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The Importance of Frailty in Older Adults With Benign Paroxysmal Positioning Vertigo

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Background and Purpose: Even though Benign Paroxysmal Positioning Vertigo (BPPV) is one of the most reported vestibular disorders, its interaction with frailty and postural control in older adults is hardly or not investigated.

Methods: Thirty-seven older adults (≥65 years) with a diagnosis of BPPV (oaBPPV) (mean age 73.13 (4.8)) were compared to 22 age-, weight-, and height-matched controls (mean age 73.5 (4.5)). Modified Fried criteria were used to assess frailty. Postural control was assessed with the timed chair stand test, mini Balance Systems Evaluation test (mini-BESTest), a Clinical Test of Sensory Interaction on Balance (CTSIB), and 10-m walk test. Falls were inquired. The Dizziness Handicap Inventory, Falls Efficacy Scale, and 15-item Geriatric Depression Scale assessed dizziness-related handicap, fear of falling, and feelings of depression, respectively. To assess the importance of frailty, all variables were also compared between frail oaBPPV, robust oaBPPV, and robust controls in a subanalysis. The significance level was set at $\alpha = 0.05$.

Results: oaBPPV reported significantly more multiple falls ($P = 0.05$) and difficulties to remain standing with increasing task difficulty of the CTSIB ($P = 0.004$). They were significantly more (pre-)frail compared to controls ($P < 0.001$). Moreover, frail oaBPPV had a significantly decreased reactive postural control ($P < 0.001$) and dynamic gait ($P < 0.001$). Their fear of falling ($P < 0.001$) and dizziness-related handicap ($P < 0.001$) were significantly higher compared to robust oaBPPV.

Discussion and Conclusions: oaBPPV were less healthy and more (pre-)frail compared to controls, impacting their daily functioning. Future research should investigate whether frailty and postural control were already decreased before the BPPV onset and if this recovers after treatment with repositioning maneuvers or if additional rehabilitation is necessary.

Impact Statement: Older adults with Benign Paroxysmal Positional Vertigo (BPPV) can present with an impaired sensory orientation, declined cognition, significantly more multiple falls, and (pre-) frailty compared to controls. Moreover, frail older adults with BPPV also had a significantly decreased reactive postural control and dynamic gait, and an increased odds of falling compared to robust controls. BPPV and frailty appear to be linked with each other, which cannot be ignored in future research and clinicians treating older adults with BPPV.

Key words: *balance, BPPV, falls, frailty, older adults*

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INTRODUCTION

Over half of the people who fall experience a vestibular disorder, with Benign Paroxysmal Positioning Vertigo (BPPV) being the second most prevalent one, after loss of vestibular function.[1]

BPPV is caused by dislodged otoconia from the utricle, which migrate into the semicircular canals of the vestibular organ. It has a 1-year prevalence of 3.4% in older adults.[2] Typical symptoms are attacks of vertigo, nausea, and balance problems, and it is diagnosed when nystagmus is provoked during a diagnostic maneuver of the affected semicircular canal.[3] However, older adults with BPPV (oaBPPV) may present with atypical symptoms such as general dizziness and lightheadedness between attacks.[4,5] Therefore, BPPV may go unrecognized, leading to a delay in diagnosis[6] and a possible vicious cycle of increased fear of falling, activity avoidance, slowness or weakness, and eventually frailty. Frailty is defined as a biological syndrome marked by age-related decline in body mass, strength, endurance, gait speed,

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and physical activity.[7] It is a high-risk state for adverse health outcomes and predicts an increased incidence of disability, hospitalization, and mortality.[7]

BPPV and frailty can both increase the odds of falling and negatively impact postural control.[5,7] Postural control (maintaining or regaining the center of mass within the base of support) involves an active alignment of the body with respect to the gravity and support surface, integration and weighting of sensorimotor strategies to stabilize the body's center of mass during internal and external perturbations. According to Horak et al, 6 components contribute to the maintenance of postural control: (1) biomechanical constraints, (2) verticality and limits of stability, (3) transitions and anticipatory postural adjustments, (4) reactive postural responses, (5) sensory orientation, and (6) stability in gait.[8] To the best of our knowledge, only limits of stability[9] and sensory orientation[10] were previously investigated and found to be impaired in oaBPPV.

This study aimed to assess well-being, postural control, and falls in oaBPPV and the interaction between frailty and BPPV. It was expected that they would be more frail and have a higher fall incidence compared to controls. Additionally, they were predicted to have decreased postural control, particularly on tasks that require appropriate sensory orientation.

METHODS

This study was approved by the ethical committees of Hospital Oost-Limburg (ZOL Genk) and Hasselt University (B3712021000013) and complied with the declaration of Helsinki. It is registered in ClinicalTrials.gov (NCT03526653).

Participants

As part of a larger prospective study, community-dwelling older adults (≥65 years old) with a diagnosis of BPPV were recruited at the Department of Otorhinolaryngology of ZOL Genk, between September 2021 and July 2023. When a diagnosis of BPPV was made, they were screened for eligibility criteria and invited to participate. Inclusion criteria were: (1) a diagnosis of posterior or lateral semicircular canal BPPV (geotropic or apogeotropic variant) and not yet treated for the current episode of BPPV; (2) able to stand independently for at least 30 seconds; (3) able to walk with or without walking aid for at least 10 m. Exclusion criteria were: (1) unable to understand and follow simple instructions; (2) temporarily or permanently living in a residential or psychiatric care center, hospital, or rehabilitation center; (3) having contraindications for the diagnostic maneuvers (eg, reduced neck mobility) or caloric irrigation test (eg, tympanic membrane perforation); (4) having a neurodegenerative disorder; (5) in the rehabilitation phase after an acute medical condition; and (6) having a resolution of BPPV before data collection was completed.

An age-, weight- and height-matched control group of older adults (≥65 years) without BPPV was recruited via the network of participating patients or researchers and public invitations. With an exception for the presence of BPPV, the same eligibility criteria applied to the controls.

Study Design

The test battery for controls and oaBPPV was similar, except for the BPPV treatment (Supplemental Digital Content, Figure S1, available at: http://links.lww.com/JNPT/A497).

After given informed consent and a confirmed diagnosis of BPPV with video Frenzel goggles (VisualEyes 505 Video Frenzel system Interacoustics), demographic data (age, gender, weight, height, use of walking aid, sleeping pattern, comorbidities, and number of medications) were collected. The duration of their complaints of BPPV was inquired and classified as "some days," "several weeks," or "several months."

To assess frailty, Fried criteria (unintentional weight loss, self-reported exhaustion, slowness, weakness, and self-reported physical inactivity),[7] adjusted as proposed by Avila-Funes et al,[11] were used due to the feasibility within the larger protocol. Participants with 3 or more frailty components were considered "frail," those with 1 or 2 criteria were "prefrail," and those with none were considered "robust." Fall history ("Have you fallen in the past 12 months?") and number of falls were investigated. Reasons for falls were classified as dizziness, accidental, syncope, or unknown.

The Dizziness Handicap Inventory (DHI),[12] Falls Efficacy Scale-International (FES-I),[13] and 15-item Geriatric Depression Scale (GDS-15)[14] were filled out at home to assess dizziness-related handicap, fear of falling, and feelings of depression and discussed with the participant during the next session, maximum 7 days later.

During this session, the Montreal Cognitive Assessment (MOCA)[15] was administered to evaluate cognition, and postural balance was objectively measured with inertial sensors (APDM Wearable Technologies). The following tests and outcome parameters were used for the extensive postural control evaluation:

- Timed chair stand test[16]: the participant is asked to stand up from a chair 5 times as fast as possible with the arms held against the chest. Total time (s), sit-to-stand time (s), and stand-to-sit time (s) were derived with inertial sensors.
- mini Balance Evaluation Systems Test (mini-BESTest)[17]: the total score and subscores for anticipatory postural control, reactive postural control, sensory orientation, and dynamic gait were calculated. The following subitems were objectified with inertial sensors:
  - Timed up and go with and without dual-task (TUG and $TUG_{dual\text{-}task}$): total time (s), sit-to-stand time (s), stand-to-sit time (s), and turn duration (s). The dual-task cost was calculated as

$$\frac{\textit{dual task time} - \textit{single task time}}{\textit{single task time}} x\ 100$$ [18]

- 10-m walk test (10MWT) at preferred gait speed and with head turns (10MWHT): gait speed (m/s), cadence (steps/min), stride length (m), stride length SD, double support (% gait cycle time), gait cycle duration (s), and gait cycle duration SD. The mean of both feet was calculated.

- Unilateral stance: total time (s), sway area (m^2/s^4), mean velocity (m/s), path length (m/s^2), and range (m/s^2) of the longest trial of the worst side.
- The Clinical Test of Sensory Interaction on Balance (CTSIB)[19] assessed the relative contribution of the sensory systems to postural control during the following 6 standing conditions: (1) firm surface, eyes open (CTSIB1); (2) firm surface, visual dome (CTSIB2); (3) firm surface, eyes closed (CTSIB3); (4) foam surface, eyes open (CTSIB4); (5) foam surface, visual dome (CTSIB5); and (6) foam surface, eyes closed (CTSIB6). Total time (s), sway area (m^2/s^4), mean velocity (m/s), path length (m/s^2), and range (m/s^2) were derived.

All postural balance tests were performed without a walking aid.

After the assessment for postural control, the presence of BPPV was re-assessed with video Frenzel, and treatment with repositioning maneuvers (RM) was performed.

Statistics

Data analysis and graph creation were done using the IBM SPSS statistics software (v25.0 for Windows, SPSS Inc) and GraphPad Prism 10 (GraphPad Software, http://www.graphpad.com).

According to the power analysis (calculated on the mean difference [case-control] of center of pressure [COP] path length during CTSIB6),[10] a sample size of at least 22 participants in each group was needed to achieve 80% power at $\alpha = 0.05$.

Data were checked for normality with Shapiro-Wilk tests. Significant outliers were identified with Tukey's method[20] and excluded if necessary based on consensus. Continuous data were analyzed with unpaired *t* test and Mann-Whitney U test for normal and nonnormal distributed data, respectively. Categorial data were analyzed with the Pearson Chi-square test. Effect sizes for nonparametric tests were calculated as Cohen's *d* according to Fritz et al.[21]

To analyze a group-, condition-, and group X condition interaction effect for CTSIB, TUG and $TUG_{dual\text{-}task}$, and 10MW(H)T, linear mixed models were fit for each outcome to compensate for possible random missing values.[22] Results on condition effects are described in the Supplemental Digital Content, Text S2, available at: http://links.lww.com/JNPT/A497, since these are considered outside the scope of this paper. For the dual-task comparison, the MOCA score was entered as a covariate. The main effects are reported as *F* values and *P* values. A Bonferroni correction was used for post hoc comparisons within each mixed model.

Spearman rho was calculated for the correlation between frailty (total score and subscores) and duration of complaints in oaBPPV.

For fall incidence, the odds ratio (OR) and 95% confidence interval (CI) were calculated. The significance level was set at $\alpha = 0.05$.

To correct for multiple comparisons, the Holm-Bonferroni correction[23] was applied within the following groups: subjective well-being (DHI and subscales, FES-I and GDS-15), frailty (total score and subscores), mini-BESTest (total score and subscores), and each test for postural control separately.

To assess the importance of frailty, a sub-analysis was conducted that compared all variables between frail oaBPPV ($oaBPPV_{frail}$), robust oaBPPV ($oaBPPV_{robust}$), and robust controls ($controls_{robust}$). Continuous data were analyzed with 1-way analysis of variance (ANOVA) and Kruskal-Wallis test for normal and nonnormal distributed data, respectively. A correction for multiple post hoc comparisons was conducted with Tukey after 1-way ANOVA and Bonferroni after Kruskal-Wallis. All other statistics were similar as described previously. Results and *P* values are presented in Supplemental Digital Content, Tables S3-S9, available at: http://links.lww.com/JNPT/A497.

Quantitative variables are expressed as mean (SD), unless stated otherwise.

RESULTS

Thirty-seven oaBPPV (23 females, mean age 73.1 (4.8)) were compared to 22 controls (12 females, mean age 73.5 (4.5)) (Supplemental Digital Content, Figure S1, available at: http://links.lww.com/JNPT/A497). Groups were matched for gender ($P = 0.77$), age ($P = 0.77$), weight ($P = 0.25$), and height ($P = 0.16$), and a significant difference was found in the number of medications ($P = 0.007$) and cognition according to MOCA ($P < 0.001$) (Table 1). All walking aids were already used before the presence of BPPV.

The sub-analyses revealed that $oaBPPV_{frail}$, $oaBPPV_{robust}$, and $controls_{robust}$ were equally matched. However, $oaBPPV_{frail}$ had a significantly higher number of medications compared to $oaBPPV_{robust}$ and $controls_{robust}$. Both $oaBPPV_{frail}$ and $oaBPPV_{robust}$ performed significantly worse on the MOCA than $controls_{robust}$.

Frailty

Significantly more oaBPPV were frail or prefrail compared to controls ($P < 0.001$). They experienced more self-reported exhaustion ($P < 0.001$), slowness ($P = 0.001$), and weakness ($P = 0.005$). No differences were found in unintentional weight loss ($P = 0.19$) or physical inactivity ($P = 0.14$) (Table 2).

Frailty ($r_s = 0.18$, $P = 0.3$), unintentional weight loss ($r_s = -0.1$, $P = 0.56$), self-reported exhaustion ($r_s = 0.26$, $P = 0.13$), slowness ($r_s = -0.1$, $P = 0.54$), weakness ($r_s = -0.22$, $P = 0.21$), and self-reported physical inactivity ($r_s = 0.07$, $P = 0.69$) of oaBPPV did not correlate with the duration of symptoms.

Subjective Well-being

The DHI (total score and physical, emotional, and functional subscale) was significantly higher in oaBPPV compared to controls (34.9 (16.5) vs 2.0 (3.2)). oaBPPV also experienced significantly more fear of falling and feelings of depression according to the FES-I (27.6 (10.1) vs 18.2 (5.3)) and GDS-15 (2.8 (2.7) 1.2(1.3)) (Figure 1).

Sub-analyses revealed that the total score and functional subscale of the DHI were significantly different between the 3 groups ($oaBPPV_{frail} > oaBPPV_{robust} > controls_{robust}$). The

Table 1. Subject Characteristics

Characteristics	oaBPPV	Control	*P* Value
N (F/M)	37 (23/14)	22 (12/10)	0.77
Age	73.1 (4.8)	73.5 (4.5)	0.77
Weight, kg	76.8 (11.3)	73.6 (8.5)	0.25
Height, m	1.7 (0.1)	1.7 (0.1)	0.16
BPPV			**<0.001**
RPSCC (n)	14	0	
LPSCC (n)	15	0	
Bilateral PSCC	4	0	
RLSCC geotropic (n)/ apogeotropic (n)	1/ 3	0	
LLSCC geotropic (n)/ apogeotropic (n)	1/ 0	0	
No BPPV (n)	0	22	
Duration of complaints			**<0.001**
Some days (n)	3	0	
Several weeks (n)	5	0	
Several months (n)	29	0	
No complaints (n)	0	22	
Walking aid			0.19
None (n)	33	22	
Crutch (n)	3	0	
Walker (n)	1	0	
Sleeping pattern			0.21
Good (n)	20	14	
Restless (n)	12	5	
Long time needed to fall asleep (n)	2	2	
Restless + long time needed (n)	3	0	
Number of comorbidities	2.9 (1.5)	2.4 (1.3)	0.1
Number of medications	5.1 (2.7)	3.3 (2.7)	**0.007**
MOCA total score	23.5 (3.8)	26.8 (2.5)	**<0.001**

Abbreviations: oaBPPV, older adults with BPPV; BPPV, Benign Paroxysmal Positioning Vertigo; Control, older adults in control group; F, female; LLSCC, left lateral semicircular canal BPPV; LPSCC, left posterior semicircular canal BPPV; M, male; MOCA, Montreal Cognitive Assessment Scale; RLSCC, right lateral semicircular canal BPPV; RPSCC, right posterior semicircular canal BPPV.

Significant differences are indicated in bold.

emotional and physical subscale was significantly higher in $oaBPPV_{frail}$ and $oaBPPV_{robust}$ compared to $controls_{robust}$. The FES-I also significantly differed between the 3 groups ($oaBPPV_{frail}$ > $oaBPPV_{robust}$ > $controls_{robust}$). $oaBPPV_{frail}$ experienced significantly more feelings of depression compared to $oaBPPV_{robust}$ and $controls_{robust}$.

Falls

Thirteen oaBPPV and 3 controls reported at least 1 fall in the past 12 months. Although the odds ratio of 3.43 (95% CI, 0.83-12.36) was not significant, oaBPPV reported significantly increased fall incidence (P = 0.04) and number of falls (P = 0.05). Five oaBPPV indicated that dizziness was their reason for falls, while 7 indicated their falls were accidental, and 1 because of syncope. All controls indicated their falls were accidental.

Table 2. Results on Frailty, Timed Chair Stand Test, Unilateral Stance, and Falls

Frailty	oaBPPV	Control	*P* Value	Cohen's *d*
Robust (n)	10	17	**<0.001**	1.27
Prefrail (n)	15	4		
Frail (n)	11	0		
Unintentional weight loss			0.46	0.37
Yes (n)/No (n)	7/ 29	3/ 18		
Self-reported exhaustion			**<0.001**	1.22
Yes (n)/No (n)	18/ 18	0/ 21		
Slowness			**0.001**	0.92
Yes (n)/No (n)	13/ 24	0/ 22		
Weakness			**0.002**	0.86
Yes (n)/No (n)	12/24	0/ 21		
Physical inactivity			0.34	0.43
Yes (n)/No (n)	7/ 29	1/ 20		
Timed chair stand test				
Total time, s	18.4 (5.9)	14.7 (3.3)	**0.003**	0.77
Sit-to-stand time, s	1.1 (0.2)	0.9 (0.2)	**0.05**	0.43
Stand-to-sit time, s	0.8 (0.2)	0.8 (0.1)	0.15	0.27
Unilateral stance				
Area, m^2/s^4	2.0 (1.9)	2.7 (3.9)	0.43	0.05
Velocity, m/s	0.3 (0.2)	0.5 (0.5)	0.18	0.24
Path, m/s^2	77.2 (48.8)	84 (82.3)	0.34	0.11
Range, m/s^2	2.9 (1.6)	3.7 (2.2)	0.08	0.37
Time, s	10.5 (6.7)	13.4 (6.6)	**0.05**	0.44
Falls				
Fall history			**0.04**	0.48
Yes (n)/No (n)	13/24	3/19	OR 3.43; 95% CI, 0.83-12.36; 0.08	
Number of falls			**0.05**	0.59
0 (n)	24	19		
1 (n)	7	2		
2 (n)	5	0		
>2 (n)	1	1		
Reason for falls				0.59
Accidental (n)	7	0		
Dizziness (n)	5	3	0.13	
Syncope (n)	1	0		
No falls (n)	24	19		

Abbreviations: BPPV, Benign Paroxysmal Positioning Vertigo; CI, confidence interval; control, older adults in control group; oaBPPV, older adults with BPPV; OR, odds ratio.

Significant differences are indicated in bold.

Sub-analyses revealed a significantly increased odds of falling (OR = 13.13; 95% CI, 1.92-89.51) in $oaBPPV_{frail}$ compared to $controls_{robust}$. No significant differences were found in fall incidence, number of falls, and reason for falls (Table 2).

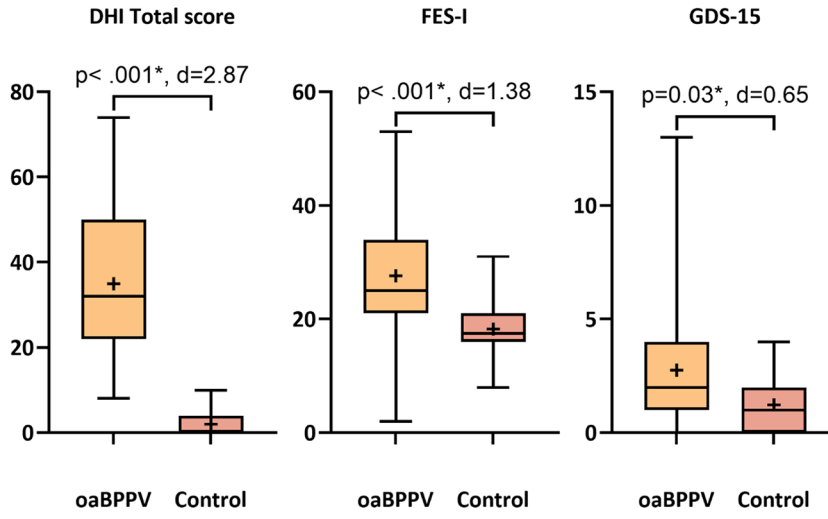

Figure 1. Subjective well-being. DHI, FES-I, and GDS-15 scores in older adults with BPPV (n = 37) compared to age-, weight-, and height-matched controls (n = 22). The boxplots indicate the medians, interquartile range, and minimum and maximum values, with the "+" indicating the mean values. Significant *P* values are indicated with "*". Abbreviations: BPPV, Benign Paroxysmal Positioning Vertigo; Control, older adults in control group; DHI, Dizziness Handicap Inventory; FES-I, Falls Efficacy Scale-International; GDS-15, 15-item Geriatric Depression Scale; oaBPPV, older adults with BPPV.

Postural Control

The total score of the "mini-BESTest" was significantly lower in oaBPPV compared to controls (21.6 (4.2) vs 24.7 (2.7)) (Figure 2). A significant difference was found in sensory orientation (5.4 (1.0) vs 5.9 (0.4)), and there was a trend toward decreased reactive postural control (4.3 (1.7) vs 5.3 (0.8)) and dynamic gait (7.8 (1.7) vs 8.7 (1.0)). Anticipatory postural control (4.1 (1.3) vs 4.7 (1.3)) did not differ.

The sub-analyses revealed that the total score, dynamic gait, and reactive postural control were significantly lower in $oaBPPV_{frail}$ compared to $oaBPPV_{robust}$ and $control_{robust}$.

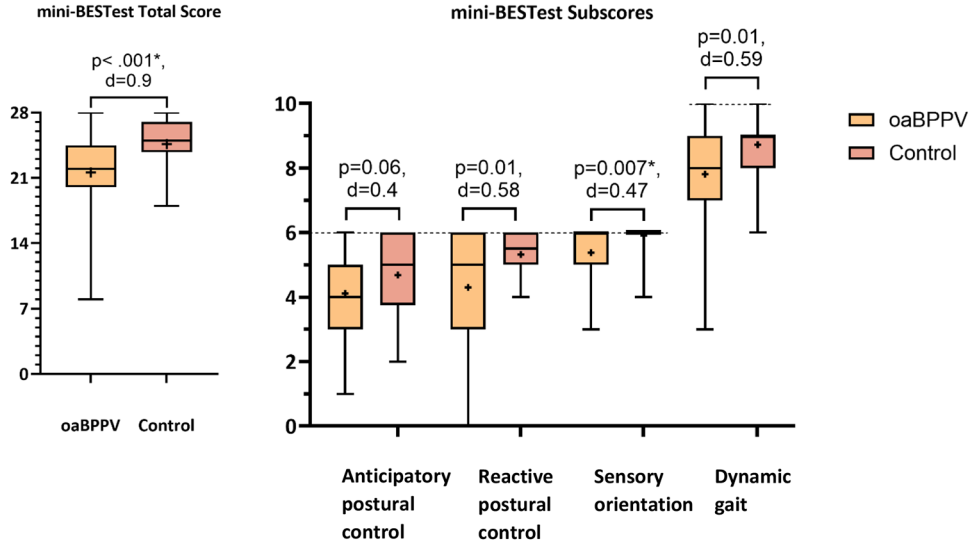

Figure 2. mini-BESTest total score and subscores. mini-BESTest total scores and subscores in older adults with BPPV (n = 37) compared to age-, weight-, and height-matched controls (n = 22). The boxplots indicate the medians, interquartile range, and minimum and maximum values, with the "+" indicating the mean values. The dotted lines indicate the maximum score possible on subscales. Significant *P* values are indicated with "*". Abbreviations: BPPV, Benign Paroxysmal Positioning Vertigo; Control, older adults in control group; Mini-BESTest; mini Balance Evaluation Systems test; oaBPPV, older adults with BPPV.

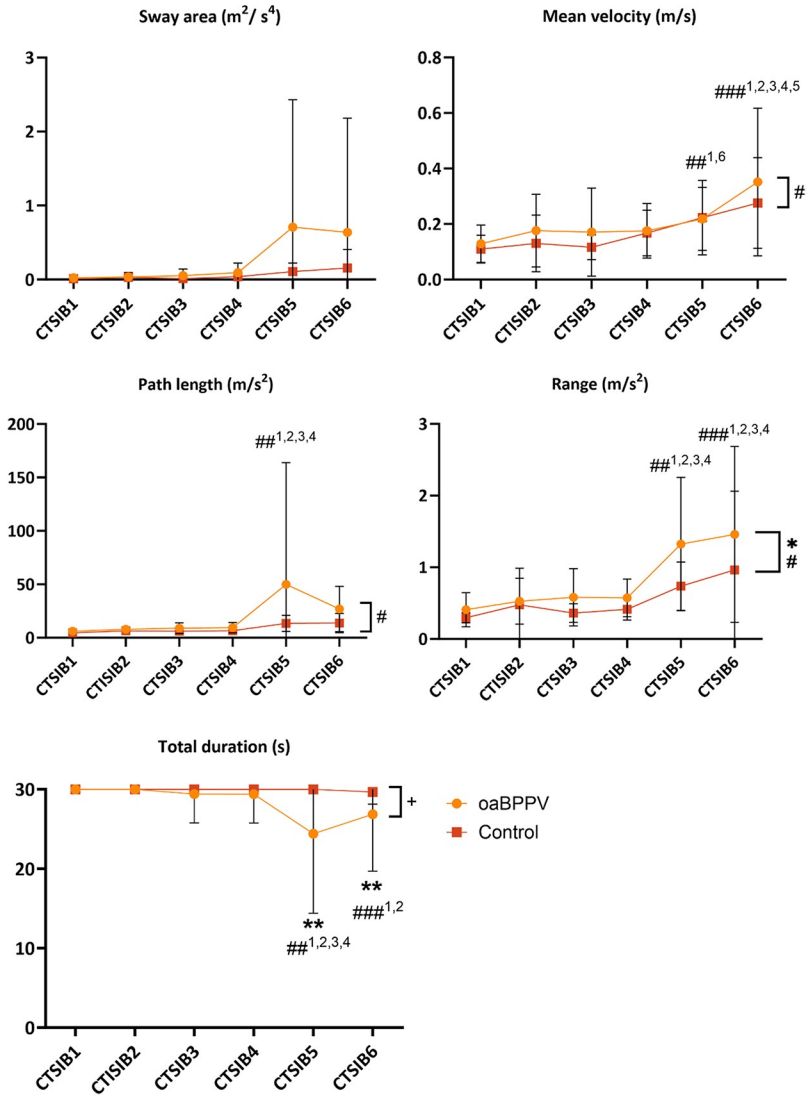

Figure 3. Plots of results on sway area (m^2/s^4), mean velocity (m/s), path length (m/s^2), range (m/s^2), and total duration (s) of CTSIB results (means and standard deviations) of the CTSIB in older adults with BPPV (n = 37) compared to age-, weight-, and height-matched controls (n = 22). *, a significant main effect for group; #, a significant main effect for condition; +, a significant group X condition interaction effect; ##, a significant post hoc comparison for CTSIB5; ###, a significant post hoc comparison CTSIB6; **, a significant post hoc comparison within condition; 1, significant in comparison to CTSIB1; 2, significant in comparison to CTSIB2; 3, significant in comparison to CTSIB3; 4, significant in comparison to CTSIB4; 5, significant in comparison to CTSIB5; 6, significant in comparison to CTSIB6. Abbreviations: BPPV, Benign Paroxysmal Positioning Vertigo; CTSIB, Clinical Test of Sensory Interaction on Balance; CTSIB1, standing on a firm surface with eyes open; CTSIB2, standing on a firm surface with a visual dome; CTSIB3, standing on a firm surface with eyes closed; CTSIB4, standing on a foam surface with eyes open; CTSIB5, standing on foam surface with a visual dome; CTSIB6, standing on a foam surface with eyes closed; oaBPPV, older adults with BPPV; Control, older adults in control group.

Sensory orientation was only significantly decreased in $oaBPPV_{frail}$ compared to $control_{robust}$. Anticipatory postural control did not differ.

oaBPPV needed significantly more time ($P = 0.003$) to complete the "timed chair stand test," and its sit-to-stand transfer ($P = 0.05$). The stand-to-sit time did not differ ($P = 0.15$) (Table 2).

Sub-analyses revealed that $oaBPPV_{frail}$ needed significantly more total time than $oaBPPV_{robust}$ and $control_{robust}$. The sit-to-stand time and stand-to-sit time did not differ.

oaBPPV had a significantly shorter performance time ($P = 0.05$) for "unilateral stance" compared to controls. The sway area ($P = 0.43$), velocity ($P = 0.18$), path ($P = 0.34$), and range ($P = 0.08$) did not differ (Table 2).

Sub-analyses revealed no significant difference.

For the "CTSIB" (Figure 3, Supplemental Digital Content, Table S11, available at: http://links.lww.com/JNPT/A497), a significant group X condition interaction effect was found for time ($F_{5,342} = 3.58$, $P = 0.004$).

Post hoc comparison revealed that oaBPPV had a significantly decreased performance time during CTSIB5 ($P < 0.001$) and CTSIB6 ($P = 0.02$) compared to controls and that they performed significantly worse during CTSIB5 compared to CTSIB1 ($P < 0.001$), CTSIB2 ($P < 0.001$), CTSIB3 ($P < 0.001$), and CTSIB4 ($P < 0.001$). Their performance time of CTSIB6 was significantly lower than the time of CTSIB1 ($P = 0.03$) and CTSIB2 ($P = 0.03$). Performance time of the 6 conditions in controls did not differ.

A significant group effect indicated that oaBPPV had a significantly increased range ($F_{1,342} = 15.55$, $P < 0.001$). A trend was seen toward an increased sway area ($F_{1,342} = 5.78$, $P = 0.02$), velocity ($F_{1,342} = 4.83$, $P = 0.03$), and path ($F_{1,342} = 5.28$, $P = 0.02$) in oaBPPV. No significant interaction effect was found in the sub-analyses. A significant group effect revealed that $oaBPPV_{frail}$ had a significantly increased sway velocity and decreased performance time compared to $control_{robust}$. $oaBPPV_{frail}$ also had a significantly increased range compared to $oaBPPV_{robust}$ and $control_{robust}$.

For the "TUG and $TUG_{dual\text{-}task}$" (Supplemental Digital Content, Table S12, available at: http://links.lww.com/JNPT/A497), no significant interaction effects were found in the main- or sub-analyses.

A significant group effect indicated that oaBPPV had a significantly increased total time ($F_{1,113} = 9.22$, $P = 0.003$). A trend was found toward an increased turn time ($F_{1,113} = 4.64$, $P = 0.03$), but sit-to-stand time ($F_{1,109} = 0.43$, $P = 0.52$) and stand-to-sit time ($F_{1,107} = 1.07$, $P = 0.3$) did not differ between groups.

A significant group effect in the sub-analyses revealed $oaBPPV_{frail}$ had a significantly increased total time compared to $oaBPPV_{robust}$ and $control_{robust}$, and a trend toward an increased turn time compared to $control_{robust}$.

The dual-task cost (%) was not significantly different ($P = 0.3$) between oaBPPV (27.8 ± 28.9) and controls (23.9 ± 30.9), nor in the sub-analyses.

For the "10MWT" and "10MWHT" (Supplemental Digital Content, Table S13, available at: http://links.lww.com/JNPT/A497), no significant interaction effects were found in the main or sub-analyses.

A significant group effect indicated that oaBPPV had a decreased gait speed ($F_{1,114} = 23.06$, $P < 0.001$) and stride length ($F_{1,114} = 26.51$, $P < 0.001$) and increased cycle duration SD ($F_{1,114} = 9.8$, $P = 0.002$). They had a trend toward a decreased cadence ($F_{1,114} = 6.08$, $P = 0.02$) and increased double support ($F_{1,114} = 12.24$, $P = 0.01$) and cycle duration ($F_{1,114} = 4.45$, $P = 0.04$). Stride length SD ($F_{1,114} = 1.79$, $P = 0.18$) did not differ.

A significant group effect in the sub-analyses revealed that $oaBPPV_{frail}$ had a significantly decreased gait speed, cadence, and stride length and increased cycle duration, cycle duration SD, and double support compared to $oaBPPV_{robust}$ and $control_{robust}$. Stride length SD did not differ.

DISCUSSION

This prospective case-control study aimed to compare frailty, well-being, postural control, and falls between oaBPPV and controls. oaBPPV had a significantly higher incidence and number of falls, decreased sensory orientation, and cognitive decline indicative of mild cognitive impairment. OaBBPV were significantly more (pre-)frail compared to controls. Additionally, $oaBPPV_{frail}$ had a significantly decreased reactive postural control and dynamic gait, and an increased odds of falling compared to $controls_{robust}$. They experienced significantly more feelings of depression, and their dizziness-related handicap and fear of falling were significantly higher than those of $oaBPPV_{robust}$. This interaction between BPPV and frailty should be considered by clinicians and in future research.

oaBPPV were significantly more (pre-)frail due to more self-reported exhaustion, slowness of gait, and weakness. However, it was not known whether the subitems of frailty were already decreased before BPPV onset or because of BPPV. Although frailty did not correlate with the duration of complaints, those subitems could be affected immediately by the presence of BPPV, in contrast to unintentional weight loss for example. Possibly, they rapidly improve after the resolution of BPPV. A positive effect of RM on gait speed[5] and time to complete the timed chair stand test,[24] which was only significantly increased in $oaBPPV_{frail,}$ was already found in previous literature.

Frailty might also be an indicator that more follow-up is needed after RM in oaBPPV. For example, only $oaBPPV_{frail}$ experienced significantly more feelings of depression. Increased feelings of depression were confirmed in previous cross-sectional studies on oaBPPV[25,26] and may predict residual dizziness after RM.[27] However, frailty was never taken into account in these studies. As the increased feelings of depression were only seen in $oaBPPV_{frail}$ and not in $oaBPPV_{robust}$, they might be linked more to the presence of frailty than BPPV. Consequently, frailty may be indicative of feelings of depression and residual dizziness or vice versa and can point out the need for further follow-up after RM in oaBPPV.

With increasing task difficulty in sensory orientation, all oaBPPV experienced significantly more difficulties to stand 30 seconds. Given the significant difference between oaBPPV and controls in performance time when standing on a foam with a visual dome or eyes closed, these tests and outcome measures were the most useful to assess the impact of BPPV on postural control.

Only $oaBPPV_{frail}$ had a significantly decreased reactive postural control and dynamic gait. The results on dynamic gait were confirmed by the results of the 10MW(H)T and $TUG_{(dual\text{-}task)}$. In contrast to the prolonged total time of TUG,[5] the trend in increased turn time was not found in previous literature,[28] possibly due to the broad age range and, consequently, more robust adults with BPPV included in these studies. Since fear of falling and dizziness-related handicap was significantly higher in $oaBPPPV_{frail}$ than $oaBPPV_{robust}$, they might experience more fear of provoking symptoms while turning and therefore turn more slowly. Future research should again investigate whether these also

improve in $oaBPPV_{frail}$ according to previous studies,[5] or if or if additional rehabilitation is needed.

The use of a postural control assessment including several domains, such as the mini-BESTest, can help clinicians unravel the interaction between BPPV, frailty, and postural control and set priorities in rehabilitation. The decreased total score and largest deficit in sensory orientation are in agreement with findings in people with bilateral vestibulopathy[29] and confirm the utility of the mini-BESTest for assessing postural control in people with vestibular disorders.

The combination of decreased postural control on multiple domains and increased medication intake and greater concern about falls in $oaBPPV_{frail}$ could create a vicious cycle and explain the significantly increased odds of falling in $oaBPPV_{frail}$ compared to $controls_{robust}$. However, the odds ratio's large confidence interval must be considered when interpreting these results.

Nevertheless, all oaBPPV had a significantly increased number and incidence of falls. Therefore, an increased awareness, screening, and treatment of BPPV are highly recommended for fall prevention in older adults, who often report vertigo as a vague unsteadiness.[4] Moreover, as the majority of oaBPPV was prefrail, treating BPPV may prevent falls and the aggravation from prefrailty to frailty, decreasing the risk of other adverse health outcomes. Conversely, BPPV might be more prevalent in (pre-)frail older adults.

Although more research is needed to resolve this chicken-and-egg situation, our results revealed that BPPV and frailty appear to be linked with each other.

Limitations

Frailty was assessed with the Fried criteria,[7] adjusted by Avila-Funes et al[11] instead of the measurement of Fried et al. The sub-analyses included small groups and no frail controls. The researcher scoring the mini-BESTest was not blinded for groups. The assessment for postural control was not performed immediately at the time of diagnosis, leading to a substantial number of oaBPPV who had a resolution of BPPV.

The elaborative protocol and recruitment via outpatient care of the hospital may have caused (self-)selection bias among oaBPPV, as they needed to delay treatment and return to the hospital multiple times. Controls that volunteered via public invitations may have also been biased, as they might be more physically and socially active. Nevertheless, a sample of oaBPPV and controls matched for sex, age, weight, and height were recruited. The results on well-being,[26,30] CTSIB, and TUG were confirmed in previous literature.[5] However, this is the first study comparing frailty, mini-BESTest, partially objectified with APDM-sensors, and cognition of oaBPPV to those of matched controls, taking their differences in frailty into account.

CONCLUSIONS

oaBPPV had a significantly higher fall incidence and number of falls, cognitive decline, and decreased sensory orientation. They were significantly more (pre-)frail compared to controls and are therefore at risk for adverse health outcomes. Moreover, $oaBPPV_{frail}$ had a significantly decreased reactive postural control and dynamic gait and increased odds of falling compared to $controls_{robust}$. Their dizziness-related handicap and fear of falling were significantly higher than those of $oaBPPV_{robust}$. Future research should investigate whether (pre-)frailty, postural control, and well-being were already decreased before the BPPV onset, if they recover after RM, or if additional rehabilitation is necessary. Nevertheless, BPPV and frailty appear to be linked with each other, which cannot be ignored in future research and clinicians treating oaBPPV.

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