REVIEW ARTICLE

Gait and Postural Control Characteristics among Individuals with Benign Paroxysmal Positional Vertigo: A Scoping Review

Haziqah Nasruddin[1, 2], Maria Justine[1], Haidzir Manaf[1,3]

[1] Center for Physiotherapy Studies, Faculty of Health Sciences, Universiti Teknologi MARA Selangor, Puncak Alam Campus, 42300 Puncak Alam, Selangor, Malaysia.
[2] Physiotherapy Department, Hospital Tuanku Ja'afar Seremban, Jalan Rasah, Bukit Rasah, 70300, Seremban Negeri Sembilan, Malaysia.
[3] Integrative Pharmacogenomics Institute, Universiti Teknologi MARA, Puncak Alam Campus, 42300 Puncak Alam, Selangor, Malaysia

ABSTRACT

Benign paroxysmal positional vertigo (BPPV) is a common peripheral vestibular disorder. Besides vertigo, unsteadiness is a common subjective complaint. This study aims to gain an overview of gait and postural control changes among individuals with BPPV compared to healthy individuals. Relevant case-control studies were searched from their inception until April 2020 using the Scopus, Web of Science and Science Direct databases. Two independent reviewers assessed the methodological quality using the Newcastle-Ottawa Scale (NOS) for case-control studies. A total of 15 studies which satisfied the eligibility criteria were included. The findings suggest evidence of gait and postural control alteration characterized by slower gait speed, reduced gait velocity, increased anterior-posterior centre of pressure, and increased sway velocity compared to controls. Individuals with BPPV showed evidence of gait and postural control alteration. Future exploration on this issue is vital to support gait and postural control alteration among individuals with BPPV.
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Corresponding Author:
Haidzir Manaf, PhD
Email: haidzir5894@uitm.edu.my
Tel: +603-32584376

INTRODUCTION

Benign paroxysmal positional vertigo (BPPV) is a peripheral vestibular disorder affecting about 2.4% of the population with a prevalence of 1.6% and incidence of 0.6% in a year (1). The prevalence of BPPV increases with age; 38.3% of individuals with BPPV are older persons aged 65 years and above, with the 60 – 69 years old age group (26.6%) being the most frequently affected (2). The BPPV involved about 85-95% on the posterior canal, 5- 15% on the horizontal canal and the least affected are the anterior and multiple canals (3,4). Individuals with BPPV typically suffer from paroxysmal vertigo and nystagmus attacks during specific movements (5). In addition, light-headedness, nausea, and unsteadiness during physical movements – such as standing or walking – are frequently reported symptoms (6–9).

Recently, other than vertigo, there has been a growing awareness of unsteadiness issues among individuals with BPPV (10). The International Classification of Vestibular Disorders defines unsteadiness as a feeling of being unstable while seated, standing, or walking without a particular directional preference (11). A recent prospective study of 314 patients attending vestibular physiotherapy specialty clinics in Australia revealed that about 75% of individuals with BPPV experienced gait unsteadiness (12). In addition, self-reported dizziness among older persons with BPPV showed that the main complaints are unsteadiness and a sense of falling rather than a vertiginous spinning sensation (13). Hence, unsteadiness could be another major symptom affecting individuals with BPPV.

Changes in balance control may contribute to unsteadiness among individuals with BPPV. Balance is a term used associated with postural control and stability. About 49% of individuals with BPPV experience balance problems (1). Postural instability may relate to the impairment of vestibular system that alter the sensory output weightage. Dysfunction of the semi-circular canals – made up by the kinetic labyrinth that senses angular acceleration or rotation of the head – may disrupt the vestibular nerve reflex which further may cause postural instability (14). Alteration of the postural stability may further affect the gait among individuals with BPPV and significantly increases the chances of falling (15).

Falls are the leading cause of disability and death worldwide (16). In the United States, a retrospective cohort study investigating demographic and clinical characteristics of individuals with BPPV revealed that 47.7% sustained at least one fall event (17). Furthermore, in the United Kingdom (UK) several studies reported that individuals who seek treatments in the fall clinics were among individuals with vestibular disorders (18–20). Unsteadiness will significantly lead to fall. As the number of studies reported on complaints of gait unsteadiness is increasing, further exploration on the nature of postural control and gait abnormalities is warranted. Therefore, quantitative measurements specific to gait and postural control need to be explored.

In view of all that has been mentioned, investigating the postural control and gait characteristics among individuals with BPPV including older adults may provide additional insight on this aspect as the percentage of BPPV in older adults is high and most of the unsteadiness complaints are among this population (1,21). To date, no systematic review covering gait and postural control characteristics among individuals with BPPV is available. Therefore, the present work aims to gain an overview of the available evidence on gait and postural control characteristics among individuals with BPPV compared with healthy individuals. This review might be helpful for researchers investigating gait and postural control in order to manage this disease.

METHODS

Protocol and Search Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for scoping review were adopted to evaluate the literature on gait and postural control in individuals with BPPV (22). Relevant studies were searched from their inception until April 2020 using the Scopus, Web of Science and ScienceDirect online databases. These databases are the largest well-established online indexed covering multidisciplinary publications and citations, including medical and health-related topics (23,24). The additional record was attained using a manual literature search. The relevant keywords were identified using a thesaurus, previous studies, and suggested keywords in the databases. Keywords similar to postural control, gait, BPPV, and searching strategies used were: ("postur* control*" or "postur* equilibrium" or "postur* balance*" or "body equilibrium" or "gait*" or "gait performance*") and ("benign paroxysmal positional vertigo").

Selection Criteria

The studies included in this review met the following inclusion criteria: (1) full-text articles of case-control studies, (2) articles published from their inception up to April 2020, (3) studies that involved human subjects with population among adults and older adults with BPPV, (4) studies that discussed gait or postural control as their primary or secondary outcome, (5) articles that reported on gait outcome (e.g., gait parameters, the score of functional walking outcomes), (6) articles that used any gait assessment equipment (e.g., force platform, three-dimensional camera system, wearable sensor, inertial motion sensor, and (7) articles in English. Studies were excluded if they only contained an abstract, book, book chapter, thesis, and conference proceedings. In addition, studies involving narrative review, systematic review with and without meta-analysis were also excluded.

Quality Assessment

Our study focused on case-control studies to identify any gait and postural control alteration among individuals with BPPV compared to the healthy person. Hence, the quality of selected studies was evaluated using the Newcastle-Ottawa Scale (NOS) for case-control studies (25). The NOS consists of three components assessing (1) the selection of cases and controls, (2) comparability of cases and controls, and (3) ascertainment of exposure for cases and controls. The total rating of NOS is nine stars, with a maximum of four stars for part one, two stars for part two, and three stars for part three. Studies with scores of $\geq$ five stars were considered to be of moderate to good quality (26). Three reviewers independently assessed the studies where any disagreement occurred; all the three reviewers deliberated until a consensus was reached.

Study Selection and Data Extraction

All searched articles were assessed. The eligibility of the inclusion of the article was screened by reading the title and abstract specific to the formulated objective. Furthermore, selected articles were reviewed by two investigators (HN and MJ) thoroughly, and any articles that did not meet the criteria were excluded. The remaining full articles were synthesized in depth. Using a predesigned form, the investigators extracted the following data: (1) name of the author(s), (2) year that the article was published, (3) study design, (4) sample size, (5) protocol used to assess gait or postural control, (6) variables measured, (7) covariates, and (8) findings. The reviewers double-checked the data entry for any discrepancies with the original published data, in which a consensus was reached.

RESULTS

Selection of Studies

The screening process is presented in Figure 1. A total of 863 records were identified in the search. Thirty-six articles were removed due to duplication. After the initial screening of titles and abstracts, 93 articles remained. Seventy-eight studies were further excluded due to irrelevant outcome criterion. Only 15 articles were eligible to be selected based on the predetermined criteria: four articles reported on gait and postural control (27–30) among individuals with BPPV, ten articles on

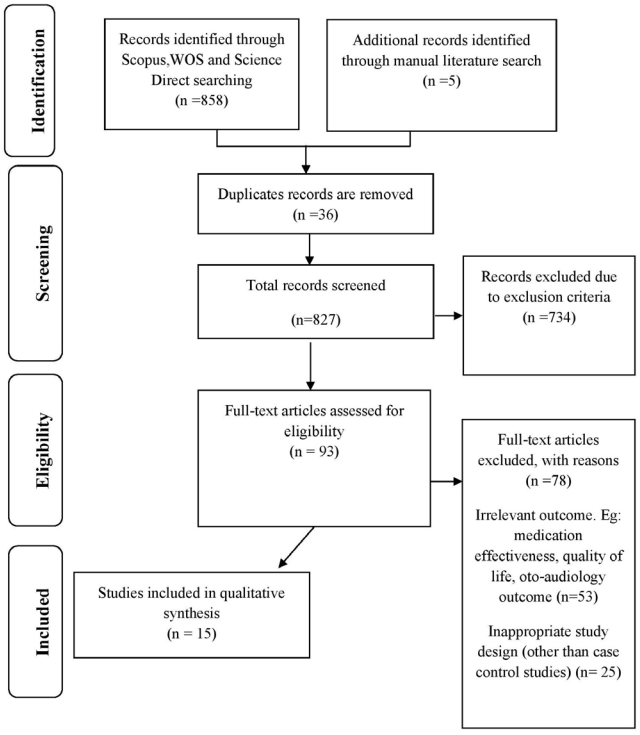

Figure 1: Flowchart of study selection

postural control (31–40), and one article on gait only (41).

Quality Assessment

Overall, the methodological quality of the 15 included case-control studies varied. Total scores ranged from two to seven stars (Table I). Almost half of the studies were rated more than five stars, indicating moderate to good methodological quality (27,28,30,32,35,36). The selection criteria were adequately described for most of the samples in the studies. Approximately half of the studies matched the study sample's age and gender with the control group. Only two studies reported covariates as integral to gait assessment in BPPV with neuropathy (30,32). The effects of gender, age, and body mass index on neuropathy in studies related to gait have been established before (42–45). All but one study (30) failed to report on the ascertainment of exposure. None of the studies explained non-response rates in the exposure criteria.

Characteristics of Participants

Tables II and III show the participants' characteristics for each of the articles included in the review. A total of 497 participants with BPPV were reviewed in this study.

Table I: Newcastle-Ottawa scale: methodological appraisal for case-control studies

	Selection				Comparability	Exposure			Total
	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 1	Criteria 1	Criteria 2	Criteria 3	
Adelsberger, Valko, Straumann, & Truster (27)	★	★	★	★			★		5
Çelebisoy, Bayam, Güleç, Köse, & Akyürekli (28)	★	★		★	★		★		5
Chang, Hsu, Yang, & Wang (29)	★	★			★				3
D'Silva et al. (30)	★	★	★	★	★★	★	★		8
Nair, Mulavara, Bloomberg, Sangi-Haghpeykar, & Cohen (31)	★						★		2
D'Silva, Kluding, Whitney, Dai, & Santos (32)	★	★		★	★★				5
Mulavara, Cohen, Peters, Sangi-Haghpeykar, & Bloomberg (33)	★		★	★			★		4
Teggi, Quaglieri, Gatti, Benazzo, & Bussi (34)	★	★	★				★		4
Monteiro, Ganança, & Caovilla (35)	★			★	★		★		4
Inukai, Koizuka, & Takahashi (36)		★	★	★	★★		★		6
Stambolieva & Angov (37)	★			★	★		★		4
Giacomini, Alessandrini, & Magrini (38)	★				★★		★		4
Di Girolamo, Ottaviani, Scarano, Picciotti, & Di Nardo (39)	★						★		2
Di Girolamo et al. (40)	★				★★		★		4
Roberts, Cohen, & Sangi-haghpeykar (41)	★		★	★			★		4

Table II: Studies on gait among individuals with benign paroxysmal positional vertigo

Authors & Year	Study Design	Population	Duration of illness	Gait Task	Validity and Reliability	Variable Measure	Main Finding
Adelsberger, Valko, Straumann, & Truster (27)	Case-control	BPPV= 7 60.57 (±9.03) Healthy = 9 33.5 (±10.6)	Not mention	walk straight 50 meters at personal pace along the corridor	N/A	gait speed (cm/s)	No significant difference in walking speed during the walking task between BPPV and healthy subjects.
Çelebisoy, Bayam, Güleç, Köse, & Akyürekli (28)	Case-control	PC BPPV =32 (55.0) HC BPPV=12 (55.6) Healthy =50 (48.3)	Not mention	Tandem walk as quickly as possible	N/A	gait speed (cm/s) end sway velocity (°/s)	The walking speed of PC BPPV ($p < 0.001$) and HC BPPV ($p = 0.007$) was significantly low. No significant different of end sway velocity from healthy in PC BPPV and HC BPPV. Walking speed of PC BPPV ($p = 0.001$) and HC BPPV ($p = 0.004$) increased significantly after treatment and the post-treatment values were not different from the values recorded in healthy controls ($p > 0.05$)
Chang, Hsu, Yang, & Wang (29)	Case-Control	BPPV = 23 (63.3 ± 9.2) Healthy = 23 (63.3 ± 9.2)	Not mention	Tandem Walk as quickly as possible and held steady at the end of the force plate	Concurrent validity with stroke. Test-retest reliability estimates for static and dynamic balance tests of Balance Master were moderate to high	gait speed (cm/s) end sway velocity (°/s)	BPPV group had slower walking speed, $P < 0.001$) and greater endpoint sway velocity ($P < 0.05$) compared to healthy group.
D'Silva et al. (30)	Case-Control	BPPV = 34 (58.85 ±10.65) BPPV+DM =16 (62 ± 7.8)	Not mention	FGA	Moderate to strong correlations with other standard tests of balance.	Total score	At baseline, no significant differences in FGA scores between the BPPV and BPPV + DM (22.7 vs 21.3, p=0.79). The FGA scores improved significantly with treatment ($p = 0.001$). No significant differences in the FGA change scores between the BPPV and BPPV + DM groups (4.09 ± 2.4 vs 2.9 ± 2.9, $p = 0.12$).
Roberts, Cohen, & Sangi-haghpeykar (41)	Case-control	BPPV = 15 VVD = 15 Healthy = 15	Not mention	Perform condition 1-4 in EO/ EC for three times each. Condition 1: walked in a straight line Condition 2: performed a naming task while walking. Condition 3: pitched heads up/ down while walking. Condition 4: performed the naming and nodding tasks, simultaneously	N/A	Veer onset Veer Velocity Angle of veering	*Veer onset* No significant different among groups during EO. The healthy group walked farther without veering compared to two patients' group during EC ($p = 0.0004$ control vs. BPPV; $p< 0.0001$ control vs. various). No different found between two patients' groups during EC. *Velocity* two patient groups walked significantly slower than the control group, with eyes open and with eyes closed (EO– $p =0.02$ control vs. BPPV, $p =0.002$ control vs. VVD; EC – $p = 0.0008$ control vs. BPPV, $p< 0.0001$ control vs. VVD). The two patient groups did not differ significantly from each other with eyes open or closed. Within each group (diseased or healthy), the two conditions that included a cognitive task were performed significantly slower than tasks without the added cognitive challenge. *Angle of veering* No group differences were seen with EO. With EC, the VVD group had a significantly greater angle of veering than controls during the two conditions with the cognitive task. During naming/walking healthy group did not have a significantly smaller angle of veering than the BPPV group (crude $p = 0.003$, adjusted $p = 0.1$) . Healthy controls did have a smaller angle of veering than the VVD group (crude $p< 0.001$; adj. $p = 0.004$). The 3 groups performed similarly when walking or when nodding/walking. *EO vs. EC* All three groups veered earlier, walked slower and had higher angle of veering with eyes closed than with eyes open ($p< 0.001$) *Velocity effect on veering* Angle was correlated with velocity only in the VVD ($p = 0.01$). In the remaining groups and conditions, as group during the eyes closed conditions ($r = -0.6$, velocity increased, the angle of veering did not significantly decrease

BPPV, Benign Paroxysmal Positional Vertigo; BMI, Body Mass Index; cm, centimeter; DM, Diabetes Mellitus; EO, Eyes Open; EC, Eyes Closed; FGA, Functional Gait Assessment; PC, Posterior Canal; HC, Horizontal Canal; s, seconds; °, degree; VVD, Various Vestibular Disease

Table III: Studies on postural control among individuals with benign paroxysmal positional vertigo

Authors & Year	Study Design	Population	Postural Control Task	Variable Measure	Main Finding
Adelsberger, Valko, Straumann, & Truster (27)	Case-Control	BPPV= 7 (60.57 ±9.03) Healthy = 9 (33.5±10.6)	R1 R2 T	COP instability	Prior therapy RI and R2= COP mean /median values were significantly lower in healthy group than in BPPV group. T= no statistically significant differences between group Post therapy R1 and R2= BPPV group shifted the mean and median COP significantly closer to the toes. T= no noticeable adaption
Çelebisoy, Bayam, Güleç, Köse, & Akyürekli (28)	Case-Control	PC BPPV =32 (55) HC BPPV = 12 (55.6) Healthy = 50 (48.3)	standing with EO/ EC standing on foam with EO/EC	center of gravity sway velocity (°/s)	The sway velocity values recorded in PC BPPV, on foam with EC were significantly high (p = 0.009). The sway velocity values recorded from the HC BPPV group were not statistically different from the healthy group.
Chang, Hsu, Yang, & Wang (29)	Case-Control	BPPV = 23 (63.3±9.2) Healthy = 23 (63.3±9.2)	stance on firm surface EO/EC stance on foam surface EO/EC left leg stance EO/EC right leg stance EO/EC	sway velocity	BPPV demonstrated greater sway velocity than healthy in the stance on foam surface with EC (P < 0.05) and in a single-leg stance with EC (P < 0.001).
D'Silva, Whitney, Santos, Dai, & Kluding (30)	Case-Control	BPPV = 34 (58.85 ±10.65) BPPV + DM = 16 (62 ± 7.8)	Quiet standing for 30 seconds in five conditions: 1: standing on a firm surface with feet together, EO. 2: standing on a firm surface with feet together, EC. 3: standing on a foam pad with feet together, EO. 4: standing on a foam pad with feet together, EC. 5: tandem standing with EO on a firm surface.	postural sway: pelvic acceleration	Range-ML showed interaction between condition and group ($F_{1,42}$ 2.3, p = 0.01, partial eta squared: 0.08). Post-hoc analysis showed that range-ML significantly higher in tandem stance in the BPPV + DM group (1.6 ± 1.3 cm/s) compared to the BPPV group (0.67 ± 0.5 cm/s) (p = 0.001). A significant main effect for group was seen for PV-AP ($F_{1,42}$: 5.8, p = 0.02, partial eta squared = 0.14). The BPPV+DM had higher sway velocity with standing on firm ground with EC (p = 0.02) and in tandem stance (p = 0.007) compared to BPPV group.
Nair, Mulavara, Bloomberg, Sangi-Haghpeykar, & Cohen (31)	Case-Control	BPPV= 17 (63±2.45) Healthy = 23 (52±3.22)	Clinical Test of Sensory Interaction and Balance (CTSIB) with EO/EC	time taken to control posture in 30 seconds	BPPV group stood for significantly less time than controls during EC (P=0.0004) No difference between the two groups in EO condition (P=0.23)

PC, posterior canal; BPPV, benign paroxysmal positional vertigo; CTSIB, clinical test of sensory interaction and balance; EC, eyes closed; EO eyes open; DM, Diabetes Mellitus; ML, mediolateral; AP, anteroposterior; PV-AP ,Peak-Velocity; COP; center of pressure; R1,Romberg Test; R2, Romberg on foam; T, Tandem Stand; SOT, The Sensory Organization Test; RD, Residual Dizziness; EOF, Eyes opened while standing on a rubber foam; ECF, Eyes closed while standing on a rubber foam; HC, Horizontal Canal; s, seconds; °, degree; cm, centimeter; W, Women; M, Men.

Twelve studies included healthy controls as comparisons with 285 participants across all studies. The mean age of individuals with BPPV ranged between 42.4 years and 66.7 years, and healthy controls ranged from 33.5 years to 63.3 years. Only one study focused mainly on elderly individuals aged ≥ 60 years compared to healthy controls (29). The study sample sizes ranged from 16 to 90 participants. Two studies stated the participants' duration of illness (34,37).

Methods Used for Gait and Postural Control Assessment

Several methods have been used to assess gait, including walking in a straight line (27), tandem walking (28,29), dual-task walking (41), and using a functional gait outcome measure (30). The postural control was assessed using the Clinical Test of Sensory Interaction on Balance (31,33), Sensory Organization Test (SOT) (33,40), standing on a firm or foam surface with Eyes Open/Eyes Closed (EO/EC) (28–30,32,34,36–38), Romberg test on firm and foam surface (27), tandem stance (27), single-leg stance with EO/EC (29), and sensory stimulation tasks (35). Only two studies reported the reliability of the outcome used. D'Silva et al. (30) reported that the Functional Gait Assessment (FGA) has a moderate to strong correlation with other standard balance assessments for BPPV. Meanwhile, Chang et al. (29) revealed that the tandem walk test assessed by the Balance Master System showed moderate to high test-retest reliability for static and dynamic balance assessment for individuals with BPPV.

Gait Characteristics among Individuals with BPPV

Gait speed was reported by two studies (28,29) under the condition of fast pace tandem walk. A significantly greater walking speed was evident in the healthy group compared to the BPPV group (22.23 vs 17.24, P = 0.001;

31.68 vs 19.72, P = 0.001). One study (27) under a straight walking condition with participant-selected pace reported no significant difference in gait speed between healthy individuals and those with BPPV. One study (41) that reported gait velocity under dual-task activities challenging the attentional demand among individuals with BPPV showed significantly reduced gait velocity compared to healthy controls especially during the EC condition (Walking – 0.82 vs 1.08, P = 0.0008; Naming – 0.56 vs 0.79, P = 0.0008; Nodding – 0.72 vs 1.02, P = 0.0008; Combination – 0.57 vs 0.81, P = 0.0008). The functional gait measured using the FGA outcome by one study (30) reported no significant difference in the severity of gait performance between BPPV with diabetes and BPPV alone groups. Both groups showed a mean score of ≤ 22, indicating a higher risk of falls (46).

Postural Control Characteristics among Individuals with BPPV

Difficulty in maintaining static postural control under visual disturbance conditions was reported in six studies (30–34,37). Additionally, three studies (28,29,35) revealed that the postural control under the combination of visual and somatosensory disturbance assessed by sway velocity was significantly greater than that of the healthy group. Furthermore, one study (27) showed the mean value of anterior-posterior centre of pressure (AP-COP) during upright standing and standing on the foam was significantly lower in healthy individuals. No significant difference was found in the mean value of medial-lateral centre of pressure during tandem position, although there was increased instability in both groups. Two studies (39,40) reported a lower equilibrium score measured by the SOT than healthy controls. The authors found that the equilibrium scores among individuals with BPPV significantly worsened in a more challenging task (40). Meanwhile, Giacomini et al. (38) examined body sway during 30 seconds of upright standing and found that the body oscillated with a broad frequency spectrum in EO and EC tests performed immediately after the Dix-Hallpike test. In another study, Inukai et al. (36) compared the enveloped area among individuals with BPPV who presented with dizziness and without dizziness. They discovered no significant difference in the enveloped area covered between both groups, where BPPV affects postural stability alone. In addition, individuals with a longer duration of vertigo were associated with having residual dizziness (34). Hence, greater postural sway among those with residual dizziness was found in several conditions except for the EO condition as compared to the control group. Meanwhile, a study showed that individuals with a longer duration of vertigo had a lower value of sway velocity compared to individuals with an acute attack of vertigo after undergoing canalith repositioning maneuver (37).

DISCUSSION

This study aimed to understand gait and postural control characteristics among individuals with BPPV compared to healthy individuals. To our knowledge, this is the first scoping review that focused on the gait and postural control characteristics among individuals with BPPV. This work is essential to identify objective measures on gait and postural control alteration among individuals with BPPV despite several self-reported gait unsteadiness (10,12,13). Thus, this review may provide a basis to further explore gait and postural control abnormalities among this population.

Gait Characteristics among Individuals with BPPV

A significantly reduced gait speed during fast-paced tandem walk was reported probably due to the compensatory mechanism of individuals with BPPV to maintain stability [37,38]. Walking on a narrow base of support is a challenging task for individuals with BPPV, as the impairment of vestibular function affects the integration of peripheral sensory function that includes the somatosensory and visual system. Reweighting due to vestibular impairment causes sensory information to shift to the lower limb during the double limb support phase to facilitate foot placement in forwarding progression during locomotion onset (47). However, one study (27) revealed no significant difference in gait speed between the healthy and BPPV groups. The authors mentioned a methodological issue wherein close monitoring during a walking task to avoid a fall incident might cause an unexpected finding. Nevertheless, the inconsistent finding may be due to variation of gait assessment used, where the authors assessed gait speed in a straight walking task with participant-selected pace. In other study populations such as ataxia gait patients, walking at a preferred gait speed minimized the gait outcome, and analysis of gait with different range of speeds is recommended (48).

In the reviewed articles, one study (41) reported significantly reduced gait velocity under dual-task activities (motor and cognitive tasks) that challenged the attentional demand among individuals with BPPV compared to the healthy controls. The authors suggested that the changes of gait velocity among individuals with BPPV may be related to the unloading of otoconia on the utricle to the posterior canal, which probably changes the inertial properties of the otoconial membrane. Hence, these changes in otolith function affect the vestibular spinal reflexes, causing alteration of the linear acceleration signal from the utricle and resulting in individuals with BPPV having difficulty controlling balance while performing the task. Therefore, as the motor-cognitive dual-task assessment is correlated with gait outcome, dual-task motor-cognitive function may

become an important factor when assessing gait among individuals with BPPV. Impaired dual tasking during walking could also be an indicator of fall risk (49). Thus, further exploration of dual-task walking is warranted to consider the dual task as a contributing factor in gait alteration.

Besides spatiotemporal characteristics, this review also found that gait alteration among individuals with BPPV can be identified through outcome measuring tool. The FGA outcome measure is a 10-item tool that evaluates postural stability during various walking tasks (50). The FGA has excellent interrater reliability (ICC = 0.84) and intrarater reliability (ICC = 0.83) for vestibular patients (51). In the study, the researcher reported that the FGA mean score was ≤ 22 for BPPV with diabetes and BPPV alone groups, and no significant difference in gait severity indicated that BPPV alone affects the walking tasks (46). Hence, with the reported gait alteration during different walking tasks, more research on this aspect is necessary to support evidence of gait abnormalities among individuals with BPPV.

Postural Control Characteristics among Individuals with BPPV

Postural control is a complex system that integrates several components, including vestibular, somatosensory, and visual systems (52). Postural control is the "act of maintaining, achieving or restoring a state of balance during any specific posture and movement" (53). The main functional goal of postural control is postural equilibrium and postural orientation (54). In the reviewed articles, six studies (30–34,37) found that individuals with BPPV presented significantly lower postural control ability than healthy controls in visual disturbance conditions. Postural stability is better with visual fixation of space-fixed targets in normal conditions than in darkness (55), indicating that visual information is used to optimize postural stability. Significantly reduced postural stability during eye closure among individuals with BPPV may be because visual deprivation is related to the alteration of visual reference to the spatial orientation (56). The sensory re-organization occurred where it may rely on the somatosensory system in maintaining postural stability despite impairment of the vestibular signal and deprivation of the visual system. Thus, significantly reduced postural stability was observed among individuals with BPPV compared to healthy individuals.

In three studies (28,29,35), significantly impaired postural control occurred with a combination of the visual and somatosensory system disturbance. In healthy individuals, with the absence of visual and somatosensory input, the vestibular system plays a significant role in maintaining postural stability. However, among individuals with BPPV, lack of otolith response due to loss of calcium from otoconia may explain postural instability (57). The re-weighting of sensory organization, which relies primarily on vestibular cues, may not be adequately compensated, suggesting that the vestibular system was impaired. Hence, the alteration of postural stability with the absence of visual and/or proprioception should be taken as a precautionary measure. Individuals with BPPV have higher chances of falling while performing daily activities that challenge the visual and somatosensory inputs.

In our review, Adelsberger et al. (27) showed that individuals with BPPV had greater ankle AP-COP sway during the Romberg test than the control group. Giacomini et al. (38) revealed significantly increased trace length, surface, and postural sway velocity during static posturography assessment both in the closed and open eyes test. Inukai et al. (36) reported greater enveloped area measurement assessed by stabilometry. Two studies also reported a significant reduction of equilibrium score in the SOT among individuals with BPPV compared to the control group (39,40). In events that challenge postural control, counter back mechanisms to maintain stability were applied to maintain posture. Normal individuals maintain their posture by leaning from the ankle to bring the centre of mass toward the front of the feet (54). With vestibular disturbance, the limit of stability may be altered, resulting in several movement strategies to recover equilibrium, including the ankle, hip, or step. Therefore, with a significantly greater postural sway parameters alteration than healthy individuals, the vestibular disturbance may affect postural stability among individuals with BPPV.

Implications and Limitations of the Study

From the finding of the current scoping review, a holistic approach in assessment and treatment for individuals with BPPV should be considered. Other than canalith repositioning maneuvers to alleviate vertigo symptoms in the treatment of BPPV, it is recommended that assessment on balance and gait be emphasized for this population. Significant heterogeneity of protocol used to assess the gait and postural control across studies existed in our review. We identified walking in a straight line (27), tandem walking (28,29), dual-task walking (41), and using a functional gait outcome measure (30) as the measuring tool to assess gait. Most of these studies use gait speed as the parameter. Gait speed identified from the existing outcome measure is an important parameter measure to determine an individual's overall walking performance (65) and functional health (58). However, another critical point that needs further attention is the reported fall incidence during walking among individuals with BPPV. In this review, a study using the functional gait outcome using FGA reveals that individuals with BPPV are at higher risk of falls. In addition, with higher prevalence of BPPV among older adults, a simpler outcome measure such as the Timed Up and Go test could be an option to assess the gait and the risk of fall during walking. The outcome measure may be beneficial as it is not time-consuming

and easy to perform by the patients and therapists. We also recommend more research exploration on gait tasks, including turning while walking, as a turning task challenges postural stability. In this review, only two studies reported the reliability of the outcome used. The reliability and validity of the outcome measurement maybe the concern for future studies.

Moreover, we found only one study that reported on the older adult population. Hence, we cannot conclude gait and postural control alteration among older individuals with BPPV, even though most subjective complaints of unsteadiness are among this target population (10). We only found two studies reported on the duration of vertigo experienced by the participants (34,37). Generally, duration of illness may influence the postural control and gait characteristics (59). Hence, such factors should be considered for future research exploration.

Selecting only English language studies may be a potential limit to this review. Moreover, the small number of studies included in this review may result in inaccurate study outcomes. Thus, future studies particularly on gait is necessary to conclude the effects of BPPV on gait alteration.

CONCLUSION

The finding of this scoping review shows evidence of gait and postural control alteration in individuals with BPPV. Besides the vestibular system, integrating somatosensory and visual systems is essential in maintaining postural control and gait among individuals with BPPV. Identifying specific postural control and gait alteration among individuals with BPPV, especially among older adults, may benefit the vestibular community in initiating specific gait screening programs, gait training, and vestibular rehabilitation programs to minimise unsteadiness issues among this population. Moreover, further exploration in this area will provide evidence of support on gait and postural control alteration concerning unsteadiness among individuals with BPPV.

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