Supplementary Online Content

Grove CR, Whitney SL, Pyle GM, Heiderscheit BC. Instrumented gait analysis to identify persistent deficits in gait stability in adults with chronic vestibular loss. *JAMA Otolaryngol Head Neck Surg.* Published online July 1, 2021. doi:10.1001/jamaoto.2021.1276

This supplementary material has been provided by the authors to give readers additional information about their work.

eAppendix 1. Criteria for a Diagnosis of Vestibular Hypofunction

Diagnosis of vestibular hypofunction was confirmed with videonystagmography and/or rotational chair testing.[1] A caloric weakness of ≥ 25% was required to confirm a diagnosis of unilateral vestibular hypofunction. A bilateral vestibular hypofunction was diagnosed by videonystagmography when the caloric tests did not reach the 25% criteria for indicating a unilateral weakness, warm irrigations produced nystagmus that was ≤ 10 °/s, each cool caloric produced nystagmus that was ≤ 5 °/s, and the total of all four caloric tests was ≤ 30 °/s. On rotational chair testing, a bilateral hypofunction was diagnosed if there was abnormally low gain for at least two adjacent frequencies (e.g. 0.01-0.02 Hz) of the slow harmonic acceleration test.

eAppendix 2. Additional Information Regarding Tests and Measures

Clinical Examination

The physical exam was conducted by a physical therapist with 27 years of experience in neurological and vestibular rehabilitation. Tests of lower extremity sensorimotor function included touch/pressure sensation (5.07-gram Semmes Weinstein filament), joint position sense, vibratory sensation (128 Hz tuning fork), range of motion, heel-to-shin coordination, and rapid alternating movements. Determination of adequate range of motion was based on visual observation of passive range of motion. Performance on the Five Times Sit to Stand Test[2] was used to determine if participants had normal lower extremity functional strength. Cervical spine clearing (active range of motion, as well as tests for the integrity of the alar and transverse ligaments) was performed before tests involving head movement. Tests of ocular alignment (cover, uncover, alternate cover, Maddox Rod tests, and near point of convergence), oculomotor function (ductions, versions, smooth pursuit, saccades, and vestibular-ocular reflex suppression), nystagmus tests (spontaneous and gaze-evoked nystagmus in room light and spontaneous nystagmus and end-gaze nystagmus with fixation removed), as well as vestibular-ocular function (vestibular-ocular reflex with slow head movements, head impulse test,[3] after-head-shaking-nystagmus,[4] vibration-induced nystagmus,[5] and the non-instrumented dynamic visual acuity test[6] were also performed with all participants. Digital, infrared video-oculography was utilized for oculomotor and vestibular-ocular tests, except dynamic visual acuity testing. Participants who used spectacles wore these when video-oculography was not in use. No healthy adults had evidence of vestibular dysfunction.

Self-report Measures

The Activities-specific Balance Confidence Scale[7] is a 16-question survey that respondents complete by answering each item by indicating how confident they feel about not becoming unsteady or falling. Scores for each item range from 0% to 100%. Higher scores indicate greater confidence.

The Dizziness Handicap Inventory[8] is a 25-question survey that is used to document how often dizziness has affected physical or emotional health or is experienced in functional situations. Respondents answer each

question as “always” = 4 points, “sometimes” = 2 points, or “never” = 0 points to indicate how often dizziness is present. The total score ranges from 0 to 100 points. Higher scores indicate greater perceived handicap.

The Visual Vertigo Analogue Scale[9] is a 9-item survey that is used to assess the intensity of visually induced dizziness. Each question is presented as a visual analog scale with two anchors, 0 (no dizziness) and 10 (extreme dizziness or activity avoidance). The mean score for the VVAS ranges from 0 to 100. Higher scores indicate greater severity of symptoms.

The Vestibular Activities and Participation Measure[10] is a 34-item questionnaire that is used to measure the impact of vestibular loss on focusing attention, moving from sitting to standing, walking on different surfaces, operating a vehicle, shopping, maintaining a job, etc. Responses are scored as “none” = 0 points, “moderate” = 2 points, “severe” = 3 points, or “unable to do” = 4 points. The mean score ranges from 0 to 4. The average score is calculated based on responses to each question that is answered. Higher scores indicate greater impact of vestibular dysfunction on daily activities and participation in life roles.

Capacity-based Measures

The non-instrumented Dynamic Visual Acuity Test was performed in sitting and with best corrected vision.[11-13] An Early Treatment Diabetic Retinopathy Study eye chart was used to establish static (head still) visual acuity first. Then, dynamic (head moving) visual acuity was established while the participant’s head was passively moved by the examiner at 2 Hz. A metronome was used to facilitate appropriate pacing of the head movement. Results are reported as the number of lines lost, i.e., the raw difference between static and dynamic visual acuity.

The Sensory Organization Test[14] is a component of computerized dynamic posturography (Bertec Balance Advantage, Bertec, Corp, Columbus, OH, USA) and is used to assess the influence of sensory input on standing balance. Composite scores are an overall measure of performance and range from 0 to 100. Higher scores indicate better balance.

The Functional Gait Assessment[15] was performed in a clinic hallway with markings that facilitate scoring embedded in the flooring pattern. The test was conducted in accordance with the original test instructions. Standardized obstacles were used for FGA item 6 (Step Over Obstacle task) and the same set of stairs was used for FGA item 10 (Stair Climbing task). A stopwatch was used to record times for FGA item 1 (Walking, Eyes Open

task) and FGA item 8 (Walking, Eyes Closed task). Participants wore their preferred, flat-soled shoes. Rest between tasks was provided if requested by participants.

The instrumented 2-minute Walk Test[16] was conducted in a vacant rehabilitation gym. The instructions to participants were standardized as follows. “Stand quietly and looking forward with your legs straight, feet pointed forward, and arms at your sides. Remain still until you hear the long tone. When you hear the long tone, start walking at a natural and comfortable pace. Continue walking along the path, turning around 180° at either end. When you hear the second, long tone, stop walking and then remain still.”

The inertial measurement units include a 3-axis accelerometer, a 3-axis gyro, a 3-axis magnetometer, and a temperature sensor (Mobility Lab, APDM, Inc., Portland, OR, USA; hardware version 1.0, software version 2.0). These wearable sensors weight < 25 grams each and were wirelessly synchronized with each other. Data are sampled at 128 Hertz. Each inertial measurement unit has a storage capacity of 8 gigabytes.

Definitions:

Gait Cycle: The time elapsed from one heel contact to the next heel contact of the same foot.

Gait Velocity: The forward distance traveled during a gait cycle divided by the duration of that gait cycle.

Cadence: The number of steps per minute.

Double Support: The percentage of the gait cycle during which both feet are in contact with the ground.

Stride Length: The forward distance traveled by either foot during a gait cycle.

Turn Angle: The rotational angle of a turn in the transverse plane.

Turn Duration: The time elapsed during the turn.

Peak Turn Velocity: The peak angular velocity of the turn in the transverse plane.

Mean Turn Velocity: The rotational angle of the turn divided by the turn duration.

eTable 1. Results of the Correlational Analyses

Measure	N	Pearson's *r* (95% CI)	ES (95% CI)
Stride Length (left)			
ABCS (Mean Score)	30	0.40 (0.04, 0.66)	0.87 (0.08, 1.67)
DHI (Total score)	30	-0.47 (-0.71, -0.14)	-1.06 (-1.89, -0.24)
VVAS (Mean Score)	30	-0.40 (-0.67, -0.05)	-0.87 (-1.67, -0.08)
DVAT (Horizontal)	30	-0.39 (-0.65, -0.03)	-0.85 (-1.64, -0.06)
DVAT (Vertical)	30	-0.39 (-0.66, -0.03)	-0.85 (-1.64, -0.06)
SOT (Composite)	30	0.51 (0.18, 0.73)	1.19 (0.34, 2.03)
FGA (Total)	30	0.57 (0.26, 0.77)	1.39 (0.5, 2.27)
Stride Length (right)			
ABCS (Mean Score)	30	0.45 (0.10, 0.70)	1.01 (0.19, 1.82)
DHI (Total score)	30	-0.52 (-0.74, -0.20)	-1.22 (-2.07, -0.37)
VVAS (Mean Score)	30	-0.36 (-0.64, 0.00)	-0.77 (-1.55, 0.01)
DVAT (Horizontal)	30	-0.43 (-0.68, -0.08)	-0.95 (-1.76, -0.15)
DVAT (Vertical)	30	-0.43 (-0.68, -0.08)	-0.95 (-1.76, -0.15)
SOT (Composite)	30	0.57 (0.26, 0.77)	1.39 (0.5, 2.27)
FGA (Total)	30	0.62 (0.33, 0.8)	1.58 (0.65, 2.51)
Peak Turn Velocity			
ABCS (Mean Score)	30	0.57 (0.26, 0.77)	1.39 (0.5, 2.27)
DHI (Total score)	30	-0.66 (-0.83, -0.4)	-1.76 (-2.73, -0.79)
VVAS (Mean Score)	30	-0.38 (-0.65, -0.02)	-0.82 (-1.61, -0.03)
DVAT (Horizontal)	30	-0.63 (-0.81, -0.35)	-1.62 (-2.56, -0.69)
DVAT (Vertical)	30	-0.61 (-0.79, -0.32)	-1.54 (-2.46, -0.62)
SOT (Composite)	30	0.63 (0.36, 0.81)	1.62 (0.69, 2.56)
FGA (Total)	30	0.68 (0.42, 0.83)	1.85 (0.86, 2.85)

Abbreviations: CI, confidence interval; ES, effect size (Cohen's *d*); ABCS, Activities-specific Balance Confidence Scale; DHI, Dizziness Handicap Inventory; VVAS, Visual Vertigo Analogue Scale; DVAT, dynamic visual acuity test, SOT, Sensory Organization Test; FGA, Functional Gait Assessment.

eTable 2. Individual Data for Healthy Adults

Age [a]	Gender	Lesion	Fall Hx	ABCS	DHI	VVAS	VAPM	FGA	SOT	SL (L)	SL (R)	PTV
31.50	Male	Healthy	No	100	0	0	NA	29	85.1	1.22	1.21	179
35.52	Male	Healthy	No	100	0	0	NA	30	86.1	1.67	1.68	198
42.41	Male	Healthy	No	100	0	0	NA	29	84.9	1.48	1.48	233
22.92	Female	Healthy	No	98	0	0	NA	30	81.5	1.50	1.49	187
27.83	Female	Healthy	No	99	0	0	NA	29	85.5	1.39	1.38	273
28.66	Female	Healthy	No	99	0	0	NA	30	90.7	1.51	1.50	316
30.03	Female	Healthy	No	99	0	0	NA	29	86.0	1.28	1.28	277
31.55	Female	Healthy	No	99	0	0	NA	29	79.9	1.39	1.39	191
35.34	Female	Healthy	No	99	0	0	NA	30	83.2	1.25	1.25	240
36.28	Female	Healthy	No	100	0	0	NA	30	86.7	1.62	1.60	254
39.67	Female	Healthy	No	98	0	0	NA	30	84.9	1.53	1.53	275
40.76	Female	Healthy	No	98	0	15	NA	29	81.7	1.36	1.36	252
41.20	Female	Healthy	No	100	0	0	NA	28	87.2	1.44	1.44	235
53.02	Female	Healthy	No	100	0	0	NA	30	76.7	1.56	1.55	287
53.68	Female	Healthy	No	100	0	0	NA	30	80.7	1.47	1.43	364
65.28	Female	Healthy	No	96	0	0	NA	27	80.8	1.38	1.37	204
51.98	Male	Healthy	Yes	100	0	0	NA	30	88.6	1.63	1.62	259

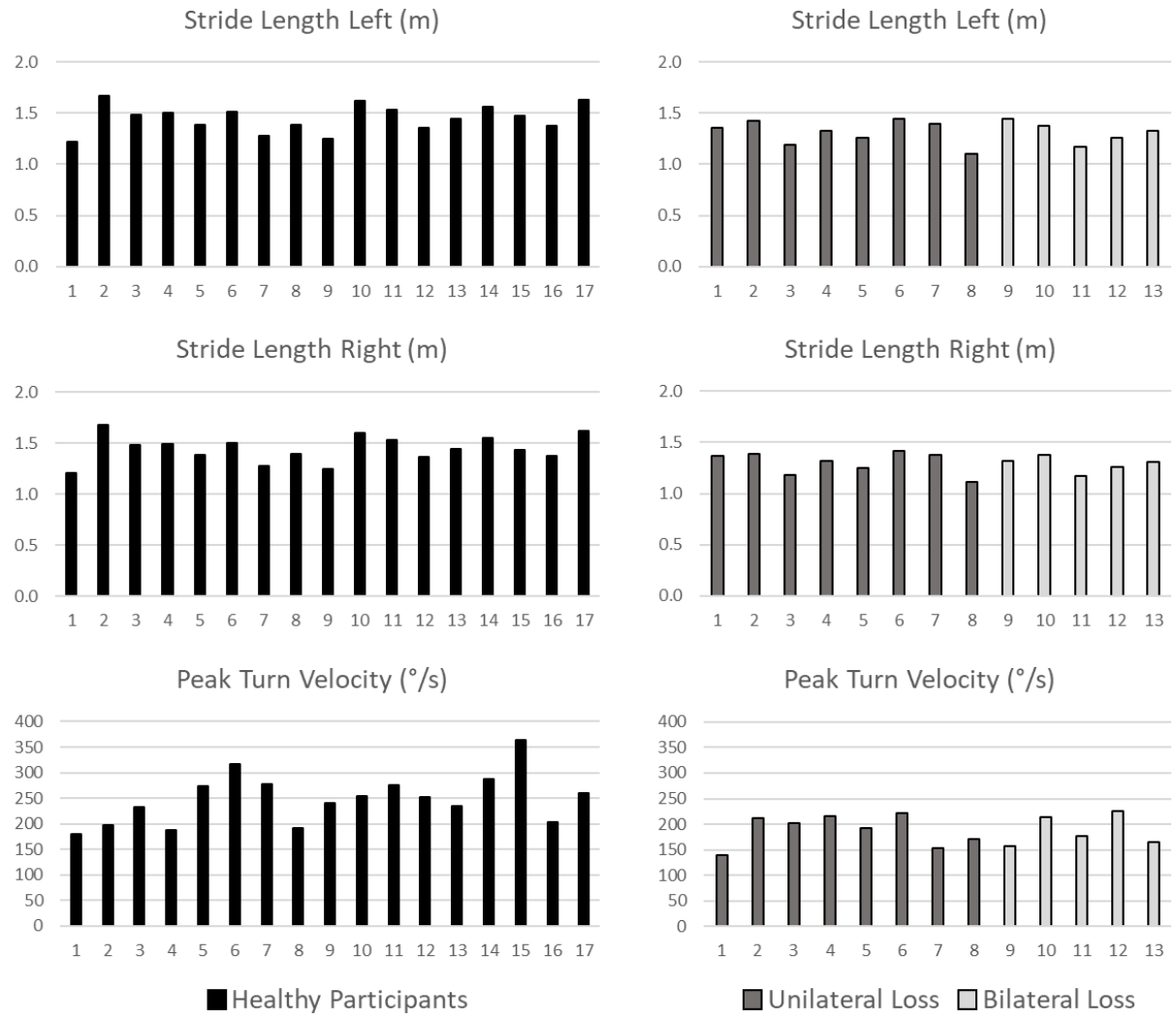
Abbreviations: Hx, history; ABCS, Activities-specific Balance Confidence Scale (average score); DHI, Dizziness Handicap Inventory (total score); VVAS, Visual Vertigo Analogue Scale (average score); Vestibular Activities and Participation Measure (average score); FGA, Functional Gait Assessment (total score); SOT, Sensory Organization Test (composite score); SL, stride length (meters); L, left; R, right; PTV, peak turn velocity (degrees per second).
[a] = Age is reported in years.

eTable 3. Individual Data for Adults With Vestibular Loss

Age [a]	Gender	Lesion	Fall Hx	ABCS	DHI	VVAS	VAPM	FGA	SOT	SL (L)	SL(R)	PTV
67.86	Male	Left	No	66	44	39	3.14	24	70.5	1.36	1.37	139
51.64	Female	Left	No	86	36	19	0.70	28	77.8	1.42	1.39	212
50.80	Male	Left	Yes	94	28	15	0.57	29	54.9	1.19	1.18	202
54.64	Male	Right	No	98	14	0	0.14	29	79.7	1.33	1.32	216
79.67	Female	Right	No	96	24	33	0.38	25	73.9	1.26	1.25	193
46.80	Male	Right	Yes	89	12	0	0.14	30	83.2	1.44	1.42	222
70.55	Male	Right	Yes	95	16	0	0.16	21	67.9	1.40	1.38	153
71.28	Female	Right	Yes	94	36	15	0.96	23	74.1	1.10	1.11	170
63.82	Male	Bilateral	No	61	32	0	1.00	15	16.1	1.44	1.32	157
45.50	Female	Bilateral	No	73	28	60	0.91	20	60.0	1.38	1.38	213
63.50	Female	Bilateral	No	99	22	0	0.52	20	46.6	1.17	1.17	177
68.12	Female	Bilateral	No	96	6	0	0.21	26	74.8	1.26	1.26	226
52.32	Male	Bilateral	Yes	45	80	54	1.43	16	60.6	1.33	1.31	165

Abbreviations: Hx, history; ABCS, Activities-specific Balance Confidence Scale (average score); DHI, Dizziness Handicap Inventory (total score); VVAS, Visual Vertigo Analogue Scale (average score); Vestibular Activities and Participation Measure (average score); FGA, Functional Gait Assessment (total score); SOT, Sensory Organization Test (composite score); SL, stride length (meters); L, left; R, right; PTV, peak turn velocity (degrees per second).
[a] = Age is reported in years.

eFigure. Individual-Level Stride Length and Peak Turn Velocity Data



Abbreviations: m, meters; °/s, degrees per second.

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