Forward and backward locomotion in individuals with dizziness

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ABSTRACT

The vestibular system plays an important role in locomotion. Individuals with vestibular pathology present with gait abnormalities, which may increase their fall frequency. Backward walking (BW) has been suggested as a predictor of falls in other patient populations; however it has not been studied in individuals with dizziness. Our aims were: (1) to investigate the differences in forward walking (FW) and BW both between and within 3 groups: Healthy controls, individuals with dizziness and vestibular pathology, and individuals with dizziness without vestibular pathology, (2) describe differences in FW and BW between individuals that have fallen and those that have not. We studied 28 healthy controls (mean 53.8 ± 17 years), 21 individuals with pathophysiology of the vestibular system (mean 68.5 ± 13 years), and 18 individuals without a vestibular cause for their dizziness (mean 67.4 ± 17 years). Subjects performed 2 FW and 2 BW trials over the GAITRite walkway. Data on history of falls in the preceding year were collected. We found BW was different to FW within each group. When comparing between groups and correcting for age and gender, only BW velocity (beta = -11.390, $p = 0.019$), cadence (beta = -8.471, $p = 0.021$), step time (beta = 0.067, $p = 0.007$) and stride time (beta = 0.137, $p = 0.005$) were significantly affected by having dizziness, with no differences in FW characteristics. There were no differences between FW and BW between fallers and non-fallers. BW appears to be a better biomarker than FW for identifying individuals with symptoms of dizziness; though it does not appear to characterize those who fall.

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1. Introduction

The vestibular system contributes significantly to locomotion through reflex mediation of gait and gaze stability. It is also critical for spatial orientation and navigation. Individuals with vestibular dysfunction present with gait abnormalities and those with bilateral hypofunction report 50% more falls than healthy individuals [2–4]. The high morbidity and mortality associated with falls cost the US health care system 30 billion dollars in 2010 [5].

Forward locomotion requires an accurate coordination of information from the vestibular, visual, somatosensory, and musculoskeletal systems [6]. Sensory and motor processing mediated through the vestibulospinal and vestibulo-ocular reflexes perform critical roles in locomotion [7–11]. This is

evidenced by a slower gait speed in benign paroxysmal positional vertigo (BPPV) [7], poor path integration in vestibular hypofunction [8,9], and increased variability in stance and swing phase characteristics in vestibular schwannoma as well as vestibular neuritis [11]. These gait aberrations may explain the increased fall risk in individuals with vestibular dysfunction, estimated to occur during locomotion nearly fifty percent of the time [12].

Although backward walking (BW) occurs much less frequently than forward walking (FW), it is still necessary for independence in daily life (e.g. removing an item from the oven), and many falls occur while moving in this direction [13,14]. The characteristics of BW have been described simply as reversal of FW [15,16]. Evidence to support this descriptor include a correlation between speed, gait cycle, and step length in both directions [15]. However, some notable differences are reported between the mechanical and temporospatial properties of FW relative to BW [15,16]. For example, compared with FW, BW is characterized by having a slower gait speed, reduced stride length, reduced swing phase, and an increase in time spent in double support [17,18]. Some argue that these differences may be explained by the anatomical constraints of the lower limbs (antero-posterior asymmetry and their multi-jointed nature) [16], while others

explain it as an inability of the central nervous system to maintain its behavioral goal of conserving the pattern of agonist and antagonist muscle action at the joints [15]. Age too appears to affect BW uniquely relative to FW, as older adults exhibit a larger magnitude of change in temporospatial characteristics during BW. Compared to younger individuals, older adults show greater decrements in gait speed, stride length, and percent of time in swing phase with a greater increment in percent of time spent in stance and double support [17,18]. BW has also has been found to have an increased variability in double support, stride length, step time and swing time when compared to younger adults [14].

Individuals with impaired mobility have even greater disparity between FW and BW. Older adults with impaired mobility and who have fallen, have slower gait speed, shorter stride length, increased time spent in double support, a wider base of support, and an increase in step-time variability in BW when compared to FW. This does not exist in older adults who have not fallen [14]. As a result, the authors suggested BW may be a clinical tool to identify risk of falling in older adults with impaired mobility [14]. In individuals with Parkinson's disease, BW is characterized by slower gait speed, shorter strides, smaller percent of time spent in swing phase, and larger percent of time spent in double support and stance phases, compared with healthy controls [13].

BW has not yet been studied in individuals with dizziness and balance disorders. The aim of this study was to investigate the temporospatial characteristics of FW and BW in individuals with complaints of dizziness and imbalance compared to healthy controls. Additionally, we were interested in the specific role vestibular pathology may have on any differences between FW and BW; thus we subdivided the individuals into two groups – those with and without a verifiable vestibular pathology but each still reporting dizziness. We defined dizziness to include symptoms of vertigo, imbalance, lightheadedness, wooziness, and/or any head-motion induced sense of malaise. We further sought to identify differences in gait parameters during FW and BW between those individuals that have fallen and those that have not. We hypothesized that individuals with dizziness and imbalance symptoms and a history of falls would have temporospatial gait characteristics indicative of motor impairment during FW and BW with an increased variability compared to those without dizziness or a history of falls.

2. Methods

Twenty-eight healthy subjects aged 23–81 years (mean 53.8 ± 17 years), 21 individuals with vestibular dizziness (VDZ), aged 36–89 years (mean 68.5 ± 13 years), and 18 individuals with non-vestibular dizziness (NVDZ), aged 36–94 years (mean 67.4 ± 17 years), were included in the study. All individuals were recruited from the outpatient otolaryngology clinic at our institution. VDZ individuals included those diagnosed with a peripheral vestibular lesion by history and physical exam: Ménière's disease based on clinical history and audiologic testing; BPPV based on positive Dix-Hallpike in the case of vertical canalithiasis or roll maneuver in the case of horizontal canalithiasis; vestibular hypofunction based on abnormal head-impulse test; and superior semicircular canal dehiscence syndrome based on abnormal CT scan. NVDZ individuals included those with complaints of dizziness but with normal vestibular function based on clinical and vestibular function testing. All study participants gave informed consent. This study was approved by the Institutional Review Board.

Both patient groups were screened for cognitive impairment using the Mini-Mental State Examination (MMSE). A threshold score of >24 was used as inclusion criteria. Subjects were also asked for data on history of falls and completed the

Dizziness Handicap Inventory. Each subject was assessed using the Dynamic Gait Index (DGI) (Table 1). The DGI is a validated behavioral measure of fall risk in vestibular hypofunction [19].

The temporospatial characteristics of gait were measured using the GAITRite™ electronic walkway (CIR Systems, Inc.). The GaitRite™ walkway contains 13,824 sensors encapsulated in a roll up carpet to produce an active area 2-feet wide and 22-feet long. Footfall information was recorded only on the central region (4.88 m) of the entire 6.7-m long walkway. The GAITRite™ walkway is a validated and reliable tool for gait analysis comparable with video analysis techniques [20].

Participants were asked to perform two FW and two BW trials. They were instructed to walk at their self-selected speed, look straight ahead (they were not allowed to turn their head during BW), and let their arms swing naturally by their sides. Subjects started and finished the walk 1 meter before and after the GAITRite™ walkway to prevent premature acceleration and deceleration of speed while walking on/off the GAITRite™. Safety during the walking trials was ensured by having an investigator walk beside the subject so as not to lead them. The patient subjects were recruited directly from the clinic and were therefore experiencing symptoms during the trials.

2.1. Statistical analysis

Only valid trials were analyzed. We considered a trial valid when it included clear footsteps and in which the participant did not step off the mat or stop walking before the 1 m area beyond the end of the mat. Approximately 15% of all trials were discarded as invalid on this basis. Mean and one standard deviation (SD) error bars were calculated for the GAITRite walkway data, captured during both FW and BW. There was no statistically difference between left foot and right foot data, therefore data from both sides were pooled to increase the number of events [21]. All variables were tested for normality using the Kolmogorov–Smirnov test. FW and BW means were compared using paired-samples Student's t-tests and one-way repeated-measures ANOVA with Bonferroni post hoc tests to control for multiple comparisons. Multiple logistic regressions, correcting for age and gender, were used to further assess how the symptom of dizziness impacts gait parameters for both FW and BW.

Only the VDZ and NVDZ groups were included in the falls analysis. Independent sample t-tests were used to assess the difference in temporospatial characteristics between fallers and non-fallers for both FW and BW. Levene's test of equality of variances was used to assess if different variances should be assumed or not for each comparison. Statistical analyses were

Table 1
Characteristics of the 3 groups participating in the study.

	HS mean (SD)	VDZ mean (SD)	NVDZ mean (SD)	p-value
N	28	21	18	
Male (n (%))	12 (43)	11 (50)	11 (61)	0.48
Age in years	53.8 (17)	68.5 (13)	67.4 (17)	0.003[*]
MMSE		28.9 (3.1)	29.2 (1.7)	0.78
VADL		46.9 (20.6)	41.5 (24.1)	0.51
DHI		30.9 (20.1)	30 (25.6)	0.37
DGI		15.3 (4.2)	17.5 (5.5)	0.19
History of falls (n (%))		9 (43)	8 (44)	1.00

HS: Healthy Subjects; VDZ: Vestibular dizziness; NVDZ: Non-vestibular dizziness; MMSE: Mini-Mental State Examination; VADL: Vestibular Activities of Daily Living; DHI: Dizziness Handicap Inventory; DGI: Dynamic Gait Index.
[*] Statistically significant between the 3 groups ($p < 0.05$).