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Walking speed and vestibular disorders in a path integration task

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Abstract

The goal of this study was to determine if parameters of gait are related to the path integration deficits in some people with vestibular disorders. We tested normals, and two groups of vestibularly impaired people, with unilateral benign paroxysmal positional vertigo and with unilateral weakness. Each group had 20 subjects. They walked straight ahead for 7.62 m, with eyes open or closed, to the beat of a metronome at 60 beats/min, 120 beats/min and 176 beats/min. When adjusted for age and sex, normals veered significantly less and walked significantly further before veering than the unilateral weakness group; all groups veered significantly less at 120 beats/min than the slower or faster cadences. Older patients walked slightly but significantly slower than younger patients at the faster speeds. Step length did not differ among diagnostic groups. These data confirm the involvement of vestibular function in path integration, suggest a differentiation by type of vestibular impairment, and suggest some differences by cadence.

Introduction

Path integration is the ability to keep track of one's position in space with reference to the starting point (1). This skill is a function of the vestibular system (2–4). Normal humans can perform a path integration task when walking along a linear path but patients with acute vestibular lesions are significantly impaired on task performance (5,6). Evidence from one study suggests that path integration skill may be speed dependent (7). The goal of the present study was to learn more about the influence of walking speed and vestibular loss on path integration skill.

Methods

Subjects

Subjects were adults, including 19 males, and 41 females. The 3 groups of subjects were a) 20 normal volunteers recruited from among staff and visitors to the Center for Balance

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Conflict of interest statement

Neither author has a conflict of interest.

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Disorders (mean age 52.5), b) 20 patients with unilateral benign paroxysmal positional vertigo (BPPV) of the posterior semicircular canal who had been referred to the senior author for vestibular rehabilitation who were tested prior to being treated (mean age 58.0), and c) 20 patients with unilateral vestibular weakness (mean age 53.9). Normal volunteers were screened by taking a health history to rule out otologic, neurologic and musculoskeletal disorders after which they were tested with head thrusts (8,9), head shaking and Dix-Hallpike maneuvers. Each BPPV patient had a unilateral, positive response to the Dix-Hallpike maneuver with classical nystagmus (10) while eye movements were recorded with infrared video-oculography, and they had no other significant otologic or neurologic problems. The unilateral weakness patients were of two subtypes: either resection of an acoustic neuroma more than 3 months prior to testing or a weakness of 20% or more on bi-thermal caloric testing with water (10) while eye movements were recorded with infrared video-oculography.

Testing

Subjects were tested in a well-lighted room, with unobstructed walking space approximately 11.5 m X 3.5 m. The floor is covered by 30.48 cm² vinyl tiles. Subjects were asked to walk straight ahead for 7.62 m with eyes either opened or closed (5), to the beat of a metronome at three different speeds -- 60 beats/min (slow), 120 beats/min (medium), 176 beats/min (fast) -- for a total of 6 conditions which were given in randomized order. Dependent measures were angle of veering from the center line, time to complete the task as timed with a stopwatch, distance walked before veering, step length, and number of steps. To calculate the angle of veering and distance walked before veering the grid on the floor, created by the lines between the vinyl tiles, was used to determine when and how far the subject drifted off course. The subject's forward and sideward drift were recorded, from which the angle was calculated. See Figure 1. The number of steps was counted by direct observation. Step length was calculated from the number of steps divided by the distance walked.

Statistical methods

Multilevel analysis (11) and mixed effect models were used to describe changes in primary outcomes of interest (angle of veering from the center line, time to complete the task, distance walked before veering, and number of steps) at various speeds (slow, medium, fast) and eye conditions (open and closed) and to compare the 3 study groups (healthy controls, BPPV, unilateral weakness) on these parameters. A separate model was produced and fitted to each outcome. Within each model, we examined significance of within subject effect (within subject over speed and over eye conditions) and between subjects (between the 3 study groups). Interaction effects were included in each model and tested. Changes over conditions were compared between groups by using a likelihood ratio statistic which follows a chi-square distribution. Adjustments were made for multiple comparisons. $P < .05$ was considered as statistically significant. All analyses were performed using SAS Statistical software (SAS, Carry, NC).

Results

Tables 1 to 3 show descriptive statistics for all dependent measures by test conditions. These measures include angle of veering from the center, step length, distance the subject walked before veering, velocity of walking, and the number of steps taken.

With eyes closed, normals veered significantly less than BPPV ($p=0.048$) and unilateral weakness patients ($p=0.0006$). When adjusted for age and sex, normals still veered significantly less than unilateral weakness subjects ($p < 0.005$). The difference between normals and BPPV subjects was no longer significant ($p=0.1$) and BPPV subjects did not

differ significantly from unilateral weakness subjects ($p=0.5$). Angle of veering was related to speed, even when adjusted for age and sex ($p=0.02$). In general with groups collapsed subjects veered less at the medium speed (5.2°) than the slow (7.2°) or fast speeds (7.1°). See Table 1.

With eyes closed normals walked farther before veering (5.3 m) than unilateral weakness patients (4.2 m); this trend remained significant after adjustment for age and sex (was significant for age ($F=20.7$, $p<0.0001$), sex ($F=8.45$, $p=0.005$) and group ($F=3.7$, $p=0.3$). When adjusted for age and sex the normal and unilateral weakness groups differed significantly ($p<0.03$), indicating that normals walked further than patients before veering but the BPPV group did not differ significantly from either group. See Table 1.

The distance walked before veering might have been a reflection of differences in step length. The diagnostic groups did not differ significantly by step length. Step length was significantly greater at the medium speed compared to the slow ($p=0.002$) or fast ($p=0.56$) speeds. Step length at slow and fast speeds did not differ significantly. Not surprisingly, step length was larger with eyes open than with eyes closed ($p<0.0001$). See Table 2.

In general within each group and visual condition velocity of walking increased significantly with increasing speed ($p<0.0001$). Walking velocity was significantly higher with eyes open than eyes closed within each group and speed condition ($p<0.001$). These relationships remained significant after controlling for age and sex. See Table 3. With the groups collapsed velocity decreased weakly with increased age at medium (Eyes open, $r=-0.3$, $p=0.009$; Eyes closed, $r=-0.3$, $p=0.02$) and fast (Eyes open, $r=-0.2$, $p=0.07$, Eyes closed, $r=-0.3$, $p<0.3$) walking speeds. For normal subjects the relationship between velocity and age was nonsignificant. For the two patient groups the relationship between velocity and age was significant but only moderate, for the BPPV group at the fast speed with eyes closed, $r=-0.5$, $p<0.03$; for the unilateral weakness group at the medium speed with eyes open, $r=-0.5$, $p<0.03$. No other significant correlations between age and velocity were found.

The number of steps did not differ significantly across the three study groups when adjusted for age and sex. Subjects took significantly fewer steps with eyes open than eyes closed; regardless of group ($p=0.0008$). In general the number of steps increased with increasing speed ($p=0.001$). See Table 3.

Discussion

Patients with unilateral weakness veered more than normals, confirming previous findings that this skill is influenced by vestibular function (5,6). Patients with BPPV are not impaired on this task, however, suggesting that they are not impaired on path integration skill. This finding extends the previous work by showing that path integration performance is affected by cadence of walking. Patients with unilateral weakness tend to walk slowly, especially in the acute phase or recovery, and they tend to complain of bumping into walls and other indications of impaired path integration. Patients with BPPV rarely complain of such problems. Thus, the type of vestibular impairment may affect this skill.

In general, this task was more easily performed at 2.0 Hz than at lower or higher frequencies. This finding supports work by other investigators that approximately 120 steps per minute, or 2.0 Hz, is the preferred walking speed for most adults (12) and path integration is more difficult at slower speeds (13). Unlike Bredin et al (13) we did not find a difference in the fast condition. Our paradigm used a defined cadence and they used a cadence defined by the subject's preferred cadence, however. Many of our subjects commented that the task was more difficult at both the slow and fast speeds. Subjects took more steps at the fast speed regardless of group, although they were not instructed how to

walk. This phenomenon may reflect the difficulty of walking at a higher cadence and the fact that preferred walking speed results from combinations of preferred cadence and preferred step length (14), so that when cadence is forced step length must be adjusted. Decreased step length may have the effect of decreasing the thoraco-pelvis relative phase (15). At all speeds the number of steps was highly variable. Many people have difficulty matching auditory metrics (16). Several subjects, including normal people, commented that they do not have musical skills or are unable to sing or dance in rhythm.

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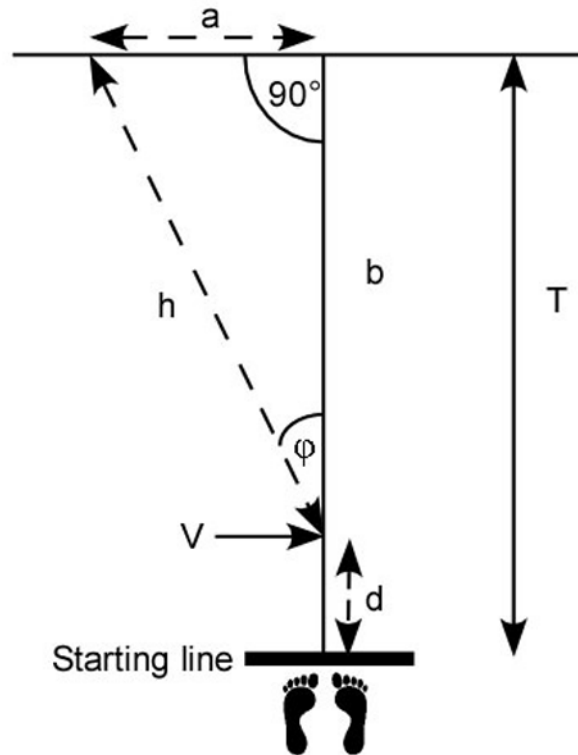


Figure 1.

Diagram of the task for a subject who veered to the left. Subjects were instructed to start at the starting line and walk this distance, T ($T=7.62$ m.). (Feet are not to scale.) Subjects who veered to either side walked the distance, d , to point, V , at which they veered some angle, ϕ , continuing along the trajectory, h , to cross the finish line at point a , h , having moved laterally through the distance, a . (From (5) and used by permission of IOS press.)

Table 1

Mean angle of veering (deg) and mean distance walked before veering (m), (standard deviations and ranges in parentheses) (N = normal, UW = unilateral weakness; EO – eyes opened, EC = eyes closed)

	Angle (deg)			Distance (m)		
	Slow	Medium	Fast	Slow	Medium	Fast
N	EO	0	0	7.62 (0)	7.62 (0)	7.62 (0)
	EC	5.06 (5.0, 0–12.3)	3.0 (3.6, 0–11.5)	4.7 (5.3, 0–19.1)	5.5 (2.2, 1.5–7.6)	5.7 (2.1, 2.1–7.62)
BPPV	EO	0	0	7.62 (0)	7.62 (0)	7.62 (0)
	EC	6.3 (5.6, 0–17.2)	6.7 (4.8, 0–17.2)	8.3 (5.9, 0–22.9)	4.2 (2.7, 0.6–7.62)	4.3 (2.2, 1.6–7.62)
UW	EO	0	0	7.62 (0)	7.62 (0)	7.62 (0)
	EC	10.3 (7.0, 0–28.7)	6.0 (5.3, 0–16.4)	8.4 (8.6, 0–32.7)	3.40 (1.9, 1.2–7.62)	4.5 (2.5, 0.9–7.62)

Table 2

Mean step length (m), (standard deviations and ranges in parentheses) (N = normal, UW = unilateral weakness; EO – eyes opened, EC = eyes closed; Vel= velocity)

		Slow length	Medium length	Fast length
N	EO	0.55 (0.07, 0.44–0.69)	0.63 (0.10, 0.42–0.85)	0.58 (0.12, 0.42–0.85)
	EC	0.49 (0.08, 0.40–0.69)	0.54 (0.09, 0.33–0.76)	0.52 (0.10, 0.35–0.64)
BPPV	EO	0.51 (0.11, 0.24–0.69)	0.56 (0.11, 0.33–0.76)	0.54 (0.14, 0.35–0.76)
	EC	0.46 (0.10, 0.28–0.69)	0.47 (0.10, 0.30–0.64)	0.47 (0.16, 0.22–0.69)
UW	EO	0.53 (0.08, 0.35–0.69)	0.57 (0.09, 0.42–0.76)	0.52 (0.12, 0.30–0.76)
	EC	0.50 (0.26, 0.24–1.52)	0.47 (0.11, 0.29–0.69)	0.44 (0.12, 0.16–0.64)

Table 3

Mean velocity (standard deviations and ranges in parentheses) and median number of steps (ranges in parentheses) (N = normal, UW = unilateral weakness; EO = eyes opened, EC = eyes closed; Vel= velocity)

	Velocity (m/s)			Steps			
	Slow	Medium	Fast	Slow	Medium	Fast	
N	EO	2.0 (0.5, 1.5-3.1)	4.2(0.7, 2.5-5.6)	4.7(1.1, 1.7-7.0)	14 (11-17)	12 (9-18)	13 (9-18)
	EC	1.7 (0.3, 1.2-2.5)	3.4(0.6, 2.5-4.7)	4.3(0.8, 2.9-5.9)	16 (11-19)	14 (10-23)	15 (12-22)
BPPV	EO	1.8 (0.4, 0.8-2.6)	3.8 (0.9, 2.2-5.4)	4.7 (1.1, 3.1-7.4)	15 (11-32)	13 (10-32)	14 (10-22)
	EC	1.6 (0.4, 1.0-2.6)	3.0 (0.8, 2.0-4.5)	3.7 (1.4, 1.5-6.4)	17 (11-27)	14 (10-22)	16 (11-35)
UW	EO	2.0 (0.5, 1.2-3.5)	3.8 (0.7, 2.8-5.4)	4.8 (1.1, 3.1-7.8)	15 (11-22)	14 (10-18)	14 (10-25)
	EC	1.6 (0.5, 0.9-3.4)	3.2 (1.0, 1.8-6.3)	3.5 (1.2, 1.6-5.7)	17 (5-32)	16 (11-26)	18 (12-47)