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THE EFFECTS OF WHOLE BODY ROTATIONS IN THE PITCH AND YAW PLANES ON POSTURAL STABILITY

Frederick R. Carrick *[*1,2], ***Guido Pagnacco***[1,2], ***Elena Oggero***[1,2],
Stephanie Sullivan[3], ***Derek Barton***[3], ***Susan Esposito***[3],
Gerry Leisman[1,4,5] ***and Robert Melillo***[1]
[1]The FR Carrick Institute for Clinical Ergonomics, Rehabilitation and Applied Neuroscience, Garden City, NY, 11530 USA;
[2]Carrick Institute for Graduate Studies, Cape Canaveral, FL, USA
[3]Life University, Marietta, Georgia
[4]F. R. Carrick Research Institute at Herzog Hospital Jerusalem, Israel 91351
[5]Faculty of Medicine, The Hebrew University of Jerusalem 91220

ABSTRACT

BACKGROUND:

Many movement disorders and neurological syndromes are associated with pathology of balance and gait and there is a need to implement preventive and therapeutic measures and strategies to identify, assess, and target high-risk persons.

METHODS:

Twenty-five Participants underwent computer-controlled multi-axis chair rotation in combinations of whole body Pitch and Yaw simultaneously over a 40 second profile at 90 deg/sec (15 RPM). Pre and post rotational Computerized Dynamic Posturography (CDP) provided outcome measures in all participants. *Results:* Whole body rotational stimulation in combined yaw and pitch planes improves stability, reduces sway and has a beneficial impact on participants.

CONCLUSIONS:

The therapeutic use of multi-axis whole body rotations in the treatment of patients with fall risk or pathology of station and gait is suggested.

Keywords: Posturography, Balance, Falls, Gyroscope, Rotational Chair, Vestibular, Movement Disorders.

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[*] Correspondence: Prof. Frederick Carrick, Carrick Institute for Graduate Studies, Department of Neurology, 203-8941 Lake Drive Cape Canaveral, Florida 32920, E-mail: drfrcarrick@gmail.com

POTENTIAL CONFLICT OF INTEREST:

Drs. Guido Pagnacco and Elena Oggero are currently employed and are part owners (25% each) of Vestibular Technologies, LLC, the company that manufactures and sells the CAPS Professional computerized dynamic posturography system used in the research, and co-own the rights to the U.S. patents that apply to that system.

INTRODUCTION

Many movement disorders are associated with pathology of balance and gait and there is a need to implement preventive and therapeutic measures and strategies to identify, assess, and target high-risk persons. Vestibular information is critical for the control of balance, posture, and eye movements. Signals from the receptors, the semicircular canals and otoliths, are carried by the eighth nerve and distributed to the four nuclei of the vestibular nuclear complex (VNC). Otolith stimulation engages brainstem structures both within and outside of the vestibular nuclear complex, many of which project to the cerebellum [1].

We desired to stimulate the vestibular system to see if we would be able to improve balance. We were specifically interested in mechanisms that would activate the neck and core musculature. The motor system that controls the neck musculature stabilizes the head to external perturbations or body movements, and generates both voluntary and orientating head movements. These movements are mediated by complex pathways involving the cerebral cortex and superior colliculus while stabilization is thought to be mediated by simple short-loop pathways that generate vestibulocollic (VCR) and cervicocollic (CCR) reflexes [2].

The VCR and CCR attempt to stabilize head position in space during whole body movements and are subserved by relatively direct, as well as indirect pathways linking vestibular nerve activity to cervical motor neurons [3,4]. Head stability is important during human balance corrections and the VCR modulates the amplitude of functionally stabilizing responses and damps mechanically induced instability of the head and neck [5]. Patients often time complain of stability problems when moving the head. The short-latency VCR is not suppressed by active head turns and its amplitude is not consistently modulated by the direction of head turns [6]. When the head rotates, VCR counteracts the rotation by causing contraction of the neck muscles that pull against the imposed motion [7].

We know that transient passive head rotations in PD (Parkinson's disease) patients are followed by an initial rapid rise in resistive torque representing reflexive head stabilization that normal participants are able to suppress [8]. PD patients have gait instability and often have absent VCR [9], prompting us to investigate its stimulation. Elderly participants rely upon a combination of active trunk mechanics and vestibular integration in order to coordinate their head and trunk motion [10].

Rotation of the body and head in vertical planes of the VCR and of activation of vestibular neurons projecting to the neck tend to be antagonistic with the vector orientations usually opposite, and the response gains and phases similar in decerebrate cats [11]. We anticipated similar activities in humans, knowing that the CCR and VCR behave approximately linearly, both individually and in combination. Acting together, the two reflexes assist each other in preventing oscillation of the head on a stationary body [12].

We considered a variety of methods of vestibular stimulation and addressed natural activation by head and body rotations. Yaw head-movement kinematics are unaffected by changes in the head's inertia when the whole body is rotated. The VCR and CCR accommodate for changes in the head's inertia that produces forces on the neck when the body moves and stabilizing the head with respect to the trunk during whole body movements. Stiffness and VCR gain appear to be the primary contributors to the control of head stabilization in space. When angular velocities of the head and trunk in yaw and pitch are induced, the behavior of the head in yaw is found to change relatively little with added inertia while in pitch, increasing inertia accentuates phase shifts at higher frequencies [13].

We thought that whole body rotations in a gyroscope might be effective in increasing balance. Incremental rotation axes for both pitch and yaw oscillations are functions of the pitch but not the yaw head positions, perhaps because of the head interface with the dens and occipital condyles during head oscillation with a contribution of the lower spine to pitch during locomotion [14]. Anteflexion and retroflexion of the head are among the main movements of the atlanto-occipital joint and head movements produce neck proprioceptive stimulation in the vestibular system [15] which we thought might be beneficial. Stabilization of the head is required for adequate motor performance, including maintaining balance while standing or walking, and for the adequate reception of sensory inputs such as visual and auditory information.

The vestibular organs (semicircular canals, utriculus, sacculus), provide the most important input for the detection of head movement and their activation evokes the VCR which stabilizes head position in space [16]. Otolith and canal inputs are superposed when animals are rotated about roll and pitch axes from an upright position, insuring that these neurons respond over a broad frequency range from very low to high frequencies [17] and allow detection of linear acceleration generated by two different head conditions, dynamic linear translation and static tilt relative to gravity [18]. Otoliths also contribute to the perception of head rotation whole-body constant-velocity pitch rotations about an earth-horizontal, interaural axis because they sense the changes in direction of the gravity vector [19].

The convergence of canal and otolith inputs contribute mainly to vestibulospinal (VSP) reflexes by sending inputs to the neck and other muscles during head inclination [20] but also activate brain structures involved in movement disorders. For instance, activation of the sacculus evokes VCR activation of a multisensory cortical vestibular network within both hemispheres, including the posterior insular cortex, the middle and superior temporal gyri, and the inferior parietal cortex [21].

There are differences between responses to vertical and horizontal rotations [22] suggesting that we would need to rotate participants in combined planes. The sensory signal from the semicircular canals in constant-velocity chair rotations undergoes neural processing to compute the percept of self-motion [23] an important contribution to human stabilization. Sensory vestibular signals are transformed from head-in-space coordinates to trunk-in-space coordinates on many secondary vestibular neurons in the vestibular nuclei by the addition of inputs related to head rotation on the trunk [24]. Stability is dependent upon adaptation to body motions and adaptation to head movements performed during fast rotation during supine head-on-axis rotation is specific to the particular plane of the head movement [25].

Postural compensatory head pitch movements may be produced predominantly by the angular vestibulocollic reflex (aVCR) at low walking speeds and by the linear vestibulocollic reflex (1VCR) at the higher speeds [26]. During mixed angular head accelerations, the VCR may be partly accomplished by VSP and vestibulo-oculospinal (VOS) convergent neurons. For instance, stimulation of the anterior semicircular and/or posterior semicircular canal nerves in decerebrate cats evoke four types of collateral projections to the oculomotor complex and spinal cord; vestibulo-ocular, vestibulospinal, vestibulo-oculospinal, and vestibular neurons [27]. We wanted to see if such stimulation in humans would evoke similar postural responses when they are accelerated in a variety of planes. Low acceleration anteroposterior movement in the standing position induces a body sway in proportion to the acceleration, pivoting on the ankle joint, while high acceleration increases body sway with the head-neck joint remaining locked upright [28].

The postural responses of the neck muscles suggest that the VCR might tonically activate them. Banovetz et al. recorded electromyographic activity of dorsal neck muscles and neck torques to study VCR, CCR, and combined reflexes in cats during rotations about many axes. They characterized neck muscles by maximal activation direction vectors and found that all muscles were excited by the nose down phase of pitch rotation and by yaw and roll away from the side on which the muscle lay. All muscles responded as though they received convergent input from all three semicircular canals [29].

The spatial response properties of medial (MVST) and lateral (LVST) vestibulospinal tract neurons during whole body sinusoidal angular rotations of cats in various planes demonstrate a maximum activation direction vector (MAD) that maximally excites the neuron [30]. We wanted to stimulate human participants in a combination of planes to attempt a similar maximized response. It is likely that activation of reticulospinal fibers, with their resultant motor consequences, are an important part of the neural substrate of the VCR [31]. Reticulospinal fibers make an important contribution to the horizontal VCR and in response to stimuli in vertical planes, the pontomedullary reticulospinal fibers depend on convergence of inputs within the neck with otolith reflexes [32].

Natural stimulation of the labyrinth of decerebrate cats in vertical planes evokes responses of pontomedullary reticulospinal neurons, the largest fraction of which project to the lumbar cord, playing a role in gravity-dependent postural reflexes of neck and limbs [33]. The effectiveness of vestibulospinal and reticulospinal fibers can be modified by spontaneous activity of neurons in the C3 ventral horn subsequent to sinusoidal vestibular stimulation of decerebrate paralyzed cats in multiple vertical planes [34].

Many movement disorders that are associated with balance pathology involve the cerebellum. All cerebellar patients demonstrate impaired otolith-ocular responses and may demonstrate severe vestibular deficits [35]. Impairment of the corresponding otolith-spinal reflexes may contribute substantially to falls which pose an important problem to neurologists caring for patients with cerebellar disorders [36]. Cerebellar disease results in a higher sensitivity of anterior rather than posterior semicircular canal pathways, perhaps through the loss of inhibition from the flocculus/paraflocculus complex on anterior canal secondary neurons in the vestibular nuclei [37]. We know that sustained centrifugation decreases gravitational modulation, reflecting a shift towards a more body centered frame of reference [38] and this is what we desired to explore.

METHODS

PARTICIPANTS

This study was approved and conducted in accordance with the Helsinki Declaration and registered (ClinicalTrials.gov NCT01188161). Twenty-five participants, 16 Males and 9 Females, participated in the study. Their age, height and weight statistics are reported in Table I.

PROCEDURE

Initial baseline Computerized Dynamic Posturography (CDP) testing was obtained after practice sessions on all participants using a CAPS Professional system (Vestibular Technologies, Cheyenne WY, USA). All tests where conducted with the subject standing on a perturbing foam cushion. Six different conditions were tested in sequence without the participants stepping away from the foam/platform in order to assess if the center of sway position changed with the changing test conditions: (1) Eyes Open Head Neutral, (2) Eyes Closed Head Neutral, (3) Eyes Closed Head Right, (4) Eyes Closed Head Left, (5) Eyes Closed Head Flexed, (6) Eyes Closed Head Extended. Participants underwent computer-controlled multi-axis chair (Gyrostim, UltraThera Technologies, Colorado Springs CO, USA) in combinations of whole body Pitch and Yaw simultaneously over a 40 second profile at 90 deg/sec (15 RPM). The acceleration rates to 90 degrees per second as well as deceleration rates were linear and occurred in 1 second. We designed rotations that would represent all combinations of pitch and yaw with Pitch direction changing two times and Yaw direction four times (Backward Pitch-20 seconds with right Yaw-10 seconds to left Yaw-10 seconds, to Forward Pitch- 20 seconds with right Yaw-10 seconds to left Yaw 10 seconds) as demonstrated in Figure 1. Post rotational CDP testing was obtained using the CAPS Professional System in the same sequencing as the pre CDP measurements.

Table I. Subject characteristics

	Males	Females	Overall
Number	16	9	25
Min Age (years)	24	24	24
Ave Age (years)	31.6	28.8	30.6
Max Age (years)	52	34	52
StDev Age (years)	8.1	3.9	6.9
Min Height (m)	1.73	1.52	1.52
Ave Height (m)	1.80	1.61	1.73
Max Height (m)	1.91	1.7	1.91
StDev Height (m)	0.06	0.06	0.11
Min Mass (kg)	61.3	50.0	50
Ave Mass (kg)	87.6	64.1	79.1
Max Mass (kg)	136.3	85.6	136.3
StDev Mass (kg)	19.1	13.5	20.6
Min BMI	19.3	18.3	18.3
Ave BMI	27.0	24.6	26.1
Max BMI	37.6	32.4	37.6
StDev BMI	5.3	5.0	5.2

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ANALYSIS

To investigate the effect of different test configurations on the pre-rotation posturographic results, one tailed t-tests for paired observations with significance set at $p<0.05$ were conducted between the results of test condition 2 (Eyes Closed Head Neutral on Perturbed Surface) and those of the other test conditions. The test condition 2 was chosen as the reference condition because it is considered the most challenging of the standard mCTSIB test conditions. The effect of gender was also investigated by performing two-tailed t-tests between the results of the male and female participants.

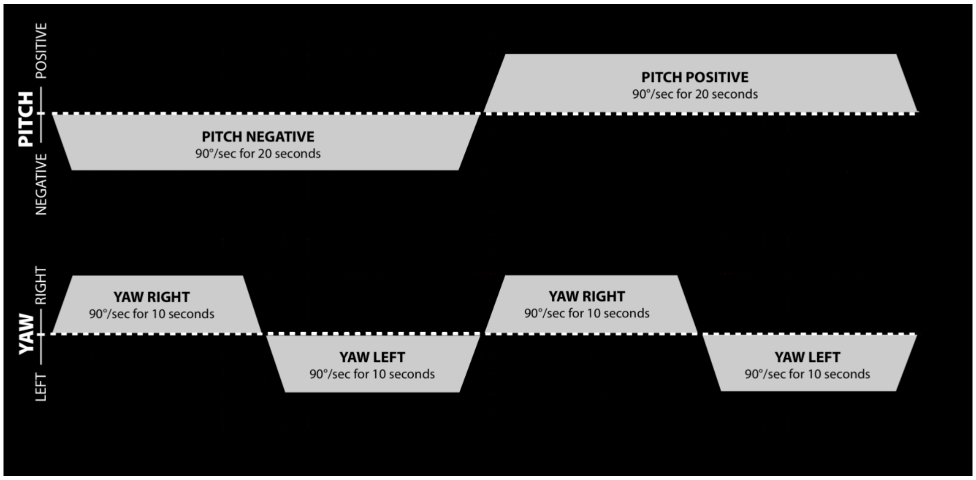

Figure 1. Multi-Axis Whole Body Rotations.

RESULTS

No significant difference was found with the two-tailed t-tests between the results of the male and female participants and therefore all subsequent analysis were performed considering male and female participants together (Tables II and III). When closing the eyes (test Condition 1 to 2) participants shifted their weight anteriorly about 5.5 mm. The results also show that there was a significant decrease in stability (and a corresponding increase in sway) as measured by the Stability Score, Average and Maximum Normalized R, Normalized 95% Circle Area, Normalized 95% Ellipse Area and Normalized Average Velocity Moment, both from test Condition 1 to 2 and from test Condition 2 to 6, (comparing head straight eyes open to eyes closed and head straight eyes closed to head extended eyes closed conditions).

This increase in sway measures was also accompanied by an increase of the Normalized Average Velocity and Acceleration as well as of the Normalized Maximum Velocity, but not of the Normalized Maximum Acceleration.

No significant differences were present between test Conditions 2 and 3 (head to the right). Between test Conditions 2 and 4 (head to the left) only the Maximum Normalized R, Normalized Maximum Velocity, and Normalized Maximum Acceleration decreased significantly.

Table II. Pre-rotational CDP results in the time domain: in bold p<0.05

		1	2	3	4	5	6
Stability Score (%)	Ave	86.6	73.3	73.6	73.3	76.1	59.8
	StDev	4.3	8.8	6.6	7.1	4.6	11.4
	t-test p	**0.000**		0.437	0.490	0.086	**0.000**
Fatigue	Ave	0.000	0.014	-0.036	-0.069	0.012	0.000
	StDev	0.244	0.329	0.232	0.231	0.243	0.434
	t-test p	0.433		0.283	0.141	0.493	0.398
Xo (mm)	Ave	0.019	-0.426	2.215	-2.367	-0.361	1.113
	StDev	5.096	6.108	9.728	7.066	6.299	7.992
	t-test p	0.363		0.094	0.134	0.480	0.264
Yo (mm)	Ave	-10.745	-5.274	-5.124	-3.134	-7.606	-0.347
	StDev	10.720	12.407	11.010	13.810	9.739	14.454
	t-test p	**0.008**		0.478	0.240	0.194	0.094
Directionality	Ave	0.347	0.279	0.209	0.265	0.238	0.301
	StDev	0.153	0.118	0.102	0.124	0.130	0.143
	t-test p	0.053		**0.026**	0.317	0.164	0.301
Normalized R Ave (mm/m)	Ave	4.255	8.745	9.071	8.969	8,175	13.028
	StDev	1.231	2.656	2.128	2.258	1.457	3.494
	t-test p	**0.000**		0.284	0.320	0.174	**0.000**
Normalized R Max (mm/m)	Ave	11.848	24.998	23.608	22.979	21.138	37.068
	StDev	3.830	7.279	6.011	5.511	4.820	11.668
	t-test p	**0.000**		0.151	**0.039**	**0.015**	**0.000**
Normalized V Ave (mm/s/m)	Ave	14.011	31.797	32.770	30.971	27.188	44.864
	StDev	4.474	10.556	8.999	8.565	5.926	14.499
	t-test p	**0.000**		0.243	0..248	**0.009**	**0.000**
Normalized V Max (mm/s/m)	Ave	69.665	144.591	134.974	120.259	105.850	214.150
	StDev	61.582	70.734	40.875	32.470	19.888	104.561
	t-test p	**0.000**		0.241	**0.037**	**0.004**	**0.006**
Normalized A Ave (mm/s^2/m)	Ave	206.263	418.263	439.605	417.191	354.561	602.908
	StDev	80.422	171.716	144.701	119.264	91.907	227.269
	t-test p	**0.000**		0.121	0.477	**0.020**	**0.000**
Normalized A Max (mm/s^2/m)	Ave	1496.5	2793.3	2221.4	1917.9	1865.2	3827.1
	StDev	2119.1	2442.1	855.6	664.4	746.8	2464.8
	t-test p	**0.008**		0.120	**0.038**	**0.014**	0.094
Normalized 95% Circle Area (mm^2/m^2)	Ave	223.6	949.8	943.4	908.1	720.4	2064.7
	StDev	136.0	684.7	459.1	432.3	236.4	1062.1
	t-test p	**0.000**		0.457	0.367	0.059	**0.000**
Normalized 95% Ellipse Area (mm^2/m^2)	Ave	132.9	605.9	640.4	605.8	493.4	1308.2
	StDev	66.4	393.9	302.6	281.8	164.4	689.0
	t-test p	**0.000**		0.338	0.500	0.094	**0.000**
Normalized Velocity Moment Ave (mm^2/s//m^2)	Ave	39.8	116.1	131.4	116.7	89.5	288.9
	StDev	26.1	68.4	62.7	53.7	31.6	.340.5
	t-test p	**0.000**		0.066	0.480	**0.028**	**0.008**

Table III. Pre-rotational CDP results in the frequency domain: in bold p<0.05

		1	2	3	4	5	6
Normalized Fz Total Power (*10-6)	Ave	20.4	122.3	105.6	91.9	58.2	376.5
	StDev	27.9	243.2	129.2	92.1	43.0	394.0
	t-test p	**0.018**		0.270	0.190	0.073	**0.001**
Fz Centroidal Frequency (Hz)	Ave	3.512	3.316	3.388	3.389	3.313	3.136
	StDev	0.542	0.424	0.290	0.326	0.345	0.234
	t-test p	0.061		0.175	0.186	0.485	**0.036**
Fz Frequency Dispersion	Ave	0.417	0.420	0.394	0.400	0.418	0.412
	StDev	0.125	0.104	0.055	0.046	0.082	0.081
	t-test p	0.458		0.107	0.155	0.432	0.379
Normalized CoPx (ML) Total Power (*10-6)	Ave	7.3	44.0	51.7	42.8	31.6	75.2
	StDev	4.1	21.1	31.1	21.0	11.2	43.0
	t-test p	**0.000**		0.071	0.347	**0.002**	**0.001**
CoPx (ML) Centroidal Frequency (Hz)	Ave	0.884	0.836	0.882	0.868	0.778	0.783
	StDev	0.147	0.148	0.196	0.212	0.147	0.233
	t-test p	0.134		0.141	0.212	0.147	0.233
CoPx (ML) Frequency Dispersion	Ave	0.749	0.772	0.776	0.805	0.762	0.794
	StDev	0.082	0.071	0.095	0.078	0.084	0.070
	t-test p	0.146		0.422	0.068	0.314	0.181
Normalized CoPy (AP) Total Power (*10-6)	Ave	13.1	53.2	46.1	44.5	40.3	133.5
	StDev	6.9	46.5	22.5	19.9	15.5	69.0
	t-test p	**0.000**		0.225	0.149	0.082	**0.000**
CoPy (AP) Centroidal Frequency (Hz)	Ave	0.835	0.794	0.888	0.842	0.845	0.825
	StDev	0.239	0.200	0.183	0.154	0.165	0.285
	t-test p	0.238		**0.035**	0.149	0.168	0.292
CoPy (AP) Frequency Dispersion	Ave	0.812	0.760	0.792	0.785	0.805	0.786
	StDev	0.097	0.068	0.082	0.066	0.091	0.081
	t-test p	**0.022**		0.061	0.061	**0.016**	0.135

Between test Conditions 2 and 5 (head flexed) there was an improvement in all stability measures (corresponding to a decrease in sway and its velocity and acceleration) although this was only significant for the Average and Maximum Normalized R, Average and Maximum Normalized Velocity and Average, Maximum Normalized Acceleration, and Average Velocity Moment.

In summary, it appears that as expected, going from eyes open to eyes closed consistently increases all the sway measurements. No consistent changes occurred with eyes closed by turning the head to the right or to the left. Flexing the head with eyes closed seemed to reduce some of the sway measures and extending it consistently increased all the sway measures. The frequency domain results showed a corresponding increase in power for the vertical ground reaction force as well as the CoP AP and ML sway from test condition 1 to 2 as well as from 2 to 6, and a decrease from test Condition 2 to 5 (except in the AP direction). All participants underwent post whole body rotation CPD testing using the same protocols as in the pre-rotational testing. To investigate the effects of the Rotation, one tailed t-tests for paired observations with significance set at p<0.05 was conducted between the pre and post CDP results for each of the testing Conditions. A preliminary analysis was conducted to see if there were any differences between male and female participants for each of the test conditions using two-tailed t-tests assuming unequal variances and as no significant differences was found, male and female participants were considered together in the rest of the analysis (Tables IV and V).

Table IV. Post-rotational CDP results in the time domain and t-test p comparing pre- and post-rotational results; in bold p<0.05

		1	2	3	4	5	6
Stability Score (%)	Ave Post	86.7	75.4	77.5	76.5	77.3	65.6
	StDev Post	4.8	7.5	6.6	8.1	5.0	9.4
	t-test p	0.469	**0.030**	**0.001**	**0.013**	0.109	**0.001**
Fatigue	Ave Post	-0.015	-0.052	-0.036	-0.065	0.069	-0.026
	StDev Post	0.257	0.345	0.259	0.289	0.228	0.313
	t-test p	0.403	0.250	0.500	0.473	0.235	0.414
Directionality	Ave Post	0.379	0.287	0.213	0.218	0.256	0.297
	StDev Post	0.166	0.130	0.086	0.131	0.122	0.128
	t-test p	0.240	0.402	0.433	0.071	0.322	0.384
Normalized R Ave (mm/m)	Ave Post	4.168	8.054	7.608	8.044	7.563	11.147
	StDev Post	1.265	2.245	2.020	2.927	1.530	2.707
	t-test p	0.396	**0.014**	**0.000**	**0.031**	**0.017**	**0.000**
Normalized R Max (mm/m)	Ave Post	11.035	22.374	19.911	20.721	20.258	30.668
	StDev Post	4.641	6.452	5.900	6.782	4.760	10.501
	t-test p	0.208	**0.009**	**0.001**	0.054	0.206	**0.006**
Normalized V Ave (mm/s/m)	Ave Post	13.035	27.876	27.953	27.602	24.717	41.776
	StDev Post	3.327	10.298	8.880	8.678	6.338	14.968
	t-test p	0.079	**0.001**	**0.001**	**0.008**	**0.001**	0.101
Normalized V Max (mm/s/m)	Ave Post	62.494	108.105	112.670	104.279	94.623	182.462
	StDev Post	38.650	43.674	43.526	32.499	21.134	102.713
	t-test p	0.306	**0.002**	**0.004**	**0.012**	**0.016**	0.117
Normalized A Ave (mm/s^2/m)	Ave Post	212.952	370.602	385.957	377.814	340.333	572.671
	StDev Post	97.807	180.472	168.131	126.256	105.605	221.262
	t-test p	0.380	**0.006**	**0.008**	**0.013**	0.174	0.232
Normalized A Max (mm/s^2/m)	Ave Post	1640.5	1838.7	1883.6	1662.3	1671.2	3289.8
	StDev Post	2056.2	1124.0	870.7	547.0	642.2	1906.2
	t-test p	0.403	**0.011**	**0.032**	**0.040**	0.151	0.215
Normalized 95% Circle Area (mm^2/m^2)	Ave Post	210.6	783.0	703.3	789.4	668.7	1562.9
	StDev Post	153.6	485.2	392.1	689.9	290.7	985.3
	t-test p	0.369	**0.013**	**0.002**	0.171	0.165	**0.002**
Normalized 95% Ellipse Area (mm^2/m^2)	Ave Post	121.1	501.4	467.5	540.0	436.7	976.3
	StDev Post	71.5	297.6	247.2	515.6	184.7	562.7
	t-test p	0.223	**0.005**	**0.001**	0.223	**0.040**	**0.002**
Normalized Velocity Moment Ave (mm^2/s//m^2)	Ave Post	48.1	102.7	112.1	101.8	96.0	191.7
	StDev Post	20.9	70.6	64.0	67.4	33.4	109.0
	t-test p	0.068	0.050	0.064	0.080	0.144	0.080

Table V. Post-rotational CDP results in the frequency domain and t-test p comparing pre and post rotational results; in bold p<0.05

		1	2	3	4	5	6
Normalized Fz Total Power (*10-6)	Ave Post	13.1	110.9	90.9	68.9	56.8	314.1
	StDev Post	12.5	281.0	185.8	79.8	91.3	578.4
	t-test p	0.073	0.206	0.235	**0.010**	0.457	0.314
Fz Centroidal Frequency (Hz)	Ave Post	3.620	3.372	3.437	3.433	3.469	3.257
	StDev Post	0.410	0.257	0.256	0.275	0.330	0.295
	t-test p	0.145	0.239	0.113	0.135	**0.002**	**0.038**
Fz Frequency Dispersion	Ave Post	0.441	0.402	0.385	0.394	0.395	0.419
	StDev Post	0.133	0.066	0.062	0.051	0.055	0.050
	t-test p	0.247	0.204	0.254	0.287	0.111	0.353
Normalized CoPx (ML) Total Power (*10-6)	Ave Post	6.8	32.3	38.8	42.2	32.3	60.1
	StDev Post	4.2	15.8	26.4	41.8	16.8	35.4
	t-test p	0.265	**0.000**	**0.003**	0.465	0.424	**0.017**
CoPx (ML) Centroidal Frequency (Hz)	Ave Post	0.779	0.771	0.785	0.750	0.757	0.766
	StDev Post	0.147	0.284	0.051	0.168	0.212	0.215
	t-test p	0.296	0.251	**0.009**	**0.027**	0.150	0.479
CoPx (ML) Frequency Dispersion	Ave Post	0.764	0.765	0.779	0.796	0.821	0.804
	StDev Post	0.084	0.089	0.069	0.080	0.068	0.071
	t-test p	0.274	0.395	0.446	0.342	**0.002**	0.334
Normalized CoPy (AP) Total Power (*10-6)	Ave Post	11.3	45.3	35.1	34.9	35.9	96.0
	StDev Post	9.2	36.7	18.0	24.2	20.0	54.2
	t-test p	0.164	0.083	**0.019**	**0.009**	0.149	**0.001**
CoPy (AP) Centroidal Frequency (Hz)	Ave Post	0.898	0.818	0.821	0.804	0.758	0.822
	StDev Post	0.281	0.198	0.118	0.166	0.166	0.153
	t-test p	0.202	0.331	**0.080**	0.158	**0.047**	0.476
CoPy (AP) Frequency Dispersion	Ave Post	0.849	0.779	0.790	0.764	0.797	0.766
	StDev Post	0.076	0.071	0.065	0.071	0.065	0.074
	t-test p	**0.007**	0.150	0.467	0.123	0.339	0.189

It appears there is an improvement in the stability and a reduction of the sway of the participants following the stimulation with the Gyrostim, although this is not always significant. Only the Average Normalized Velocity Moment appears to increase, although in a non-significant way, for test conditions 1 and 5 between pre and post Gyrostim stimulation, and the normalized Maximum Acceleration also increases in a non-significant way for test condition 1. Consistently with the stability improvements there were improvements also manifesting in a reduction of the total vertical ground reaction force, AP and ML sway power, sometimes accompanied by a decrease in the centroidal frequencies of the sway with an increase in the centroidal frequency of the vertical ground reaction force.

DISCUSSION

The pre-rotational CDP results indicated that sway increased and the stability decreased in going from eyes open to eyes closed, as was expected. Turning the head with the eyes closed both to the right and to the left had only minor effects on the stability and sway. These responses were found in normal participants and might not be the same in patients with problems of balance and gait. We found that flexing the head with eyes closed produced a stabilizing effect, although this was not significantly consistent across all the measures, whereas extending the head significantly increased the subject's instability across almost all measures. This suggests that patients with or without balance problems or a risk of falls might benefit from strategies that encourage head flexion while any activity that involves head extension should be avoided. It appears that whole body rotational stimulation in combined yaw and pitch planes improves stability, reduces sway and has a beneficial impact on participants.

The therapeutic use of such systems in the treatment of patients with fall risk or pathology of station and gait is suggested but not yet tested. The benefits we found were not always significant, possibly because the stimulation was generalized and was not tailored to the subject. We would encourage future investigations of this modality in specific conditions and with specific combinations of yaw and pitch in maintained planes.

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