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Deborah S Nichols, Terri M Glenn and Karen J Hutchinson

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Changes in the Mean Center of Balance During Balance Testing in Young Adults

Background and Purpose. The analysis of standing balance is now possible using commercially available force platforms. In order to establish appropriate testing and treatment protocols for patient populations, we contend data should be collected relative to the typical response of nonpatient groups. More importantly, we need to better understand response characteristics of persons with intact nervous systems. The purpose of this study was to evaluate the typical response of young adults without known musculoskeletal or neurological impairments to balance testing with the Balance System™. **Subjects.** Sixty-six subjects without known impairments (mean age= 23.6 years, SD= 4.5, range= 21–47) were evaluated in a single testing session. **Methods.** Center of balance (COB), a vertical force measurement, was evaluated under each of 18 conditions: 2 visual conditions (eyes open, eyes closed), 3 platform conditions (stable, vertical tilt, linear translation), and 3 foot positions (apart, together, tandem). **Results.** An effect was found for average displacement to the left along the x axis under all testing conditions. The COB locus along the y axis was dependent on the foot position, platform condition, and visual condition. **Conclusion and Discussion.** Movement of the COB toward the center of the base of support accompanied closing of the eyes, narrowing of the base of support, and movement of the support surface. These findings are consistent with the need to move the center of gravity away from the limits of stability under more challenging stance conditions. This study contributes to the existing knowledge base related to standing balance function in young adults without musculoskeletal or neurological impairments and provides data that can be used for criterion-based comparisons of young adult patients. [Nichols DS, Glenn TM, Hutchinson KJ. Changes in the mean center of pressure during balance testing. *Phys Ther.* 1995;75:699–706.]

**Deborah S Nichols
Terri M Glenn
Karen J Hutchinson**

Key Words: Balance assessment, Center of pressure, Postural control.

DS Nichols, PhD, PT, is Assistant Professor, Physical Therapy Division, School of Allied Medical Professions, The Ohio State University, 1583 Perry St, Columbus, OH 43210 (USA) (Nichols.3@postbox.acs.ohio-state.edu). Address all correspondence to Dr Nichols.

TM Glenn, PhD, PT, is Lecturer, Physical Therapy Division, School of Allied Medical Professions, The Ohio State University.

KJ Hutchinson, PT, is a doctoral student in the Neuroscience Program, The Ohio State University. She was Graduate Research Assistant, Physical Therapy Division, School of Allied Medical Professions, The Ohio State University, when this study was completed.

The testing protocol was approved by The Ohio State University Biomedical Sciences Human Subject Review Committee.

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Balance can be defined as the ability to maintain the body's center of gravity (COG) within the base of support with minimal sway.^{1,2} The COG refers to a point in the body at which the total force of gravity is considered to act and that is projected vertically onto the support surface.³ The maintenance of the COG within the base of support involves integration of visual, vestibular, and somatosensory system inputs with motor control system outputs that coordinate muscular contractions.⁴ As

the base of support (BOS) changes, these sensory systems must detect the change, and the motor system must adapt to the new demands of the posture so that balance can be maintained.

Although the demands of remaining upright during standing necessitate that the COG be maintained within the BOS, postural sway results in movement of the COG during quiet stance.^{1,5-9} This movement is constrained within the individual's limits of stability, which are the points at which balance is lost and a correcting strategy is required to return the COG within the base of support. These points are said to define a cone about the base of support.^{1,6}

The quantification of balance has taken several forms, including measuring the movement of the COG (postural sway) under various testing conditions. This is most commonly done by using force platforms, which can measure the vertical force projected on them by a standing subject. As the subject sways in any direction, the relative pressure on each foot changes, allowing for a determination of the direction and magnitude of the sway.

Furthermore, the instantaneous center of pressure (COP) and mean center of pressure (MCOP) can be computed as the center point of the vertical projections onto the force platform at any point in time or for the duration of a test, respectively.^{5,10-12} Measurements of COP reflect not only the ground reaction force (force necessary to oppose the vertical force) but also the moment data produced by the muscle response required to maintain stance.¹³

In the absence of postural sway, there is no moment and the COP is therefore equal to the vertical projection of the COG.¹⁴ With postural sway, however, there is a distortion between the movement of the COG and the

change in the COP measurement,¹⁵ reflecting the motor response to produce balance recovery (moment).¹⁶ In addition, during movement there is a smooth transition of the COG from the starting position to the terminal position; however, the COP tends to vacillate anterior and posterior to the COG as the movement is produced.¹⁷ Nonetheless, the MCOP is thought to represent the average vertical projection of the center of gravity (MCOG) over the course of a testing trial.¹⁵

During testing of nonpatient populations on a stable force platform, it has been reported that the MCOP has been located at various points within the base of support.^{5,7,16} These measurements suggest that during quiet stance, the individual assumes his or her own comfortable stance for the moment, and that this stance is reflected in the measurement of the MCOP. When the maintenance of balance is challenged, however, the individual must return the COP (COG) within the base of support quickly, or balance will be lost.^{1,6} Nashner¹ suggests that if the COG is located at the extremes of the cone of stability at the time that balance is disturbed, the individual will be unable to return the COG within the BOS and a fall will result. This suggests that as the demands for remaining erect increase, the MCOP measured should be closer to the center of the base of support (CBOS). Kirby et al⁵ noted that changes in foot position (ie, varying the anterior-posterior or medial-lateral distance between the feet or the amount of toeing-in or toeing-out) resulted in movement of the MCOP. The MCOP was reported to be more lateral, usually to the right, when the feet were placed together and more posterior when the feet were placed in a tandem position; the latter finding was independent of whether the dominant or nondominant foot was posterior.⁵ All testing, however, was conducted under static conditions that did not challenge the postural control system.

Testing conditions, including visual input and surface characteristics, have also been reported to alter the measured amount of postural sway. Many researchers^{8,18-20} have reported an increase in postural sway with visual deprivation (eyes closed); however, the locus of the MCOP during these tests was not reported. In addition, changes in the support surface, either compliance or size, have been noted to increase postural sway and alter the balance strategy used to maintain stance.^{1,19} Again, the locus of the MCOP was not examined.

Many force-plate systems are commercially available for the evaluation of balance in clinical settings. The Balance System™* is one such system. Unlike other systems, however, the Balance System™ measures ground reaction force without measuring moment; therefore, it provides a measure of a COB (related to but not equal to COP) that is said to reflect the change in the percentage of body weight recorded on each footplate away from the geometric CBOS.²¹ Because force platform systems, including the Balance System™, are being used more frequently for the evaluation and treatment of patients with neurologic and orthopedic injuries, we contend that typical responses to testing under a variety of conditions in nonpatient populations should be determined so that patient responses can be compared with measurements obtained from persons without deficits.

The objective of our study was to evaluate the typical changes in the locus of the COB associated with testing conditions (foot position, platform condition, and visual condition) in young adults without known orthopedic or neurologic disorders when testing with the Balance System™. Testing was conducted to evaluate (1) the locus of the COB during static stance with the feet in three different foot positions (apart, together, tandem) (2) changes in the COB during balance disturbances created by vertical rotation or linear translation of the support platform, (3) changes in the COB measurement associated with visual deprivation (eyes closed), and

*Chattanooga Group Inc, 4717 Adams Rd, PO Box 489, Hixson, TN 37343.

(4) interactive effects of these testing conditions.

Method

Subjects

A sample of convenience, consisting of 66 subjects recruited from the students in the Physical Therapy Division, School of Allied Medical Professions, The Ohio State University (Columbus, Ohio), participated in this study. The subjects (18 male, 48 female) ranged in age from 21 to 47 years ($\bar{X}=23.6$, $SD=4.5$). All subjects were Caucasian. Subjects with a history of orthopedic, neurologic, or vestibular disease as well as those taking any medication that might influence their balance were excluded from the study; these criteria were evaluated by an interview with each subject. Each subject participated in a single 30-minute testing session. Informed consent was received from all subjects.

Instrumentation

Balance testing was conducted using the Balance System™, which is designed to measure vertical forces. This unit is composed of a platform capable of vertical rotation and linear translation, four independent force transducers embedded within two footplates, and a computer. The two footplates comprise the support surface for the heel and toe of each foot during testing; therefore, the relative pressure on the toe versus the heel can be determined for each foot. These footplates are movable on the platform, allowing for testing with the feet in a variety of positions. Input to the computer allows the relative platform position of each footplate to be replicated on a grid on the computer screen from which the computer calculates the geometrical CBOS. The COB is then determined from the vertical force measurements recorded by the force transducers. These data are provided as x and y coordinates (COBx, COBy), representing the percentage of change in body weight distribution away from the geometrical center as well as the direction of that change. If the COB is the same as the

geometrical CBOS, the x,y coordinates (COBx, COBy) would be 0. A weight shift forward is depicted as a positive COBy; conversely, a weight shift posteriorly results in a negative COBy. Likewise, a weight shift to the right results in a positive COBx and a weight shift to the left results in a negative COBx.²²

Peer-reviewed analysis of the mechanical properties of the device was not available, and all descriptions of performance characteristics are those claimed by the manufacturer.²² Each force transducer collects the force data at a rate of 20 Hz or 25 data points per second during a 10-second test; this sampling rate allows for the collection of 1,000 data points per test (25 data points \times 4 transducers \times 10 seconds). Each set of 4 data points (1 from each transducer) is used to compute an instantaneous COB, and all 1,000 data points are used to compute a mean COB, defined by its x,y coordinates (COBx and COBy) for the test duration.

According to the manufacturer,²² the Balance System™ platform can produce a sinusoidal vertical tilt (tilt the toes up and down relative to the heel) or linear translation (anterior-posterior) at a constant speed, creating mild disturbances of balance. The total vertical displacement of the toes during the vertical-tilt condition is claimed to be 8 degrees (4° up and 4° down), which occurs at a speed of 2°/s. The total linear displacement is said to be 4.31 cm (1.5 in) (1.9 cm [0.75 in] forward and 1.9 cm backward), which occurs at a speed of 2.54 cm (1 in) each 0.8 seconds.²² All descriptions, as noted earlier, are based on the manufacturer's information and were not verified as part of this study.

Testing

Each subject underwent a series of tests on the Balance System™. With the subject's feet in each of three positions (apart, together, and modified tandem), testing was conducted under two visual conditions (eyes open [EO] and eyes closed [EC]) and three platform conditions (stable, vertical tilt,

and linear translation). This involved a single test under each of these 18 conditions for every subject. Each test lasted 10 seconds, with the total testing session for each subject lasting 20 to 30 minutes. Randomization of the test order was conducted, varying the order of foot placement and platform condition, to prevent ordering effects. Testing with eyes open, however, was always conducted before testing with eyes closed under each condition.

Foot positions were individualized for each subject. The distance separating the footplates in the feet-apart condition was established as the comfortable stance posture of the individual, but this distance was maintained at least as a 5.08-cm (2-in) separation to differentiate the feet-apart condition from the feet-together condition. The modified tandem position consisted of placing the footplates, one ahead of the other, a distance of a "natural" step for each subject, with the same lateral distance separating them as in the feet-apart condition. In both the feet-apart and tandem conditions, the toes could be turned out from the heel to provide a comfortable stance for each subject. For the tandem condition, the placement of the foot (left/right) in the forward position was also randomly determined. Foot dominance was not evaluated. During the feet-together condition, the footplates were placed together in the midline of the platform.

In a pilot study, the COBx and COBy measurements for these conditions were found to demonstrate acceptable levels of test-retest reliability. Three groups ($n=11$) of young adults without any known diagnosis underwent three separate trials of each testing condition in a given foot position (apart, together, or tandem). Intraclass correlation coefficients (ICC[1,1]) calculated were above the .60 level, ranging from .60 to .97 for all tests except for COBy under the feet-apart/vertical-tilt/EC (ICC=.56), tandem/vertical-tilt/EC (ICC=.41), and tandem/linear-translation/EC (ICC=.42) conditions (unpublished data, this laboratory). We believe the lower ICCs reflect a learning effect with repeated

Table 1. Sample Distribution of Center of Balance X-Coordinate Measurements^a

Foot Position	Platform Condition					
	Stable		Vertical Tilt		Linear Translation	
	EO ^b	EC ^c	EO	EC	EO	EC
Apart						
Range	-19.2 to 11.8	-18.1 to 11.4	-22.5 to 14.3	-22.2 to 12.2	-16.2 to 11.7	-21.0 to 9.8
\bar{X}	-1.56	-1.75	-1.47	-1.79	-1.46	-2.09
SD	6.01	6.04	6.95	6.07	6.39	5.65
SE	0.74	0.74	0.86	0.75	0.79	0.70
CI ^d	-3.01 to -0.11	-3.21 to -0.29	-3.15 to 0.21	-3.25 to -0.33	-3.00 to 0.08	-3.45 to -0.73
Together						
Range	-15.2 to 12.6	-19.7 to 21.5	-19.0 to 24.8	-28.8 to 21.5	-17.3 to 29.3	-22.7 to 25.8
\bar{X}	-2.34	-1.19	-1.19	-1.64	-1.93	-1.14
SD	6.54	7.62	8.19	9.16	8.07	7.72
SE	0.80	0.94	1.01	1.13	0.99	0.95
CI	-3.92 to -0.76	-3.03 to 0.65	-3.17 to 0.79	-3.85 to 0.57	-3.88 to 0.02	-3.00 to 0.72
Tandem						
Range	-35.8 to 33.7	-32.7 to 38.8	-38.2 to 29.5	-29.4 to 36.9	-33.6 to 38.0	-28.1 to 31.0
\bar{X}	-1.35	-1.75	-1.60	-0.80	-2.44	-2.30
SD	15.48	14.96	14.56	15.38	15.50	14.51
SE	1.91	1.84	1.79	1.89	1.91	1.79
CI	-5.08 to 2.38	-5.36 to 1.86	-5.11 to 1.91	-4.51 to 2.91	-6.18 to 1.30	-5.80 to 1.20

^aExpressed as change in percentage of body weight on each footplate away from the geometric center of the base of support.

^bEO=eyes-open visual condition.

^cEC=eyes-closed visual condition.

^dCI=confidence interval.

testing. In the present protocol, we used a single-trial design to minimize learning effects.

Data Analysis

Repeated-measures one-way analyses of variance (ANOVAs) were conducted to analyze the location of the COBx and COBy across testing conditions, using visual condition (EO,EC), platform condition (stable, vertical tilt, linear translation), and foot position (apart, together, tandem) as the within-subject factors. The probability values were adjusted by the Geisser-Greenhouse method appropriate for repeated-measures designs.²³ A Tukey Honestly Significant Difference *post hoc* analysis was used to evaluate any main effect or interaction.

Results

General Findings

All subjects were able to complete the 18 tests in the study protocol. Several subjects lost their balance during testing, as indicated by opening their eyes, grabbing the handrails, or taking a step, primarily during the EC/feet-together/vertical-tilt condition. The trial was stopped at the point balance was lost, and retesting was conducted for that particular trial. No subject lost his or her balance during the retesting trial.

The mean, standard deviation, standard error, and 95% confidence interval were computed for the COBx (Tab. 1) and COBy (Tab. 2) for each testing condition. The significant effects for the ANOVAs are depicted in Table 3.

COBx

The analysis of the COBx identified an overall subject preference for weight distribution toward the left across testing conditions ($P<.05$). This asymmetry was not influenced by the testing conditions.

COBy

The analysis of the COBy revealed that the locus of the COB along the y axis was dependent on the visual condition ($P<.05$), platform condition ($P<.001$), and foot position ($P<.01$). *Post hoc* analysis determined that the COBy was displaced posteriorly in the EO condition but returned to an almost neutral position in the EC condition (Fig. 1). The locus of the COB along the y axis was different for each platform condition, being posterior during stable stance, returning to al-

Table 2. Sample Distribution of Center of Balance Y-Coordinate Measurements^a

Foot Position	Platform Condition					
	Stable		Vertical Tilt		Linear Translation	
	EO ^b	EC ^c	EO	EC	EO	EC
Apart						
Range	-43.5 to 49.4	-34.9 to 43.3	-25.8 to 38.8	-42.7 to 47.2	-34.0 to 38.2	-28.4 to 34.1
\bar{X}	-5.33	-1.68	-0.54	1.89	4.65	5.50
SD	18.12	16.56	14.10	18.02	14.53	13.67
SE	2.23	2.04	1.74	2.22	1.79	1.68
CI ^d	-9.70 to -0.96	-5.68 to 2.32	-3.94 to 2.86	-2.46 to 6.24	1.14 to 8.16	2.20 to 8.80
Together						
Range	-39.4 to 45.5	-25.6 to 37.4	-29.1 to 28.9	-27.3 to 38.0	-31.0 to 32.6	-23.9 to 47.2
\bar{X}	-4.81	-3.21	-1.64	2.34	2.73	3.66
SD	17.05	14.75	15.74	15.49	14.15	15.96
SE	2.10	1.82	1.94	1.91	1.74	1.96
CI	-8.92 to -0.70	-6.77 to 0.45	-5.44 to 2.16	-1.40 to 6.08	-0.68 to 6.14	-0.19 to 7.51
Tandem						
Range	-41.9 to 29.0	-30.3 to 35.8	-30.8 to 26.6	-48.6 to 35.2	-36.2 to 22.5	-36.6 to 29.8
\bar{X}	-8.85	-5.37	-1.40	-1.25	-1.04	-1.31
SD	14.34	12.59	13.50	16.50	14.76	15.05
SE	1.76	1.55	1.66	2.03	1.82	1.85
CI	-12.3 to -5.39	-8.41 to -2.33	-4.66 to 1.86	-5.23 to 2.73	-4.60 to 2.52	-4.94 to 2.32

^aExpressed as change in percentage of body weight on each footplate away from the geometrical center of the base of support.

^bEO=eyes-open visual condition.

^cEC=eyes-closed visual condition.

^dCI=confidence interval.

most neutral during vertical tilt, and moving anteriorly during linear translation (Fig. 2). During stance with the feet apart and together, the COBy tended to be closer to the geometrical center but moved more posterior with the feet in tandem (Fig. 3). This result occurred despite the randomization of right/left foot placement in the posterior positions and demonstrates a tendency for individuals to stand on the posterior foot in the tandem position.

Discussion

We sought to evaluate changes in the COB, as measured by the Balance System™, secondary to testing conditions in young adults without known impairment of systems that could affect balance. The findings suggest

that testing conditions affect COBy measurements but not COBx measurements.

The effect for the overall COBx mean suggests that subjects tended to maintain their weight slightly to the left for all testing conditions. This finding is in contrast to the findings of Kirby et al,⁵ who reported a tendency for a weight shift to the right, which was significant only in the feet-together position. Dickstein et al,²⁴ however, examining the standing balance of geriatric subjects, found the MCOP to be over the left foot. Murray et al¹⁶ reported that 16 men had their weight on the right and 8 men had their weight on the left during double-limb stance. These differences in the reported COP/COBx position may be secondary to testing

Table 3. Significant Effects of the Analyses of Variance

Variable	df	SS	F	P
COBx ^a -mean	1	3256.87	4.83	.0315
COBy ^b -visual condition	1	818.93	4.81	.0319
COBy-platform condition	2	11982.30	31.75	.0000
COBy-foot position	2	2956.19	5.67	.0067

^aCOBx=center of balance for the x coordinate.

^bCOBy=center of balance for the y coordinate.

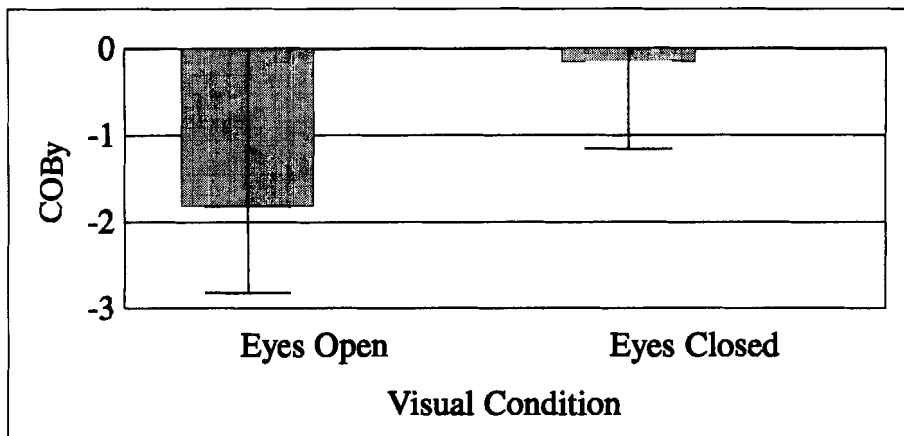


Figure 1. Locus of center of balance for the y coordinate (COBy) associated with visual condition. A significant change in the COBy toward the center of the base of support was noted in the eyes-closed condition ($P < .05$).

protocols. In our study, a 10-second test was used. Kirby et al⁵ used a 20-second test, and Murray et al¹⁶ used a 15-second test. Dickstein et al²⁴ did not describe the testing interval. Single-limb stance studies have suggested that stance on the right leg is more difficult than stance on the left leg, which suggests a preferred stance leg.¹⁸ Increased medial-lateral sway during a longer test might account for movement from this preferred stance leg (left) to the less preferred leg (right) in the study by Kirby et al.⁵ Interestingly, Murray et al¹⁶ found that weight distribution to the right and left was independent of leg dominance.

An alternative explanation focuses on the setup of the Balance System™. With this unit, the examiner stands to the left of the platform and is visible to the subject. This factor may have resulted in the subjects orienting themselves to the left side of the platform despite instructions to look straight ahead. The orientation of the examiner to the force platform in the other studies was not reported.^{5,16,24} We believe that further evaluation of the COBx is needed to determine the relevance of this finding.

The measurement of COBy demonstrated significant effects for each test-

ing variable. The changes noted in the locus of the COBy in our study are in agreement with the expectation of Nashner¹ for MCOP movement. During stance with the eyes open or the platform stable, the COBy was located the furthest from the CBOS. Closing the eyes or moving the platform (either vertically or linearly) resulted in movement of the COBy toward the CBOS. Therefore, as the demands for maintaining balance increased, the subjects appeared to bring their COB closer to the geometrical CBOS to prevent a fall. Altering the foot position also changed the COBy locus. With the feet apart or together, the COBy was located relatively close to the CBOS. With the feet in the tandem position, however, the COBy was located posteriorly, demonstrating a tendency for subjects to stand with a greater amount of weight distributed on the posterior foot. This finding is consistent with the report of Kirby et al⁵ that the COP was posterior in the tandem position, regardless of whether the dominant or nondominant foot was posterior. The tendency for the COBy to be closer to the CBOS when the feet were positioned apart or together suggests that a more narrow base of support is more challenging, thereby necessitating this movement of the MCOP further from the limits of stability. This finding is also consistent with the results of the study by Kirby et al.⁵

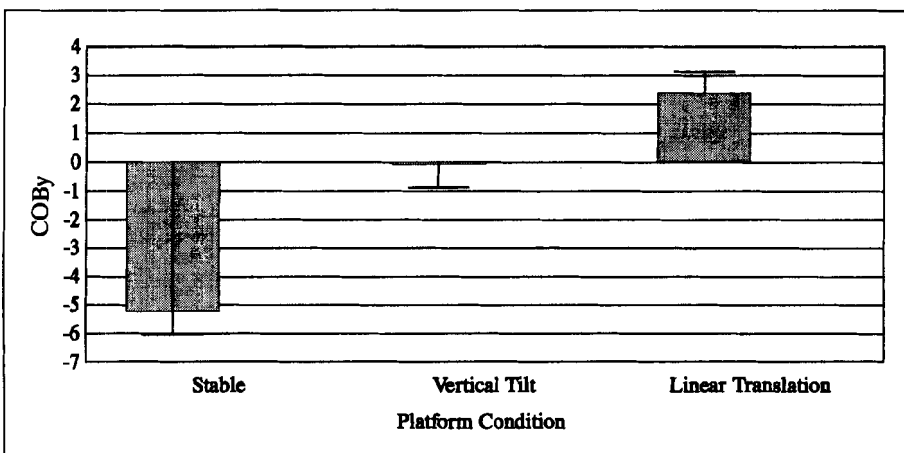


Figure 2. Locus of center of balance for the y coordinate (COBy) associated with platform condition. A significant main effect for platform condition was found ($P < .001$). Each condition was significantly different from the others.

The ranges, as well as the standard deviations, of the COBx and COBy measurements under each of the testing conditions were relatively large (Tabs. 2, 3), demonstrating substantial variation in COB locus between subjects. We believe the robust nature of the findings, however, suggests that the patterns identified were consistent between subjects. Most, but not all, subjects had a COBx measurement that was oriented to the left. In addition, the relative movements of the COB along the y axis followed the described patterns of movement for most subjects. There was a tendency for an individual subject to have a characteristic COB locus (eg, anterior or posterior), but the changes associated with the testing conditions, such

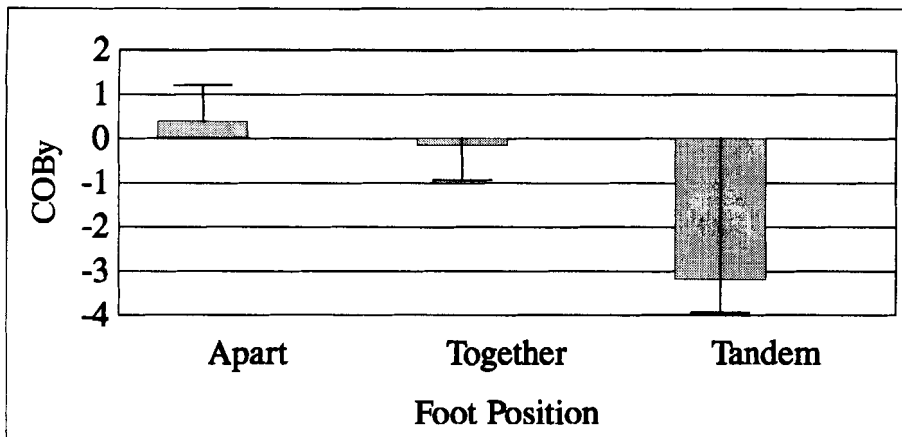


Figure 3. Locus of center of balance for the y coordinate (COBy) associated with foot position. A significant main effect for foot position was found ($P < .01$). The COBy in the tandem condition was significantly more posterior than the COBy in the other two conditions.

as centering of the COB under more challenging conditions, occurred despite this characteristic orientation. For example, a subject who had a forward orientation under the stable conditions typically had a more forward orientation under the linear-translation conditions and an orientation somewhere between the two during the vertical-tilt conditions. Thus, stance is characterized by an individualized posture, especially along the anterior-posterior axis. As the task of maintaining stance becomes more difficult, however, the stance posture between individuals becomes more similar and less individualized.

Anthropometric measurements and limb dominance were not evaluated as part of our study. Murray et al¹⁷ reported that height did not effect COG or COP measurements. Nashner¹ stated that height and foot length covary, resulting in approximately equal limits of stability for individuals of different sizes. In addition, in our study we used a repeated-measures analysis in which each subject served as his or her own control; therefore, the variables of height, weight, and foot length should not have affected the trends described.

Age, however, has repeatedly been found to affect postural sway^{8,11,18} as well as COP measurements.^{11,16} In our

study, we evaluated changes in young adults with no known musculoskeletal or neurologic pathologies; therefore, the data reported reflect the changes in the COB in this population of subjects only. Evaluation of these findings in older subjects is now under way.

Our study identified typical changes in the COB measurement of the Balance System™ in the testing of young adults without any known pathology. This measurement reflects the vertical force measurement used in the calculation of COP. Grabiner et al²¹ developed a mathematical formula for conversion of COB coordinates to COP data, but only for testing with the feet aligned side by side on the platform. We would expect, however, that the magnitude of the COP measurements by other force platform systems would vary under the different testing conditions used in our study, but that the locus of the MCOP would be similar to the COB locus in our study.

Conclusions

The findings of our study indicate that the locus of the COB along the y axis is affected by visual deprivation, foot position, and movement of the support surface. Movement of the COB toward the geometric CBOS along the y axis accompanied closing of the eyes, narrowing of the base of support

(feet apart or together), and movement of the support surface (vertical tilt or linear translation).

Although a relatively small sample of convenience was used in our study, we believe the data developed could be appropriate to use for some comparisons when evaluating patients with neurological impairments whose ages correspond to the age range of the subjects in our study. Patients whose COB measurements fall outside the 95% confidence interval under the described testing conditions (Tab. 2) could be considered to be functioning abnormally under these testing conditions. As our study indicates, it is not sufficient for a patient to be able to maintain the COB within the BOS during quiet stance, or even to shift weight from one foot to the other under static conditions. The patient must also be able to move the COB closer to the geometric CBOS under more challenging conditions (visual deprivation, perturbations, changes in foot position). Treatment goals should reflect this need. It should be noted, however, that the relative interaction between the ability to move the COB under these testing conditions and the ability to move the COB during functional tasks, such as reaching forward, has not been evaluated. Research into this relationship is needed.

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