collect published studies to find risk factors for falls in community-dwelling older adults.

Methods: We searched for literature from the founding of PubMed, EMBASE, the Cochrane Library, the Web of Science, the China National Knowledge Infrastructure (CNKI), the China Science and Technology Periodicals Database (VIP), and the Wanfang database until September 2022. The studies were selected using inclusion and exclusion criteria. We collected information from relevant studies to compare the impact of potential risk factors such as age, female gender, fear of falling, history of falls, unclear vision, depression, and balance disorder on falls among community-dwelling older adults.

Results: A total of 31 studies were included with 70,868 community seniors. A significant risk factor for falls in the community of older adults was dementia (2.01, 95% CI: 1.41–2.86), age (1.15, 95% CI: 1.09–1.22), female gender (1.52, 95% CI: 1.27–1.81), fear of falling (2.82, 95% CI: 1.68–4.74), history of falls (3.22, 95% CI: 1.98–5.23), vision unclear (1.56, 95% CI: 1.29–1.89), depression (1.23, 95% CI: 1.10–1.37), and balance disorder (3.00, 95% CI: 2.05–4.39).

Conclusion: This study provides preliminary evidence that falls among community-dwelling older adults are associated with factors such as age, female gender, fear of falling, history of falls, unclear vision, depression, and balance disorders. The results of this research may help improve clinician awareness, risk stratification, and fall prevention among community-dwelling older adults.

Systematic review registration: identifier INPLASY2022120080.

KEYWORDS

community, older adults, risk factors, meta-analysis, systematic review

Introduction

With the advancement of society and medical and health standards, the older adults of the world (60 and older) now account for 12.3% of the total population. The average life expectancy has risen to 71 years (1). In 2018, China had 249 million people aged 60 and older, accounting for 17.9% of the total population, and approximately 167 million people aged 65 and older, accounting for 11.9% (2). The community serves as a place for older adults to live and participate in activities. According to the survey, roughly 84.5% of the older adults in the community choose a home or a combination of the community and the house for older adults.

Consequently, older adults are more inclined to fall inside the community and even at home (3). In community settings, the incidence of falls for men and women aged 65 and older ranges from 21 to 23% and from 43 to 44%, respectively (4). The community serves as a place for older adults to live and participate in activities. According to a survey, roughly 84.5% of the older adults in the community choose a home or a combination of the community and the house for older adults. Consequently, older adults are more inclined to fall inside the community and even at home (3). In Community Settings, the incidence of falls among men and women aged 65 and older was 21–23% and 43–44%, respectively (4). Falls are a leading cause of injury, related disability, and premature death among older adults (5). Injuries vary in severity, with 40–60% of falls resulting in severe lacerations, non-vertebral fractures, and traumatic head injuries (6). Prolonged lying after a fall can lead to dehydration, rhabdomyolysis, pressure sores, and pneumonia, all of which can increase hospital stays (7). Falls are also associated with successive radial, humerus, vertebral, and hip fractures (8). Approximately 95% of hip fractures are caused by falls (9). A previous study estimated that 10–20% of patients with hip fractures are admitted to nursing homes, and 20% die within 12 months (10, 11). In addition, falling can cause not only physical damage but also psychological damage (12). Falling can lead to a "fear" of falling. This "fear" can appear in 20–40% of people who fall, causing weakness and leading to a downward spiral in physical health that leads to functional decline, social isolation, and depression (12). The impacts of falls are not confined to the individual but affect families and the community. Injury from a fall also imposes a heavy financial burden on patients and their families. Fall injuries cost RMB ¥70 billion ($10 billion) in the United States and RMB ¥3.99 billion ($570 million) annually in the Netherlands, and per capita direct economic burden of China due to falls is 3,800 yuan (13–15). Falls in older adults can also result in disability, reduced quality of life, loss of independence, and hospitalization.

The risk of falls increases with the number of risk factors in each individual (16). According to the research, falls in older adults are multifactorial events involving internal (patient-related), external (environment-related), and behavioral (activity-related) aspects (17, 18). However, the sample size of each study was small, and the reported risk factors were inconsistent, so nursing professionals could not determine the risk factors for falls among older adults in the community. The meta-analysis reported pain, weakness, gait problems, dizziness, and age as risk factors for falls among older adults in the community (19–22). The reports on the relationship between poor vision and fall risk are inconsistent and controversial (23, 24). In recent years, some studies reported on the impact of risk factors such as dementia, bone and joint disease, and depression on falls of older adults in the community (25–29). However, it has yet to attract the attention of nursing professionals. To better prevent older adults from falling in the community, it is necessary to have a more comprehensive understanding of the risk factors leading to falls among older adults. This study aimed to systematically review the risk factors for falls among older adults in the community to comprehensively and systematically understand the risk factors among older adults and provide the basis for formulating relevant intervention measures.

Methods

A meta-analysis was conducted in adherence to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (30).

Data source collection

In PubMed, Web of Science, Embase, Cochrane Library, China National Knowledge Infrastructure (CNKI), Wanfang Data database, and Chinese Periodical database (VIP), a literature search was conducted to identify studies published as of September 2022 associated with risk factors for falls in older adults in the community. The search terms included "Elderly OR Aged or Older adults" and "Domicile OR Domiciles OR Community OR Communities OR Community Health Services OR Primary health care OR Characteristic, Residence OR Characteristics, Residence OR Residence Characteristic OR Residential Selection OR Residential Selections OR Selection, Residential OR Selections, Residential OR Neighborhood OR Neighborhoods OR Place of Birth OR Birth Place OR Living Arrangements OR Arrangement, Living OR Arrangements, Living OR Living Arrangement" and "Falls OR Falling OR Falls, Accidental OR Accidental fall OR fall, accidental OR Slip and Fall OR Fall and Slip" and "Risk factors OR Risk factor OR Relevant factors OR Influencing factor." Table 1 shows the search strategy in the PubMed database. The

TABLE 1 Search strategy in PubMed database.

Number	Search terms	Results
#1	((elderly[MeSH Terms]) OR (aged[MeSH Terms])) OR (older adults[MeSH Terms])	3,423,715
#2	((((((((((((((((((Domicile[MeSH Terms]) OR (Domiciles[MeSH Terms])) OR (Community[MeSH Terms])) OR (Communities[MeSH Terms])) OR (Community Health Services[MeSH Terms])) OR (Primary health care[MeSH Terms])) OR (Characteristic, Residence[MeSH Terms])) OR (Characteristics, Residence[MeSH Terms])) OR (Residence Characteristic[MeSH Terms])) OR (Residential Selection[MeSH Terms])) OR (Residential Selections[MeSH Terms])) OR (Selection, Residential[MeSH Terms])) OR (Selections, Residential[MeSH Terms])) OR (Neighborhood[MeSH Terms])) OR (Neighborhoods[MeSH Terms])) OR (Place of Birth[MeSH Terms])) OR (Birth Place[MeSH Terms])) OR (Living Arrangements[MeSH Terms])) OR (Arrangement, Living[MeSH Terms])) OR (Arrangements, Living[MeSH Terms])) OR (Living Arrangement[MeSH Terms])	560,689
#3	((((((falls[MeSH Terms]) OR (falling[MeSH Terms])) OR (falls, Accidenta [MeSH Terms])) OR (accidental fall[MeSH Terms])) OR (fall, accidental[MeSH Terms])) OR (Slip and Fall[MeSH Terms])) OR (Fall and Slip[MeSH Terms])	27,698
#4	(((risk factors[MeSH Terms]) OR (risk factor[MeSH Terms])) OR (relevant factors[MeSH Terms])) OR (influencing factor[MeSH Terms])	940,556
#5	(((#1) AND (#2)) AND (#3)) AND (#4)	711

complete search strategies for all databases are available in Supplementary material 1.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) the study was an observational study that could be a cross-sectional, cohort, or case-control study; (2) the older adults in the community were in fact the research participants; (3) data on fall risk factors in community-dwelling older adults with 95% confidence intervals (95% CI) or odds ratios were some of the outcome types (ORs); (4) the study which met the fall definition: an unexpected event in which the participant rests on the ground, floor, or lower level; and (5) types of comparison: comparisons of fall risk factors among community-dwelling older adults.

The following types of records were excluded: (1) replicated research data; (2) incomplete data; and (3) non-original studies (conference abstracts, editorials, letters, reviews, meta-analyses, commentaries, or case reports).

Data extraction

Two researchers independently screened the literature and extracted data according to the inclusion and exclusion criteria. In disagreements, the two parties discussed and resolved them or consulted experts. Data extraction contents included author, year, study type, number of cases and control groups, relevant risk factors, and so on.

Statistical analysis

Review Manager 5.3 was used for statistical analysis. $I^2 > 50\%$ or a $P < 0.1$ was considered significant for heterogeneity (31). For homogeneous data ($I^2 < 50\%$ or $P > 0.05$), the fixed-effects model was used to calculate the 95% CI and pooled ORs. The random-effects model was used in all other cases. Sensitivity analysis was carried out by eliminating one study at a time. When at least three study samples examined the same outcome measure, data were pooled and analyzed in random-effects meta-analysis models (32).

Quality assessment

To evaluate the quality of case-control studies and cohort studies, we used Quality Assessment Scale for Non-Experimental Studies (33), based on prospective cohort studies and retrospective case-control studies, using an adapted Newcastle-Ottawa Scale (34) (the Newcastle-Ottawa Scale, NOS), including study population selection (comparability, exposure, or outcomes); cross-sectional studies were assessed using the AHRQ-recommended quality evaluation criteria (35).

Results

Study selection

Through the database, a total of 7,263 related literature were retrieved and a total of 2,156 repeated literature were removed. After further reading the full-text, 5,076 pieces of literature were eliminated and 31 types were finally included (25–29, 36–61), totaling 70,868 study subjects. The study and characteristics of the participants are shown in Table 2.

TABLE 2 Study and characteristics of the participants.

Study	Year	Country	Type of study	Male/ Female	N	Quality assessment	Risk factors
Xu et al. (25)	2016	China	Cross-sectional study	656/566	1,222	8	Dementia: 1.732 (1.466, 3.835); Age: 1.459 (1.295, 1.714)
Qin et al. (26)	2006	China	Cross-sectional study	619/893	1,512	8	Dementia: 4.89 (1.31, 18.27); Fear of falling: 2.12 (1.51, 2.97)
Shi et al. (36)	2013	China	Cross-sectional study	183/289	472	7	Fear of falling: 2.23 (1.47, 3.85)
Shi et al. (27)	2016	China	Cross-sectional study	619/893	1,512	8	Female: 1.56 (1.12, 2.18); Fear of falling: 1.72 (1.41, 2.10)
Ji et al. (37)	2012	China	Cross-sectional study	495/585	1,080	8	Age: 2.395 (1.902, 3.001); Fear of falling: 1.433 (1.12, 1.833)
Xie et al. (38)	2019	China	Cross-sectional study	301/481	782	7	Age: 1.325 (1.259, 1.9); Female: 1.252 (1.131, 1.387); Vision Unclear: 3.027 (2.354, 3.636)
Shen et al. (39)	2020	China	Cross-sectional study	400/212	612	7	Age: 1.717 (1.21, 2.438); Female: 1.888 (1.328, 2.685); Osteoporosis: 3.378 (2.399, 4.755)
Wan et al. (28)	2018	China	Cross-sectional study	719/867	1,586	7	Dementia: 2.092 (1.18, 3.702) Age: 1.311 (1.114, 1.543)
Kyrdalen et al. (29)	2017	Norway	Cross-sectional study	41/67	108	8	Depression: 1.31 (1.09, 1.58); History of falls: 3.7 (1.18, 11.65)
Lastrucci et al. (40)	2018	Italy	Array research	NA	1,220	7	Age: 1.03 (1.01, 1.05)
Gamage et al. (41)	2019	Sri Lanka	Cross-sectional study	125/175	300	8	Age: 0.1 (0, 0.3); Balance disorder: 4.2 (2, 8.4)
Jindal et al. (42)	2019	India	Cross-sectional study	273/213	486	7	Depression: 1.62 (1.04, 2.51)
Stalenhoef et al. (43)	2002	Netherlands	Cross-sectional study	115/172	287	8	Age: 1 (0.5, 2.2); Female: 0.7 (0.3, 1.5); History of falls: 3.1 (1.5, 6.7)
Shi et al. (44)	2014	China	Cross-sectional study	289/173	462	7	Age: 2.2 (1.37, 3.53)
Sai et al. (45)	2001	USA	Cross-sectional study	89/48	137	7	Depression: 1.19 (1.02, 1.38); History of falls: 3.85 (1.56, 9.5)
Ooi et al. (46)	2021	Malaysia	Prospective cohort study	840/838	1,678	8	Female: 1.57 (1.04, 2.36); History of falls: 1.86 (1.19, 2.92); Depression: 1.1 (1.02, 1.2)
Carrasco et al. (47)	2018	Spain	Cross-sectional study	113/395	508	8	Female: 1.724 (1.069, 2.782); Depression: 0.763 (0.463, 1.258); Osteoporosis: 0.751 (0.414, 1.363)
Jia et al. (48)	2017	China	Cross-sectional study	1,578/1,619	3,197	8	Vision unclear: 1.43 (1.13, 1.82); Osteoporosis: 1.81 (1.04, 3.13); Balance disorder: 2.65 (1.477, 4.754)
Almada (49)	2020	Portugal	Cross-sectional study	NA	4,1098	9	Age: 1.257 (1.128, 1.402); Female: 1.313 (1.208, 1.426); Fear of falling: 3.747 (3.443, 4.078)
Almada et al. (50)	2021	Thailand	Cross-sectional study	223/239	462	7	Age: 1.07 (1.04, 1.11); Female: 3.83 (2.39, 6.13); Fear of falling: 30.09 (14.65, 61.77)
Lu et al. (51)	2016	China	Cross-sectional study	701/899	1,600	8	History of falls: 9.488 (6.544, 13.757)

(Continued)

TABLE 2 (Continued)

Study	Year	Country	Type of study	Male/ Female	N	Quality assessment	Risk factors
Pellicer-García et al. (52)	2020	Spain	Cross-sectional study	44/169	213	7	Age: 1.092 (1.015, 1.176); Depression: 11.24 (4.169, 30.302)
Lin et al. (53)	2011	China	Cross-sectional study	704/673	1,377	8	Age: 1.03 (1, 1.06); Female: 1.94 (1.36, 2.76)
Teno et al. (54)	1990	USA	Case control study	NA	586	8	Age: 1.06 (1.02, 1.1); Female: 1.3 (0.8, 2.4); Vision Unclear: 1.7 (0.6, 4.8)
Liao et al. (55)	2012	China	Cross-sectional study	534/631	1,165	8	Age: 1.03 (1.01, 1.06); Female: 0.64 (0.46, 0.89)
Tsai et al. (56)	2020	China	Cross-sectional study	1,523/1,677	3,200	9	Age: 1.13 (0.81, 1.58);Female: 0.93 (0.72, 1.2); Vision Unclear: 1.92 (1.36, 2.72); Depression: 1.45 (1.06, 1.98)
Fong et al. (57)	2011	China	Retrospective cross-sectional study	116/483	559	7	Female: 2.5 (1.29, 4.83)
Tinetti et al. (58)	1995	USA	Cohort study	299/804	1 103	8	Female: 1.9 (1.1, 3.1)
Shuyi et al. (59)	2022	China	Prospectively study	106/145	251	7	Female: 2.71 (1.4, 5.27); Balance disorder: 2.6 (1.29, 5.24)
Leung et al. (60)	2009	China	Cross-sectional survey	619/954	1,573	8	Vision unclear: 1.29 (10.2, 1.62)
Wong et al. (61)	2013	Australia	Prospective study	258/264	520	7	Female: 1.05 (0.73, 1.49)

Characteristics of the studies

The included studies were published from 1995 to 2022: one study in Norway, one in Italy, one in Sri Lanka, one in India, one in the Netherlands, three in the USA, two in Spain, one in Australia, one in Thailand, one in Portugal, one in Malaysia, and seventeen in China. The sample sizes included in the study ranged from 251 to 41,098. The flow diagram is shown in Figure 1.

Falls risk factors

Dementia

The relationship between dementia and the risk of falls in the community was reported in three studies. Dementia significantly impacts falls (2.01, 95% CI: 1.41–2.86, Z = 3.86, p = 0.0001), and heterogeneity is negligible (I^2= 6%) (Figure 2A).

Age

A link between age and the risk of falls in the community was reported in 16 studies. Age significantly affected falls (1.15, 95% CI: 1.09–1.22, $Z = 5$, $p < 0.00001$). There is a high degree of heterogeneity (I^2= 92%) between studies. Therefore, these studies were grouped by region, type of study, and gender, but the results were still highly heterogeneous (Figure 2B).

Female gender

Associations between women and the risk of falls in their communities are reported in 16 studies. Older women had a significant impact on falls (1.52, 95% CI: 1.27–1.81, Z = 4.56, $p < 0.00001$), and heterogeneity was negligible (I^2= 84%). There was a high degree of heterogeneity between studies. Therefore, these studies were grouped by region and type of study, but the results were still highly heterogeneous (Figure 2C).

Fear of falling

The relationship between fear of falling and the risk of falls in the community was reported in six studies. Fear of falling has a significant impact on falls of older

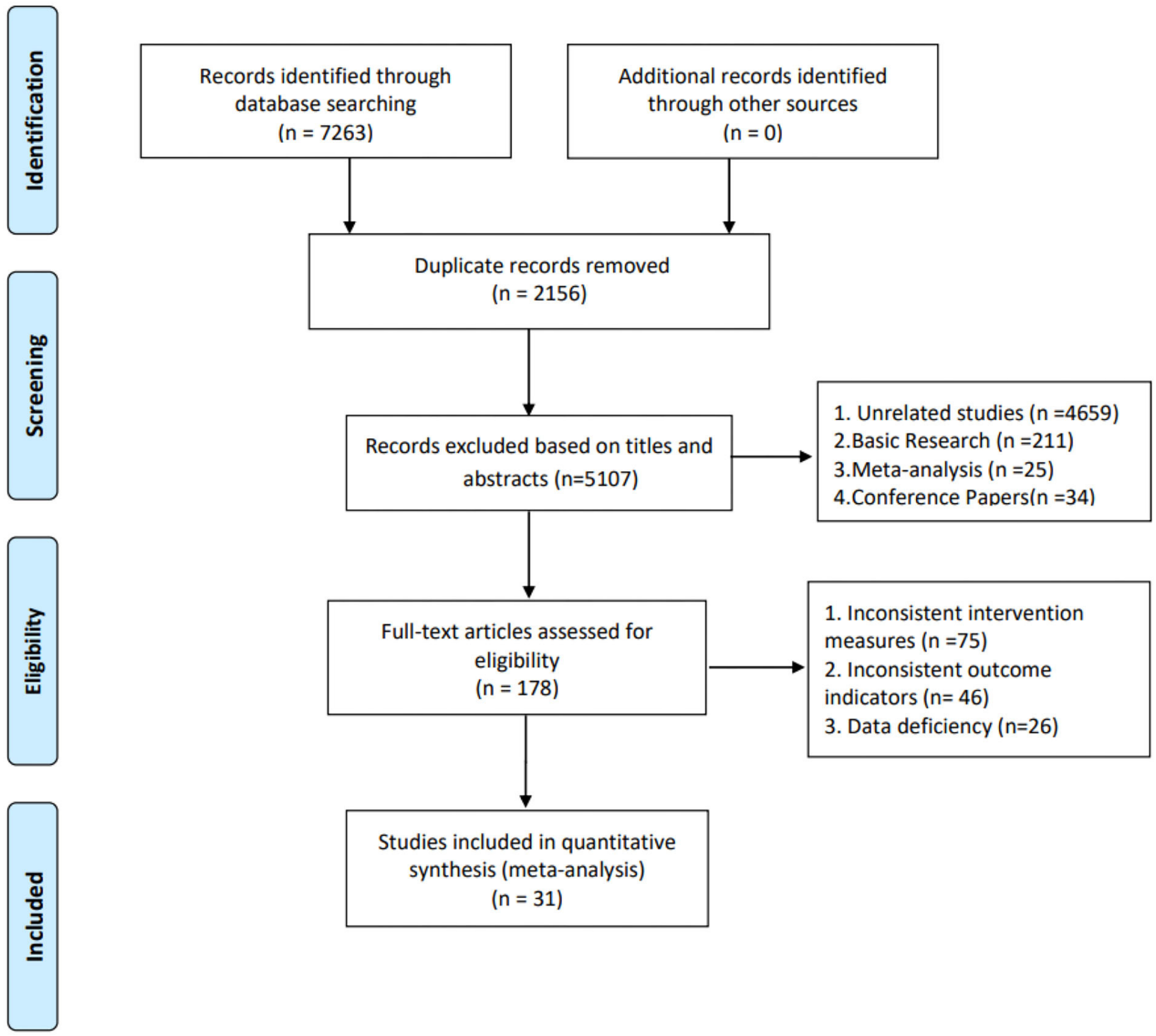

FIGURE 1
Flow diagram.

adults in the community (2.82, 95% CI: 1.68–4.74, Z = 3.91, $p < 0.0001$), and there is a high degree of heterogeneity between studies (I^2= 97%). Therefore, these studies are grouped by region, research type, and gender, but the results are still highly heterogeneous (Figure 3A).

History of falls

The relationship between past falls and community fall risk was reported in five studies. The study had direct heterogeneity (I^2= 68%). After sensitivity analysis, the study of Lu et al. (51) was excluded. History of falls significantly impacts the falls of older adults in the community (3.22, 95% CI: 1.98–5.23, $Z = 4.72$, $p < 0.0001$, I^2= 0) (Figure 2B).

Vision unclear

The relationship between visual impairment and fall risk in the community was reported in five studies. The study had direct heterogeneity (I^2= 68%). After sensitivity analysis, the study of Xie et al. (38) was excluded. The study found that visual impairment significantly impacted falls of older adults in the community (1.56, 95% CI: 1.29–1.89, $Z = 4.63$, $p < 0.00001$, I^2= 0) (Figure 2C).

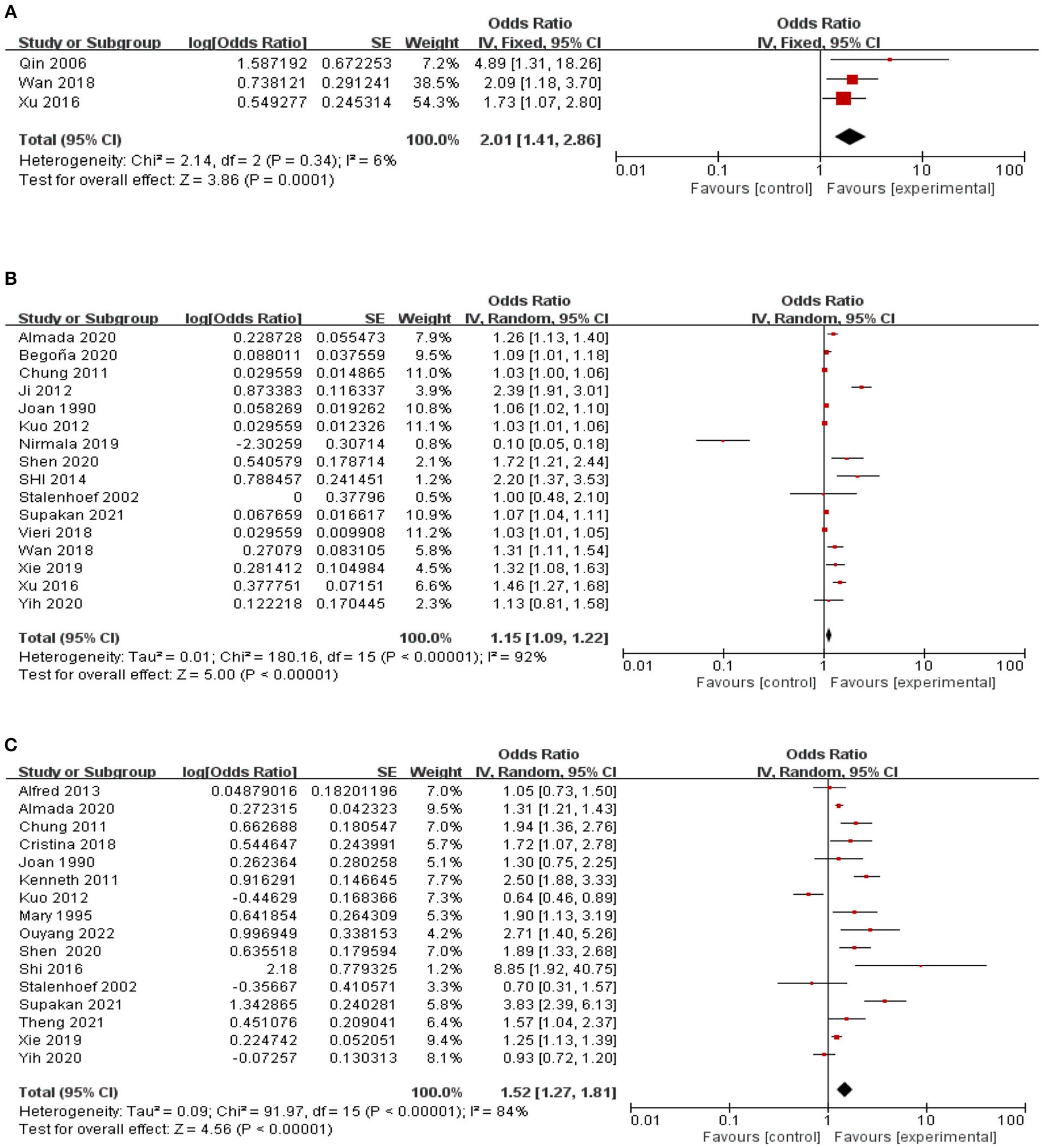

FIGURE 2
A forest plot for the association between falls among community-dwelling older adults. **(A)** Dementia. **(B)** Age. **(C)** Female.

Depression

The relationship between depression and community fall risk was reported in seven studies. The study had heterogeneity (I^2=70%). After sensitivity analysis, the study of Begoña et al. (52) was excluded. The study found that visual impairment significantly impacted falls of older adults in the community (1.23, 95% CI: 1.10–1.37, Z = 3.66, p = 0.0003, I^2= 12%) (Figure 4A).

Osteoporosis

The association between osteoporosis and the risk of falls among older people in the community was reported in three studies. Osteoporosis has no significant impact on the fall risk of middle-aged and older adults in the community (1.71, 95% CI: 0.71–4.08, Z = 1.20, p = 0.23), with high heterogeneity (I^2= 89%) (Figure 4B).

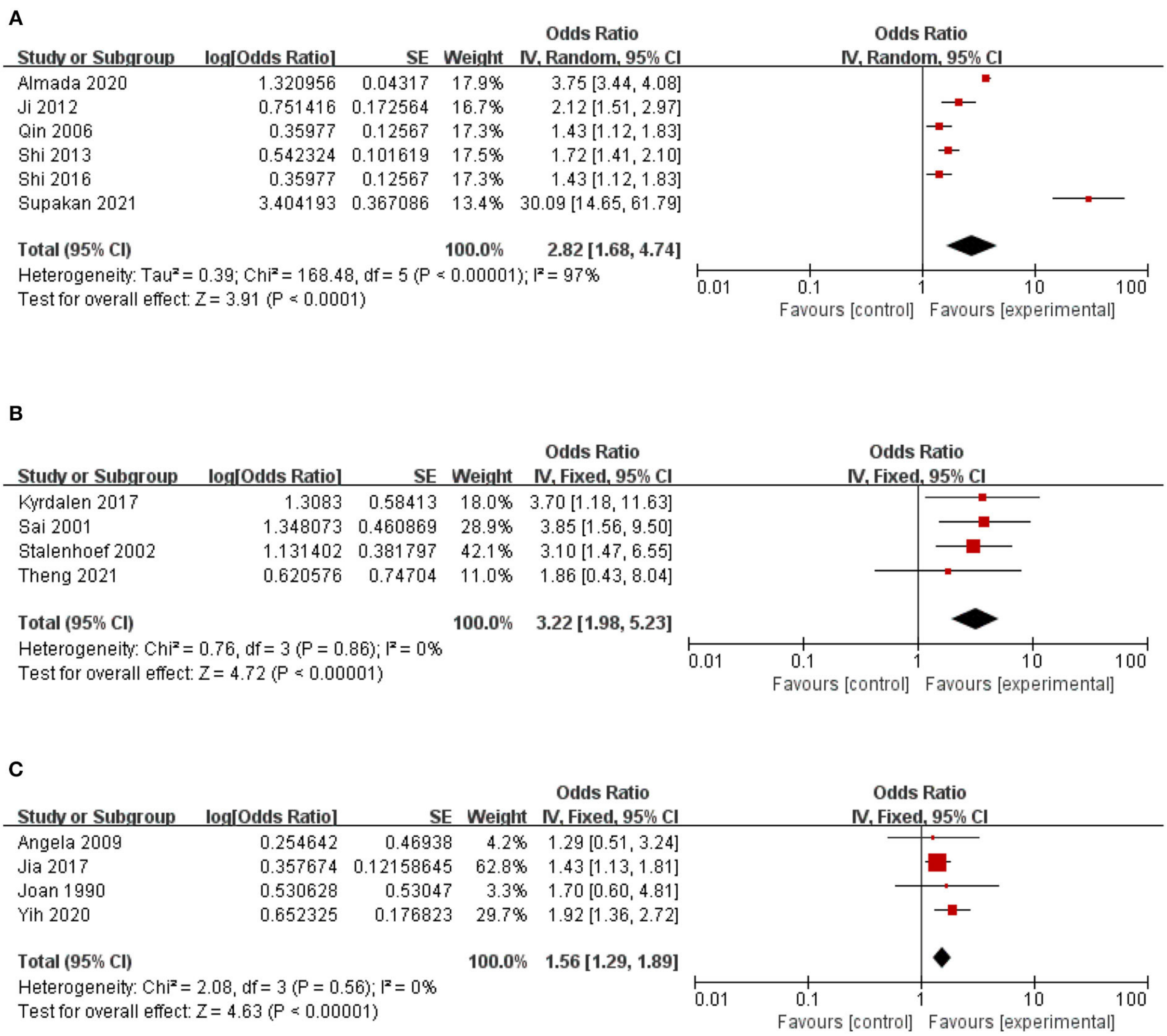

FIGURE 3
A forest plot for the association between falls among community-dwelling older adults. **(A)** Fear of falling. **(B)** History of falls. **(C)** Vision Unclear.

Balance disorder

The relationship between balance disorders and the risk of falls in the community was reported in three studies. Balance significantly impacts falls (3.00, 95% CI: 2.05–4.39, $Z = 5.66$, $p < 0.00001$, $I^2 = 0$) (Figure 4C).

Sensitivity analysis

In the analysis of visual impairment, history of falls, and depression, we conducted a sensitivity analysis by excluding each study one by one to explore whether a study significantly affected the results or contributed to heterogeneity. We found that the results were not affected by any research, and our meta-analysis was relatively robust. However, after excluding the studies of Xie et al. (38), Lu et al. (51), and Begoña et al. (52) the heterogeneity was significantly reduced, indicating that these two studies were the primary sources of the heterogeneity of visual impairment and depression.

Bias assessment

Finally, funnel plots were constructed to qualitatively analyze the publication bias among the included studies. Fall risk factors for women and older people in the community were

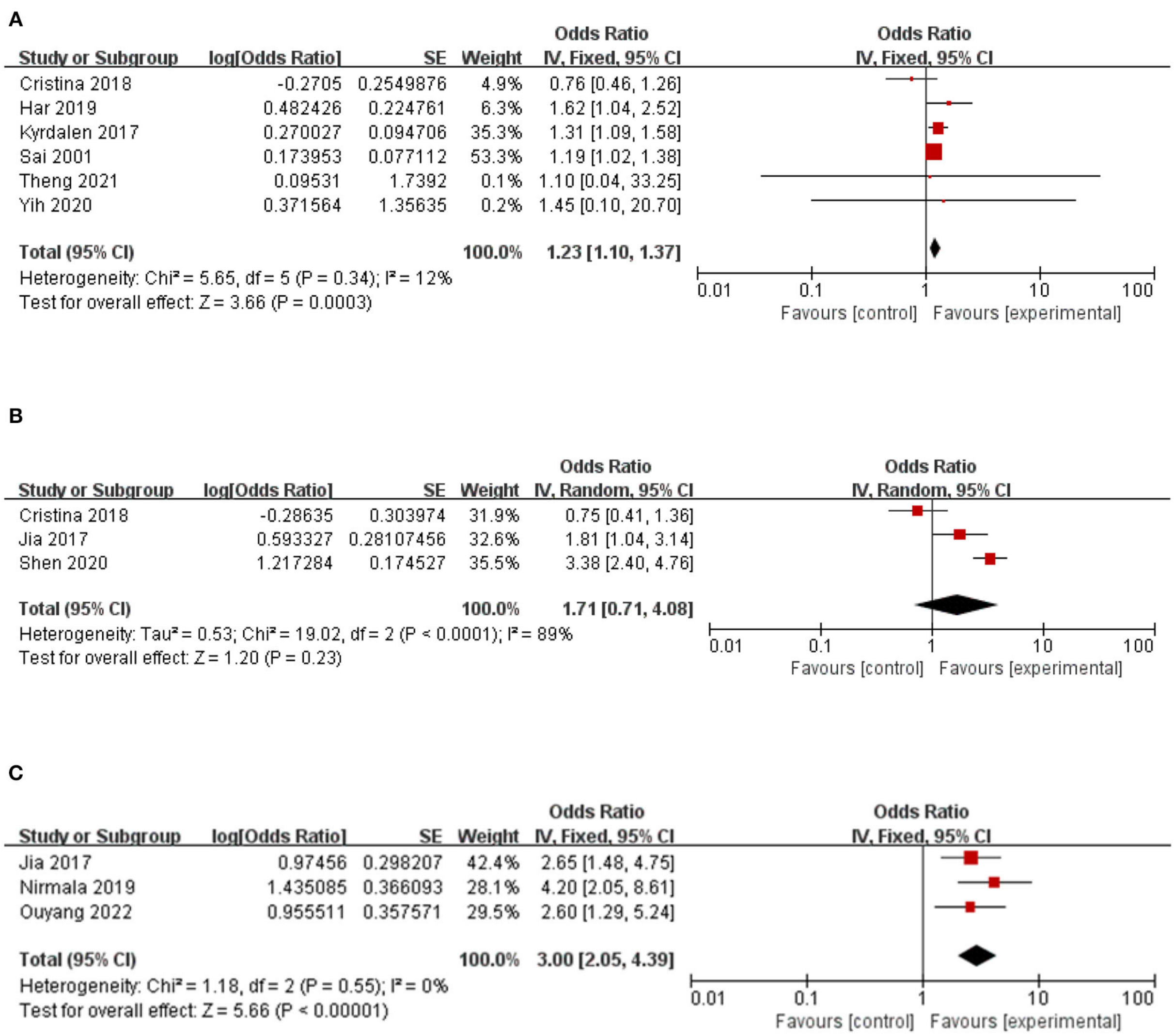

FIGURE 4
A forest plot for the association between falls among community-dwelling older adults. **(A)** Depression. **(B)** Osteoporosis. **(C)** Balance disorder.

used as examples. The funnel diagram shows a symmetrical distribution without apparent publishing deviation (Figure 5).

Discussion

An analysis of the included studies found that the risk factors for falls among older adults in the community are fear of falling, age, female gender, balance disorder, dementia, depression, previous falls, and unclear vision. This study found that fear of falling was closely related to falls among older adults in the community, which was consistent with the results of Sousa et al. (62). Studies showed that fear of falling and other fall-related psychological problems are common among older adults in the community and nursing homes after falls (63). The fear of falling often reduces activities in older adults, which weakens muscle strength and increases the risk of falling, increasing the fear of losing and forming a vicious circle (64). A research report pointed out that the fear of falling among older adults in the Chinese community is 41–5%, and the incidence of fear of loss among older adults in older adult care institutions is 79.4% (65, 66). According to this study, older adults should receive proper psychological intervention following a fall to reduce the psychological fear of losing and avoid falling again. This study identified age as a risk factor for falls in older people. The higher the age, the greater the risk of falling. This result is consistent with Sousa et al. (62) and Deandrea et al. (19). Because of the potential for the age-related decline, position senses, hearing, visual, and physical functions of older adults will all deteriorate. Moreover, older adults are frequently accompanied by a variety

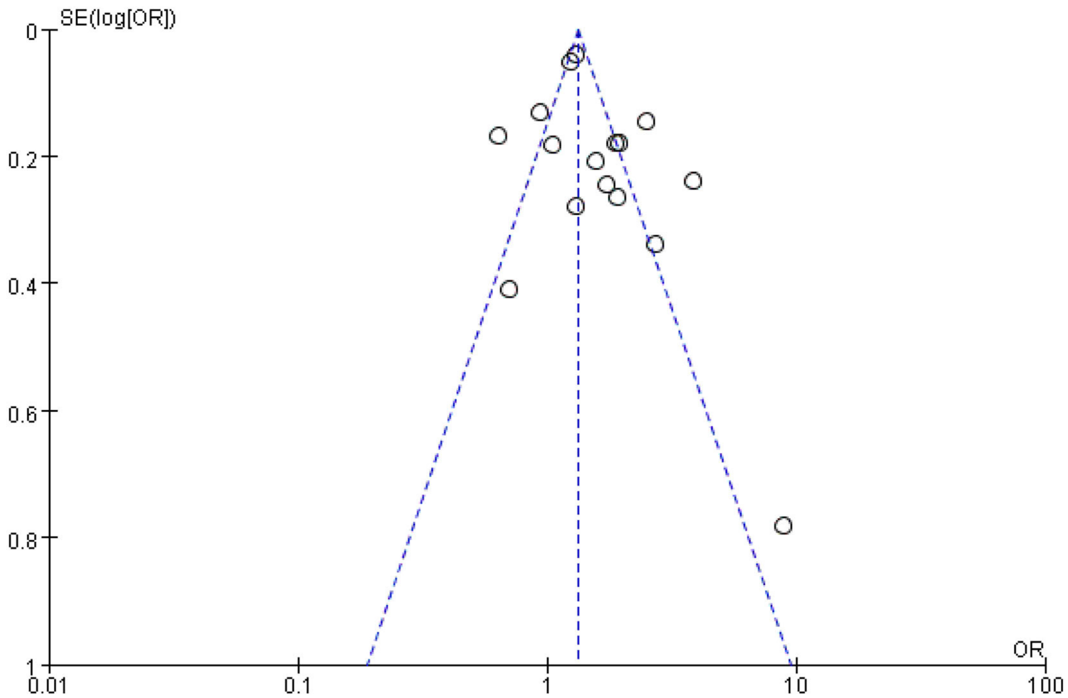

FIGURE 5
Publication bias of women.

of chronic diseases. The presence of chronic diseases will impair the cognitive and balance abilities of older adults, increasing the risk of falls in older adults. Therefore, it is reasonable to believe that aging and falls among more senior adults in the community are mutually causal.

This study found balance disorders to be a risk factor for falls in community-dwelling older adults. This result was not reported in the studies of Sousa et al. (62), Deandrea et al. (19), and Chantanachai et al. (32). According to King et al., the age of 60 is a watershed in balance ability. After 60 years, the balance ability of older adults declines by 16% every 10 years, and the risk of falls also increases (67). With the increase in age, the aging of the bodies of older adults leads to weakened muscle strength and decreased joint flexibility, resulting in damage to the balance function, which will directly affect the mobility of older adults. Older adults with good balance ability have strong lower extremity muscles, high physical sensitivity, quick responses, and a low probability of falling.

In contrast, older adults with poor balance experience lower extremity weakness and reduced physical sensitivity, which increases the risk of falls (68). In addition, this study found that depression is a risk factor for falls in older adults in the community. Considering that it may be related to unstable emotions, depression weakens the attention of older adults, resulting in a decline in their ability to respond to and perceive environmental risk factors, increasing the risk of falling.

In addition, this study identified a history of falls, visual impairment, and dementia as risk factors for falls among older adults in the community. A history of falls is a risk factor among older adults in the community, and this result has not been reported in Chantanachai et al. (32) study. When comparing the older adult patients who fell in the past 6 months with the matched group who did not fall, 57% of the falls were unable to walk at the fastest speed, with short steps and small lateral swings (69). Compared with non-falling people, the variability of kinematic measurement in falling people increases (69). The changes in these actions reflect the limitation of mobility and increase the risk of falls in older adults. Older adults with a history of falls are also associated with higher symptoms of depression and anxiety (70), thus increasing the risk of falls in older adults. This study confirms that older adults with a visual impairment are 1.56 times more likely to fall than those without a visual impairment. This result is not reported in Jehu et al. (22) and Stubbs et al. (21). In the case of insufficient visual input, the ability to balance control and obstacle avoidance will be impaired due to misjudgment of distance and misunderstanding of spatial information. It has been found that impaired depth perception is one of the essential visual risk factors for older adults living in communities to fall repeatedly (71). Postural stability is a complex skill that depends on the coordination of the motor and sensory systems to perceive environmental stimuli and respond to disturbances to control body movements (72, 73). Dementia can reduce cognitive ability and gait stability, affect the ability of older adults to cope with the external environment, and increase the risk of falls in older adults.

Our findings found no association between osteoporosis and falls in older adults in the community. However, older adult patients with osteoporosis should be watched with alertness as it has been proven to be an essential risk factor for falls among older adults in the community (47). In older adult patients, calcium loss is high, and the decline of muscle content, strength, and function can significantly increase the risk of falls and fractures. Some countries, such as the United States, recommend screening for osteoporosis for all women ≥ 65 years of age (74). Therefore, we need to be more alert to osteoporosis. Similarly, the results of this meta-analysis showed that osteoporosis is not a risk factor for falls among older adults in the community, which may be because only a small sample study was included.

In conclusion, this systematic review and meta-analysis study provides strong evidence for the risk factors for falls among older adults in the community. We further confirmed that age, female gender, fear of falling, depression, visual impairment, dementia, and balance disorder increase the risk of falls for older adults in the community. In addition, the results of this study will help formulate the best practice guide for preventing falls among older adults in the community and provide a basis for establishing a prediction model.

Limitations

There were some limitations in the present study. First, the articles included in this study were meta-integrated, but some results included only 2–3 pieces, which may have resulted in selection bias. Second, individual heterogeneity exists in the populations included in the literature of this study regarding regions, races, and socioeconomic levels. Third, because few studies involve some risk factors, meta-analysis cannot be performed, and more large-scale studies are required. Therefore, it is necessary to conduct more carefully designed studies on the potential fall risk factors in community-dwelling older adults.

Conclusion

In conclusion, this meta-analysis identified some risk factors for community-dwelling older adults and provided a reference for preventing falls. However, more strictly designed studies are needed to substantiate our findings and identify practical measures for preventing falls.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YL and LH designed the study. RX and YY acquired, analyzed, and interpreted the data. XD, YL, YY, and HZ revised the manuscript. HZ plays the role of inspection, assistance and drafting the work or revising it critically for important intellectual content in the modification phase of the article. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2022.1019094/full#supplementary-material

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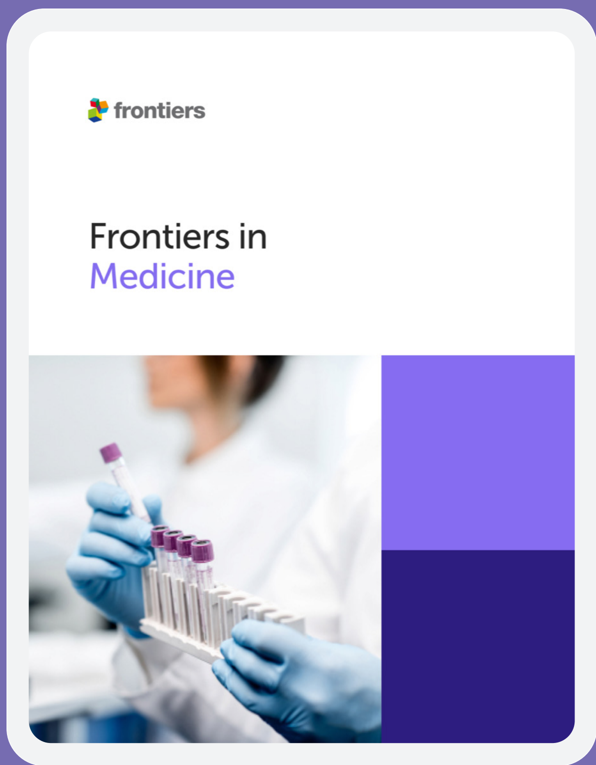

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