

# EquiTest modification with shank and hip angle measurements: differences with age among normal subjects

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The Sensory Organization Test protocol of the EquiTest system (NeuroCom International, Clackamas Oregon) tests utilization of visual, vestibular, and proprioceptive sensors by manipulating the accuracy of visual and/or somatosensory inputs during quiet stance. In the standard Sensory Organization Test, both manipulation of sensory input (sway-referencing) and assessment of postural sway are based on ground reaction forces measured from a forceplate. The purpose of our investigation was to examine the use of kinematic measurements to provide a more direct feedback signal for sway-referencing and for assessment of sway. We compared three methods of sway-referencing: the standard EquiTest method based on ground reaction torque, kinematic feedback based on servo-controlling to shank motion, and a more complex kinematic feedback based on servo-controlling to follow position of the center of mass (COM) as calculated from a two-link biomechanical model. Fifty-one normal subjects (ages 20–79) performed the randomized protocol. When using either shank or COM angle for sway-referencing feedback as compared to the standard EquiTest protocol, the Equilibrium Quotient and Strategy Score assessments were decreased for all age groups in the platform sway-referenced conditions (SOT 4, 5, 6). For all groups of subjects, there

were significant differences in one or more of the kinematic sway measures of shank, hip, or COM angle when using either of the alternative sway-referencing parameters as compared to the standard EquiTest protocol. The increased sensitivities arising from use of kinematics had the effect of amplifying differences with age. For sway-referencing, the direct kinematic feedback may enhance ability to reduce proprioceptive information by servo-controlling more closely to actual ankle motion. For assessment, kinematics measurements can potentially increase sensitivity for detection of balance disorders, because it may be possible to discriminate between body sway and acceleration and to determine the phase relationship between ankle and hip motion.

**Keywords:** Postural sway, joint kinematics, dynamic posturography, age effects

## 1. Introduction

The Sensory Organization Test protocol of the EquiTest system (Neurocom International, Clackamas, OR) can assist in identifying postural control abnormalities stemming from a wide variety of pathological conditions [?]. It tests utilization of visual, vestibular, and proprioceptive sensors by manipulating the accuracy of visual and/or somatosensory inputs during quiet stance. Balance performance is assessed by quantifying body sway with two indicators: the Equilibrium Quotient as an indicator of postural unsteadiness, and the Strategy Score as an indicator of how much hip motion exists relative to ankle motion [?]. Patients suffering from

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Table 1

Altered sensory conditions of the Sensory Organization Test (EquiTest, NeuroCom Intl., Clackamas, Oregon). For sway-referenced conditions, movement of the support platform and/or visual surround is matched to postural sway of the subject, thus rendering proprioceptive or visual input inaccurate

Condition	Visual	Proprioceptive	Vestibular
1	normal	normal	normal
2	absent	normal	normal
3	sway-referenced	normal	normal
4	normal	sway-referenced	normal
5	absent	sway-referenced	normal
5	sway-referenced	sway-referenced	normal

vestibular disorders as well as the elderly have been shown to have greater unsteadiness and/or more hip motion than normal young subjects on one or more of the sensory conditions [3–8].

In the standard Sensory Organization Test, both assessment and manipulation of sensory input are based on ground reaction forces measured from a force plate. The Equilibrium Quotient uses the Center of Mass (COM) movement as calculated from horizontal reaction forces to summarize the amount of sway. The Strategy Score uses the Center of Pressure (COP, proportional to ground reaction torque) to assess the relative contributions of joint motion to that sway. Sensory input is manipulated by using the COP to estimate motion of the center of mass (COM). The visual surround and/or the support surface may be servo-controlled to rotate about an axis collinear with the ankles so as to match this estimated center of mass motion. When the visual surround is servo-controlled, the visual input which accompanies body motion is reduced or set into conflict with body movement; this sensory condition is referred to as “visual sway-referencing.” Proprioceptive input from the ankles is similarly reduced or put into conflict in the “platform sway-referencing” condition, in which the support surface is servo-controlled. The SOT consists of six conditions which involve different combinations of altered sensory input (Table 1).

Because the force plate is used as an indirect measure of body motion, there are drawbacks to the standard SOT in terms of assessment and sway-referencing. First, COP measurement cannot discriminate between body sway and acceleration, because both contribute to the ground reaction torque. A subject can therefore produce the same Equilibrium Score by applying large amplitude, high frequency ankle torque which results in little body motion, or by applying lower frequency ankle torque with large amplitude body motion. Second, although large hip motions do generally produce relatively large horizontal reaction forces, the Strategy

Score does not indicate whether hip motion is in or out of phase with ankle motion, leaving out a potentially useful characteristic of posture control. Finally, the estimate of COM motion used for sway-referencing is also subject to error due to the ambiguity of body sway and acceleration. The EquiTest system partially addresses this ambiguity by applying a low-pass filter to the ground reaction torque, but the filter itself introduces a lag in the response, so that sway-referencing can be out of phase with actual body sway [9].

These drawbacks may be avoided by measuring kinematics directly. Others [4,10,11] have measured ankle and hip motion by attaching lightweight rods behind the hips and shoulders, and sensing rotation of these “sway bars” as the attachment points move forward during body motion. These direct measurements have been used for assessment of sway or to provide a more direct feedback signal for sway-referencing. For sway-referencing, the direct kinematic feedback may enhance ability to reduce proprioceptive information by servo-controlling more closely to actual ankle motion, potentially making these conditions more challenging. For assessment, kinematic measurements can potentially increase sensitivity for detection of balance disorders, because it may be possible to discriminate between body sway and acceleration and to determine the phase relationship between ankle and hip motion. However, to date there have been few comparisons between the standard and modified forms of SOT to determine whether these potential improvements are significant.

The purpose of our investigation was to examine the use of direct kinematic measurements for both sway-referencing feedback and assessment of balance during the Sensory Organization Test. Our first specific aim was to compare three methods of sway-referencing: the standard EquiTest method based on ground reaction torque, kinematic feedback based on servo-controlling to shank motion, and a more complex kinematic feedback based on servo-controlling to follow position of the center of mass as calculated from a two-link biomechanical model. We used the standard EquiTest scores along with kinematic indicators of shank, hip, and COM angle to quantify any differences in postural sway induced by these methods. Our second specific aim was to examine whether kinematics-based assessment and sway-referencing were able to provide more sensitive differentiation between normal young and elderly subjects.

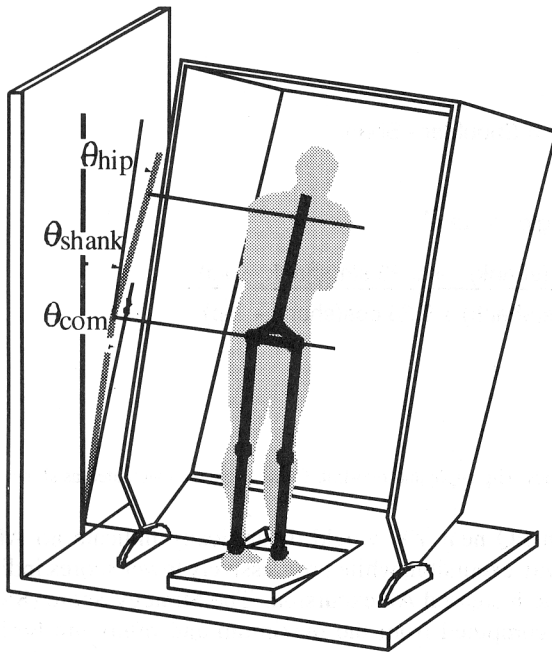


Fig. 1. Attachment of sway bars and location of optical encoders to measure kinematics of shank and shoulder angles during the Sensory Organization Test.

## 2. Methods

### 2.1. Modification with shank and hip angle kinematic measurements

The standard EquiTest balance platform was modified with the addition of optical encoders and sway bars to measure kinematics of hip and shoulder motion in the sagittal plane. The lightweight sway bars attached directly to the safety harness and to a belt positioned around the pelvis, and were not noticeable by the subject (Fig. 1). Movement of the sway bars was measured by the optical encoders with input to two of the auxiliary channels available in the standard EquiTest program. Sway angles were sampled at 50 Hz. Modifications in the EquiTest software were made to allow various options for sway-referencing of the visual surround and floor support, including the standard EquiTest COM calculation, shank angle as measured by the encoders, and COM angle as calculated from a two-link biomechanical model.

### 2.2. Subjects and data collection

Data from 51 normal subjects in the age range of 20 to 79 years were included in our analysis. Subjects were

from a putatively normal population recruited from the community and grouped into four age categories: 20–29 years ( $n = 19$ ), 30–49 ( $n = 9$ ), 50–59 ( $n = 9$ ) and 60–79 ( $n = 14$ ). Though all subjects denied histories of significant head trauma, otologic or neurologic disease, visual impairments not correctable with lenses, limb or spinal fracture, or persistent symptoms of vertigo, lightheadedness, or unsteadiness, additional data from five other subjects were excluded from the analysis because performance on the standard Sensory Organization test protocol was found to be clinically abnormal. Informed consent was obtained from all subjects.

Subjects performed the Sensory Organization Test by standing quietly on the force platform for 20 sec and facing the visual surround within the test apparatus. Subjects stood without shoes, and wore a safety harness which would support their weight in the event of a fall. Three series of the Sensory Organization tests were presented to each subject in random order: the standard SOT protocol as described above, the protocol with visual surround and floor support sway-referenced to the shank angle, and the protocol with visual surround and floor support sway-referenced to the two-link COM angle. Within each series, the order of the sensory conditions was also randomized. For standard EquiTest sway-referencing, one trial of each of conditions 1 and 2 were presented, as well as 3 trials each of conditions 3–6. For shank angle or two-link COM angle sway-referencing, 3 trials each of conditions 3–6 were presented. A trial was stopped by the operator when subjects exceeded their limits of stability and took a step, opened their eyes (if the condition required eyes closed) or touched the visual surround with their hands in order to maintain upright stance.

### 2.3. Two-link biomechanical model

A two-link inverted pendulum is the simplest multi-joint model of postural sway and is sufficient to evaluate strategy-oriented hypotheses [12]. Using such a two-link rigid body model, the sway bar measurements were used to compute approximate hip and shank angles, assuming relatively little knee motion. The shank angle was defined as the angle from vertical of the leg segment, the trunk angle as the angle from vertical of the head, arms, and trunk segment, and the hip angle as the difference between the two (Fig. 2). Angles were measured positive in flexion with zero corresponding to full upright position. We also defined the two-link COM angle  $\theta_{com}$  as the angle of the line connecting

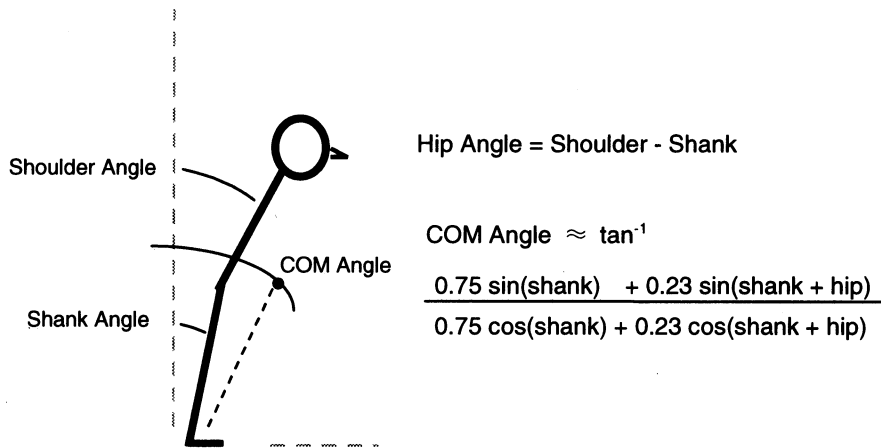


Fig. 2. Two-link biomechanical model using shank and shoulder joint kinematics. Hip angle and two-link COM angle are calculated as shown.

the COM position and the ankle axis, with respect to vertical. This angle was calculated using a two-link biomechanical model from the shank and hip angle measurements:

$$\theta_{\text{com}} \approx \tan^{-1} \frac{0.75 \sin(\theta_{\text{shank}}) + 0.23 \sin(\theta_{\text{shank}} + \theta_{\text{hip}})}{0.75 \cos(\theta_{\text{shank}}) + 0.23 \cos(\theta_{\text{shank}} + \theta_{\text{hip}})}$$

This formula is an approximation based on inertial values for a two-link system and was derived assuming that subjects had average body mass distribution and average proportional lengths of various body segments [12]. Peterka and Black [4] found that the error in a similar measurement of  $\theta_{\text{com}}$  due to deviations of individual subjects from the average body configurations was likely less than 10%.

#### 2.4. Outcome measures

Five outcome measures were calculated for all trials. These included the standard EquiTest measures, the Equilibrium Quotient and Strategy Score; root-mean-square (RMS) of the kinematic measurements  $\theta_{\text{shank}}$  and  $\theta_{\text{hip}}$ ; as well as RMS of anteroposterior (AP) COP motion as calculated from the horizontal reaction forces. The Equilibrium Quotient (EQ) is the angular difference between a subject's calculated maximum AP forceplate COM displacement ( $\theta_{\text{max}} - \theta_{\text{min}}$ ) and the theoretical maximum of 12.5 degrees and is calculated by [2]:

$$\text{Equilibrium Quotient} = \frac{12.5^\circ - (\theta_{\text{max}} - \theta_{\text{min}})}{12.5^\circ} \times 100$$

An EQ near 100 would theoretically indicate no AP sway excursion, while progressively lower scores indicate increased AP excursion. The Strategy Score (SS) is computed from the maximum and minimum horizontal shear forces detected by the support platform ( $SH_{\text{max}}$ ,  $SH_{\text{min}}$ ) and referenced to a theoretical maximum shear force of 25 lbs and is calculated by [2]:

$$\text{Strategy Score} = 1 - \frac{SH_{\text{max}} - SH_{\text{min}}}{25} \times 100$$

Such shear forces are produced by sudden trunk acceleration, which is considered to occur in association with a hip strategy for postural control. An SS near 100 theoretically indicates slow shifts in the COM location through vertically directed ground forces (typically slow upper body movement as could happen with rotation dominantly about the ankle) while a low score indicates use of rapid upper body movement which can, but does not need to be associated with hip joint rotations [5,13]. The kinematic measurements of  $\theta_{\text{shank}}$  and  $\theta_{\text{hip}}$  provided direct indicators of relative amounts of ankle and hip motion.

Kinematic measures ( $\theta_{\text{shank}}$  and  $\theta_{\text{hip}}$ ) were bandpass filtered before calculating RMS sway. The high cut-off frequency was set at 3.5 Hz to filter noise, and a low cut-off frequency of 0.5 Hz was used to ensure that at least ten cycles of the lowest frequency component in the data contributed to the RMS measure [14].

Each of the outcome measures was averaged over the number of successful trials for that particular SOT condition. Comparisons of the EQ and SS were made using ANOVA and post-hoc Tukey t-tests to examine differences between the age groups. Paired dependent t-tests were used for comparisons of the kinematics and COP excursion. All comparisons were considered statistically significant for p-values less than 0.05.

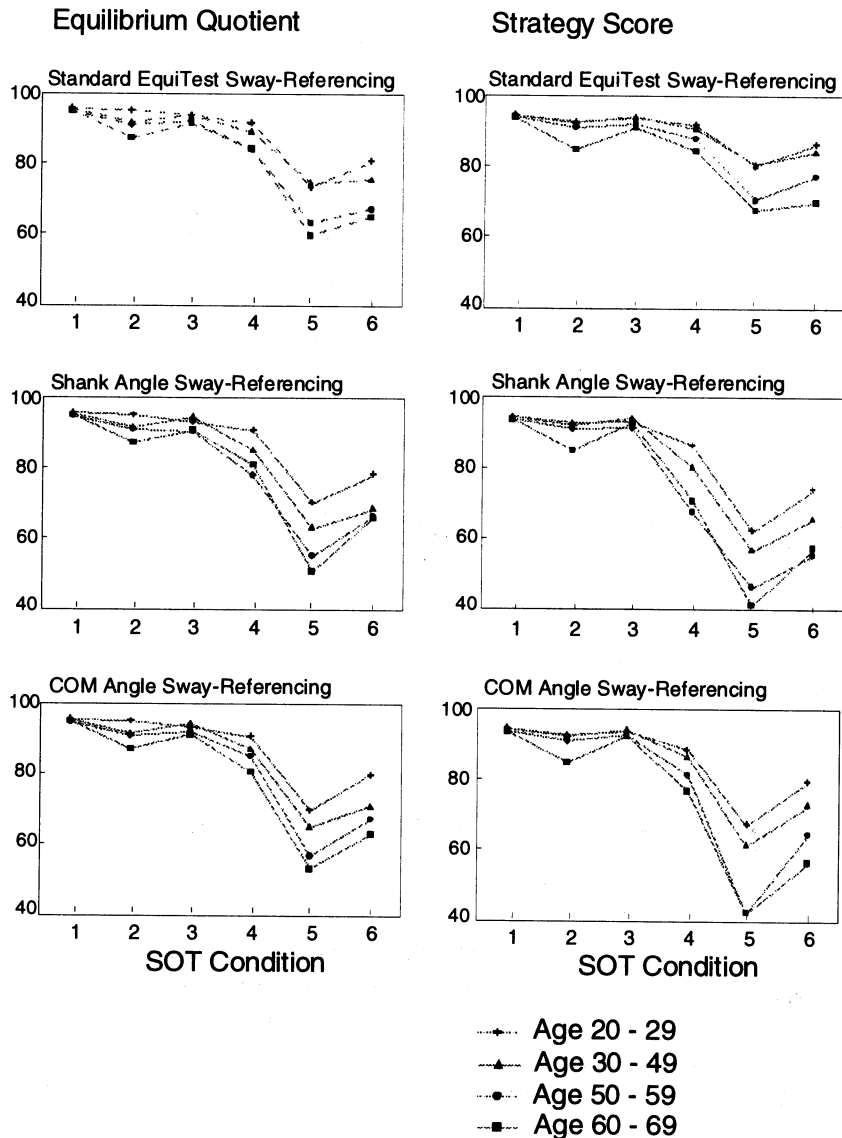


Fig. 3. (A) Mean Equilibrium Quotients and (B) mean Strategy Scores of each age group on the six conditions of the Sensory Organization Test comparing the standard EquiTest protocol, use of the shank angle or two-link COM angle for sway-referencing feedback.

### 3. Results

The use of kinematic feedback for sway referencing tended to amplify the difficulty of altered sensory conditions, regardless of whether balance was assessed with conventional or kinematic measures. Equilibrium Quotients were notably lower, though not significantly different, for all age groups in platform sway-referenced conditions (SOT 4, 5, and 6), when using either shank or COM angle as the feedback reference (Fig. 3A; numerical scores are provided in Table 2 for quantitative comparison), with the shank reference hav-

ing the largest effect. The difference in mean scores ranged as high as 9.0 (59.7 using conventional platform sway-referencing, 50.7 shank angle, 53.1 COM angle;  $p = 0.06$ ) for the oldest age group in SOT condition 5, and were less pronounced for SOT conditions 4 and 6. There was little difference in scores associated with visual sway-referencing alone, as evidenced by a maximum change of 1.6 (92.2 conventional visual sway-referencing, 90.6 shank angle, 92.2 using COM angle, all for age group 50–59), and one case in which shank angle sway-referencing resulted in a slightly increased score (93.9 conventional visual sway-referencing vs.

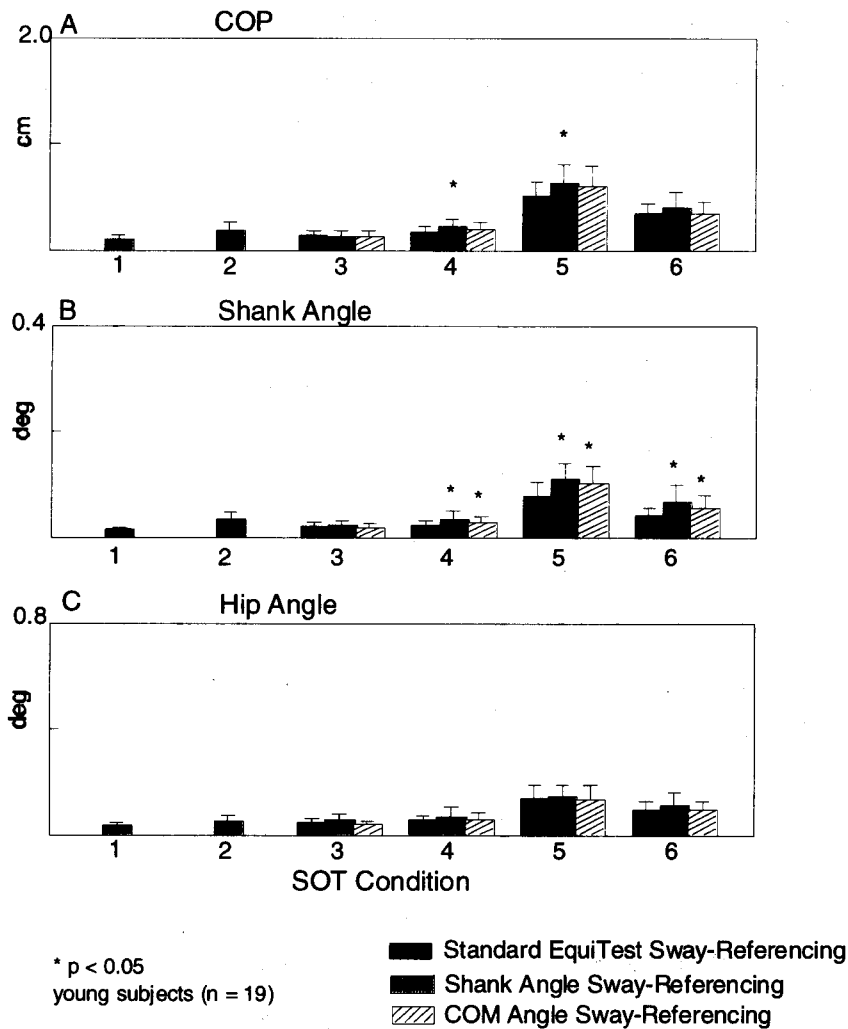


Fig. 4. Mean root-mean-square of (A) center of pressure (COP); (B) shank angle and (C) hip angle for young subjects ( $n = 19$ ; ages 20–29) comparing the standard EquiTest protocol with use of the shank angle and two-link COM angle for sway-referencing feedback on altered sensory conditions of the Sensory Organization Test.

94.7 shank angle, for age group 30–49). Similar and statistically significant trends were also found using RMS COP, which is similar to the Equilibrium Quotient (Fig. 4A for age group 20–29, Fig. 5A for age group 60–79).

The Strategy Score was reduced for all age groups when using kinematic platform sway-referencing (Fig. 3B; numerical scores are provided in Table 3 for quantitative comparison). Again, the largest difference occurred in SOT condition 5, (67.7 conventional platform sway-referencing vs. 40.9 shank angle, age group 60–79;  $p < 0.01$ ), with smaller differences for SOT conditions 4 and 6 (both  $p < 0.05$ ). The type of visual sway-referencing did not result in consistent or statistically significant differences, with a maximum differ-

ence of 1.9 (91.1 conventional visual sway-referencing vs. 93.0 shank angle, for age group 60–79, SOT condition 3).

The combination of kinematic measures of sway with kinematic platform sway-referencing provided significantly more information than the force plate measures. Shank angle sway was significantly increased ( $p < 0.05$ ) for the 20–29 age group, in all platform sway-referenced conditions, comparing kinematics vs. force-plate references (Fig. 4B). Hip angle sway exhibited a slight but statistically insignificant increase for this group as well (Fig. 4C). The increase in shank angle sway was also significant for the 60–79 age group for SOT conditions 4 and 5 (Fig. 5B); higher variability made condition 6 differences insignificant. Unlike

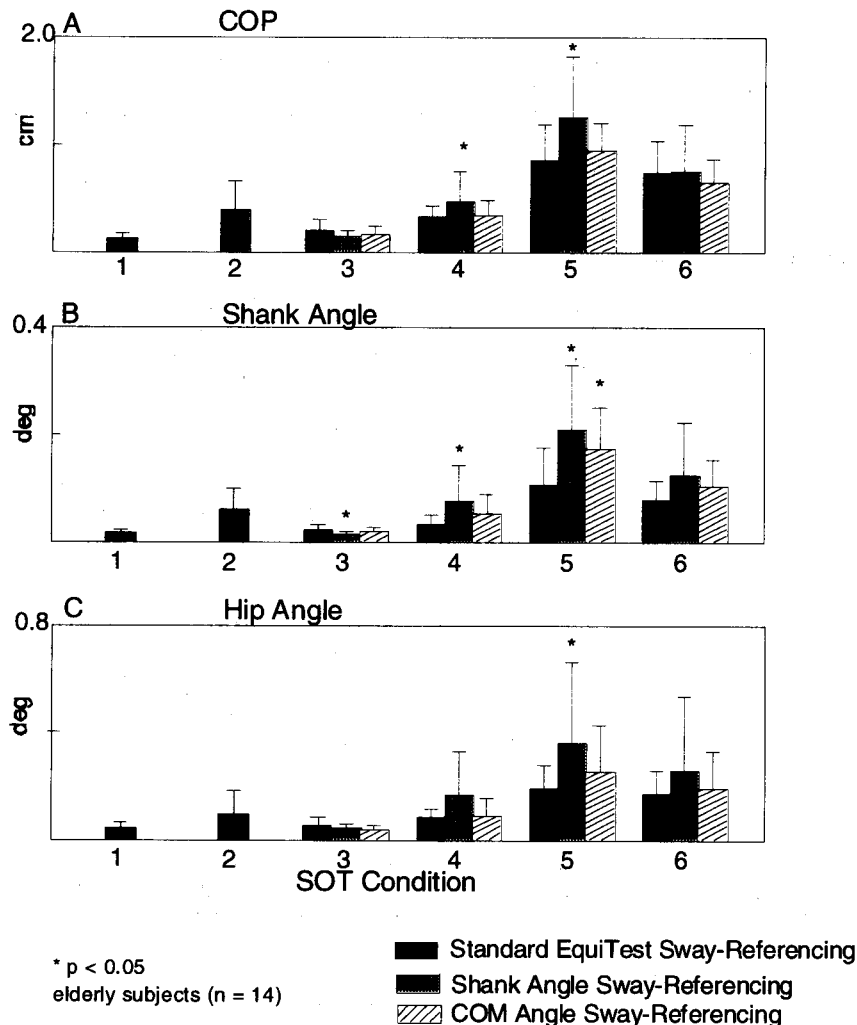


Fig. 5. Mean root-mean-square of (A) center of pressure (COP); (B) shank angle and (C) hip angle for the oldest subjects ( $n = 14$ ; ages 60–79) comparing the standard EquiTest protocol with use of the shank angle or two-link COM angle for sway-referencing feedback on altered sensory conditions of the Sensory Organization Test.

the youngest age group, the oldest subjects exhibited a large increase (significant for SOT 5) in hip sway when kinematic platform sway-referencing was used (Fig. 5C).

The increased sensitivities arising from use of kinematics have the effect of amplifying differences with age. Using the conventional measure of the Equilibrium Quotient, significant age effects were seen between the 20–29 and 30–49 age groups in two of the kinematic platform sway-referenced conditions (SOT 4 and 6; Table 2), groups for which conventional SOT measures show little difference. These differences grow larger for older age groups and include all three platform sway-referenced conditions (Tables 2 and 3). Such differences in sway are especially pronounced

when shank and hip kinematics are used as outcome measures (compare Fig. 5 for 60–79 age group, Fig. 4 for 20–29). For example, the combination of kinematic measures and sway-referencing results in significant ( $p < 0.05$ ) differences between the youngest and oldest age groups for all sway-referenced conditions, including SOT condition 3 (compare Tables 4A and 4B).

#### 4. Discussion

Our results indicate that kinematic sway-referencing increases the difficulty of the task. For all age groups of subjects, there were significant differences in one or

Table 2

Mean Equilibrium Quotients of each age group on the six conditions of the Sensory Organization Test comparing the standard EquiTest protocol with use of the shank angle or two-link COM angle for sway-referencing feedback. Sensory Organization Test conditions 1 and 2 were performed only with the standard EquiTest protocol

	Sensory Organization Test					
	1	2	3	4	5	6
<b>Equilibrium Quotient (mean <math>\pm</math> 1 SD)</b>						
<b>Standard EquiTest Sway-Referencing</b>						
Age group						
20–29	95.8 (14)	95.3 (1.9)	93.9 (2.4)	91.7 (2.1)	73.5 (5.8)	81.0 (5.0)
30–49	95.7 (2.2)	91.8 (4.0)	93.9 (1.4)	89.3 (5.7)	74.8 (8.9)	75.7 (8.8)*
50–59	94.9 (1.5)	91.1 (2.8)	92.2 (2.4)	84.3 (8.2)*	63.6 (7.7)*	67.2 (11.5)*
60–69	95.3 (1.9)	87.4 (5.4)*	91.6 (2.1)*	84.4 (6.1)*	59.7 (11.4)*	65.0 (9.4)*
<b>Shank Angle Sway-Referencing</b>						
Age group						
20–29	–	–	93.3 (2.5)	90.9 (3.2)	70.5 (7.0)	78.6 (4.8)
30–49	–	–	94.7 (1.9)	85.2 (9.6)*	63.4 (15.7)	68.8 (13.5)*
50–59	–	–	90.6 (7.1)	78.1 (14.7)*	55.2 (6.1)*	66.7 (13.4)*
60–69	–	–	90.9 (2.4)*	81.2 (13.9)*	50.7 (13.1)*	66.0 (12.6)*
<b>COM Angle Sway-Referencing</b>						
Age group						
20–29	–	–	93.5 (1.9)	91.0 (3.9)	69.8 (7.8)	80.0 (7.1)
30–49	–	–	94.6 (1.1)	87.4 (6.4)	65.1 (10.9)	71.1 (13.9)*
50–59	–	–	92.2 (4.0)	85.3 (5.0)*	56.9 (7.1)*	67.4 (9.8)*
60–69	–	–	91.4 (2.7)*	80.8 (15.2)*	53.1 (12.3)*	63.0 (14.2)*

\* $p < 0.05$  for paired t-test comparison to young subjects (age 20–29)

Table 3

Mean Strategy Scores of each age group on the six conditions of the Sensory Organization Test comparing the standard EquiTest protocol with use of the shank angle or two-link COM angle for sway-referencing feedback. Sensory Organization Test conditions 1 and 2 were performed only with the standard EquiTest protocol

	Sensory Organization Test					
	1	2	3	4	5	6
<b>Strategy Score (mean <math>\pm</math> 1 SD)</b>						
<b>Standard EquiTest Sway-Referencing</b>						
Age group						
20–29	94.7 (1.1)	92.8 (2.6)	93.9 (1.5)	91.9 (1.9)	80.4 (5.4)	86.4 (2.9)
30–49	94.7 (1.5)	92.4 (3.6)	94.1 (1.2)	90.9 (2.9)	80.7 (5.2)	84.2 (3.1)
50–59	94.0 (1.7)	91.1 (2.6)	92.2 (3.7)	88.0 (4.4)*	70.6 (7.5)*	77.3 (7.5)*
60–69	93.9 (1.5)	85.0 (9.1)*	91.1 (5.4)	84.6 (4.7)*	67.7 (12.4)*	69.8 (11.4)*
<b>Shank Angle Sway-Referencing</b>						
Age group						
20–29	–	–	93.2 (2.1)	86.5 (4.5)	62.3 (8.6)	74.1 (8.4)
30–49	–	–	94.2 (1.1)	80.3 (11.7)**	56.8 (19.7)	65.7 (15.7)**
50–59	–	–	91.4 (5.0)	67.6 (26.5)*	26.2 (20.8)*	55.3 (23.3)*
60–69	–	–	93.0 (1.7)*	70.8 (18.0)*	40.9 (11.8)*	57.2 (17.5)*
<b>COM Angle Sway-Referencing</b>						
Age group						
20–29	–	–	94.0 (1.4)	88.7 (3.1)	67.6 (8.8)	79.7 (5.2)
30–49	–	–	94.3 (1.2)	86.7 (6.3)	61.7 (8.9)	73.1 (8.5)*
50–59	–	–	92.8 (3.3)	81.4 (8.5)*	42.3 (19.9)*	64.7 (15.2)*
60–69	–	–	92.5 (3.0)*	77.0 (14.2)*	42.2 (15.8)*	56.5 (15.6)*

\* $p < 0.05$  for paired t-test comparison to young subjects (age 20–29)

\*\* $0.05 < p < 0.075$  for paired t-test comparison to young subjects (age 20–29)

Table 4

Comparison of root-mean-square shank and hip angles between young ( $n = 19$ ; ages 20–29) and old ( $n = 14$ ; ages 60–79) subjects using (A) the standard EquiTest protocol and (B) the shank angle for sway-referencing feedback

A Standard EquiTest sway-referencing			B Shank angle sway-referencing		
Condition	Shank	Hip	Condition	Shank	Hip
3	–	–	3	$p < 0.01$	$p = 0.02$
4	$p < 0.01$	$p < 0.01$	4	$p = 0.04$	$p = 0.04$
5	–	–	5	$p < 0.01$	$p < 0.01$
6	$p < 0.01$	$p < 0.01$	6	$p = 0.04$	$p = 0.02$

Comparison of joint kinematics between young ( $n = 19$ ) and older ( $n = 14$ ) subjects

more of the kinematic sway measures when using either of the alternative sway-referencing parameters as compared to the standard EquiTest protocol. There were no significant differences between use of the shank or two-link COM angles for sway-referencing, though use of the shank angle caused a significant change in sway for more of the SOT conditions than did use of the two-link COM angle.

The feedback signal for visual sway-referencing appears to be less important. Conventional and kinematic feedback signals result in similar measures in SOT condition 3, although the combination of both visual and platform sway-referencing appeared to be more difficult than platform sway-referencing alone. The relatively weak dependence on visual sway referencing may be due to the fact that motion about many joints affects the visual field, so that referencing to lower-body or two-link COM angle only partially reduces visual information.

Of the two types of kinematic sway-referencing considered, the use of shank angle appears to be advantageous. Both methods increase the difficulty of the SOT, but the shank angle reference appears to alter proprioceptive information more effectively (see Tables 2 and 3). We propose that the use of the shank angle for sway-referencing provides more direct kinematic feedback which may reduce the proprioceptive information by servo-controlling more closely to the actual ankle motion. Alternatively, the kinematic feedback may induce greater variability in the ankle angle, thus rendering this information as unreliable and subsequently ignored by the CNS for maintenance of stance. The functional outcome of either of these possibilities would be the same. The shank angle is also simpler to implement, because it can be used directly in feedback without need to compute the two-link COM angle or filter the COP signal.

The addition of kinematic measures of shank and hip sway are useful for examining age effects, and to inves-

tigate changes in joint coordination among the different altered sensory conditions [14]. Shank angle sway followed the same trends as conventional measures, but tended to amplify age effects (see Fig. 5B), thereby increasing test sensitivity. Hip angle sway also exhibited amplified age effects, especially when combined with shank angle sway referencing. Of particular interest was the large increase in hip sway (see Figs. 4 and 5) for shank angle sway-referenced conditions, which primarily disrupt ankle proprioception. Such an increase was not seen in young subjects or when conventional sway-referencing was used. When ankle proprioception is greatly diminished (and especially when vision is absent), older subjects are much more unsteady at the hip than younger subjects. This observation illustrates the compounding effect of sensory loss in the elderly [13–15], and may be due to inability to identify and disregard inaccurate sensory inputs, or reduced function in vestibular and other sensors which provide accurate information.

We chose to include only trials in which the subjects were successful in maintaining upright stance for at least one trial of each condition, because scores in loss of balance trials – typically assigned a 0 in the EquiTest protocol – are not suitable for inclusion in a statistical mean. Since older subjects fell more often than the young subjects, excluding loss of balance trials is the more conservative approach.

Still to be examined is the phase relationship between the ankle and hip joints. Multivariate analysis can be used to examine how shank and hip angles co-vary, and has been shown to reveal coordination changes due to altered sensory conditions [14] or readaptation to earth gravity following spaceflight [16]. Multivariate effects may also reveal more subtle differences in posture coordination with age. Such methods may enable us to further define the strategy used by a subject, including a direct evaluation of the actual amount of upper body sway relative to lower extremity movement.

Future work will include efforts to increase the sensitivity of the EquiTest for patients with unilateral vestibular lesions. Although many unilateral patients perform poorly, with SOT results similar to those of a patient with bilateral vestibular hypofunction, some subjects may perform within the normal range on the SOT. The balance function results for these patients do not correlate with findings on other clinical tests such as rotary chair or electronystagmography. With an increase in sensitivity of the test due to increased responsiveness of the sway-referencing to changes in body sway, it may be possible to detect differences for dizzy patients who otherwise perform well on the SOT. An individual who is compensated under normal conditions may find it more difficult to successfully maintain stance under more stressful situations. It is also possible that increased SOT sensitivity will aid in determining the cause of balance dysfunction, by associating patterns of movement with central or peripheral disorders.

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