Effect of Coordination Training on Proprioception of the Functionally Unstable Ankle

By: Julie N. Bernier, EdD, ATC* and David H. Perrin, PhD, ATC†

Bernier, J.N., & Perrin, D.H. (1998). Effect of coordination training on proprioception of the functionally unstable ankle. Journal of Orthopaedic and Sports Physical Therapy, 27:264-275.

*****Note: Figures may be missing from this format of the document**

Abstract:

Exercises to improve joint proprioception and coordination of the functionally unstable ankle are advocated throughout the literature, yet there is little evidence that these exercises have any effect on proprioception and balance. The purpose of this study was to determine the effects of a 6-week coordination and balance training program on proprioception of subjects with functional ankle instability. Forty-five subjects (age = 22.53 ± 3.95 years, height = 172.04 ± 10.0 cm, weight = 71.72 ± 15.7 kg) were randomly placed into a control (Group 1), sham (Group 2), or experimental (Group 3) group. The experimental group trained 3 days per week, 10 minutes each day, performing various balance and proprioception exercises. Postural sway and active and passive joint position sense were assessed. Analysis of variance for postural sway modified equilibrium score for anterior and posterior sway, as well as medial and lateral sway revealed significant four-way interactions. Tukey post hoc analyses revealed that Group 3 performed significantly better ($p < .05$) than Group 1 and Group 2 on the posttests. There were no significant differences for joint position sense or postural sway index. Results suggest that balance and coordination training can improve some measures of postural sway. It is still unclear if joint position sense can be improved in the functionally unstable ankle.

Article:

Inversion ankle sprains are among the most common injuries in sports (22,39,70). Often, recurrent injury ensues, and functional instability (1517) becomes evident in as many as 33 (3) to 42% (18) of the patients suffering from an acute ankle injury. Contributing factors to functional ankle instability are decreased range of motion (4), decreased strength of ankle evertors (3,60,66), and a decrease in joint proprioception (8,18, 21,25,43,61,66,67). Some authors reported symptoms of functional instability in the absence of mechanical instability (14,16,66).

The ability to detect motion in the foot and make postural adjustments in response to these detected motions is crucial in the prevention of ankle injury. Similarly, the ability of an individual to sense the position of the foot prior to heel strike is of the utmost importance. Studies have shown that functional ankle instability results in a decreased ability to maintain balance (16,69) and a decrease in joint position sense (25).

Freeman et al (18) proposed that ankle injury may cause disruption of joint afferents located in the supporting ligaments and capsule, leading to an impairment of the postural control system. Using a modified Rom- berg's test, they found a decrease in the ability to maintain static balance on the injured limb when compared to the uninjured limb of patients with unilateral ankle injury. From their finding of decreased postural control, they proposed a partial deafferentation of joint mechanoreceptors in the functionally unstable ankle, which contributed to symptoms of functional instability (18).

* Assistant Professor, Athletic Training Education Coordinator, HPER, MSC :22, Plymouth State College, Plymouth, NH 03264. At the time of this study, Dr. Bernier was a doctoral candidate, University of Virginia, Charlottesville, VA.
† Professor and Director, Health and Physical Education, University of Virginia, Charlottesville, VA

Numerous mechanoreceptors are present in joint capsule, ligament, muscle, and skin. Mechanoreceptors are sensitive to joint pressure and tension caused by both dynamic movement and static position. These afferent nerve fibers provide a sense of movement and position as well as contributing to a complex reflex system that acts to control posture and coordination.

Control of posture entails reflex mechanisms involving coordinated activity of three balance senses: visual, vestibular, and somatosensory systems (31,47). In order to maintain balance, a body is in a constant state of automatic movement (38,46,47), attempting to keep the center of gravity over the base of support. Balance is preserved by movements at the ankle, knee, and hip and may be disturbed when the center of balance cannot be properly sensed or when corrective movements are not executed in a smooth coordinated fashion.

These three balance senses work in combination and are all critical to the execution of coordinated postural corrections. Impairment of one component is compensated for by the other two. Often, one of the systems provides faulty information or sensory conflict. In this case, it is crucial that the other two senses provide accurate information so that sensory organization can take place. Sensory organization is a process by which all three senses receive input and a determination is made whether any of the input is misleading (47).

The vestibular system plays only a minor role in the maintenance of balance when visual and somatosensory systems are functioning (47,49). The primary role of the vestibular system is to signal sensation of acceleration of the head in relation to the body and to the environment (35, 47). It allows independent control of head and eye positions.

Vision is an important sense for the control of balance. When somatosensory conflict is present, such as a moving platform or a compliant foam surface, balance is significantly decreased with eyes closed compared to eyes open. On a stable surface, closing the eyes should cause only minimal increases in postural sway in normal subjects. However, if somatosensory input is disrupted due to injury, closing the eyes will increase sway significantly (12,13,34,47).

Mechanoreceptors provide information to the three movement systems, which aid in the regulation of balance. The myotatic stretch reflex is the first mechanism to react at approximately 40 msec. An externally imposed rotation or increased load to the joint triggers muscle spindles to increase activity in the muscle and improve muscle stiffness properties. Muscle stiffness is described as the muscle's resistance to stretch and is dependent upon the level of activation of the muscle (47). Stretch reflexes may at times be inappropriate or insufficient and act to destabilize balance (46). Therefore, other movement systems which rely on alternate input are required to maintain balance.

The second system, which is the first effective response to control balance, comes from the automatic systems. They too are triggered by external perturbations. The response is somewhat slower than the myotatic stretch reflex at 90-100 msec. Somatosensory input results in automatic responses which are governed by the degree of intensity of the stimulus in combination with the individual's past experiences (47).

The third system involved in balance control is the voluntary system. It is the slowest responding system at approximately 150 msec. Voluntary and automatic responses are often used in conjunction with each other, with automatic responses occurring first followed by voluntary purposeful behaviors (48).

Several authors (26,53,56,62,67) suggested that inversion ankle sprains may occur due to an improper positioning of the foot just prior to, and at, heel strike. Improper positioning may be due to the loss of proprioceptive input from mechanoreceptors. Joint position sense is a component of proprioception and is often measured to assess proprioception. Results of joint position sense studies in the functionally unstable ankle have demonstrated varying results. Glen- cross and Thornton (25) reported a decrease in active joint position sense of the functionally unstable ankle over that of the uninjured ankle. Gross (30), however, failed to reveal any significant differences between injured and uninjured limbs in either active or passive joint position sense of the ankle.

Joint position sense at the ankle is typically measured in a nonweightbearing position but usually involves uniplanar measurement. Glencross and Thornton (25) measured joint position sense in a dorsiflexion/plantar flexion pattern. Gross (30) mea sured inversion/eversion joint position sense and did not report the position of the ankle in the sagittal plane. Since ankle and foot motion rarely involve uniplanar motion, these tests may not be accurate indicators of position sense during functional activity. No attempts have been made to evaluate joint position sense in a nonweight-bearing position with combined motions about the subtalar and talocrural joints. Further, the effects of training on joint position sense are not known.

Exercises to improve joint proprioception and coordination of the ankle are advocated for individuals with functional ankle instability throughout the literature (1,5,6,15, 18,23,36,38,40,42,51,54,63,69). Little attention, however, has been given to the efficacy of these rehabilitation protocols.

Two studies (23,68) revealed that static postural sway can be improved with 6 weeks and 8 weeks of ankle disk training, respectively. Additionally, Tropp et al (67) and Freeman et al (18) reported a decrease in symptoms of functional instability and repeated episode of injury following a training regimen of balance-type exercises. It has not been shown, however, if dynamic postural sway can be improved. Additionally, the visual system can compensate for defects in the central pathways or of the vestibular system (2). A ratio of balance measures with eyes open to that of eyes closed is an indicator of somatosensory input (10-13,47,49). Visual cues were not removed in the testing procedures of previous studies (66-68).

The purpose of this study was to determine if ankle joint proprioception in subjects with functional instability of the ankle could be improved with 6 weeks of training. The parameters of interest were sway index and a modified equilibrium score assessed in a weight-bearing position under both static and dynamic conditions with and without visual cues. Additionally, degrees of en-or for active and passive position sense were assessed in a nonweight-bearing position.

METHODS

Subjects

The study was approved by the institution's review board for the use of human subjects. All subjects were informed of the procedures and signed a consent form prior to participation. The subject population consisted of 48 males and females, ranging in age from 18 to 32 years old, who reported a history of chronic ankle functional instability at the time of the study. Functional instability was defined as at least one significant ankle inversion sprain in which the subject was on crutches or unable to bear weight, followed by repeated injury and/or a feeling of instability and giving way. All subjects suffered a minimum of at least two episodes in the 12 months prior to testing. Subjects were all pain-free at the onset of the study.

Subjects were randomly assigned to one of three groups. Group 1 (N = 14) served as a control and was asked not to participate in any strengthening or balance-type activities during the 6-week period. Group 2 (N = 14) received a sham treatment of electrical stimulation to the peroneus longus and brevis muscles. The subjects receiving the sham treatment were told they would receive a subsensory treatment of microcurrent electrical stimulation. No electrical stimulation was actually delivered to the subjects. Group 3 (N = 17), the experimental group, participated in 6 weeks of balance and coordination training.

Instrumentation

The Balance System (Chattanooga Group Inc., Hixson, TN) was used to assess postural sway. Single limb stance was assessed under four conditions. Joint position sense was as sessed using the KinCom II (Chattanooga Group Inc., Hixson, TN) isokinetic dynamometer. Testing was conducted at a slow velocity (5°/sec).

Test Procedures

Subjects reported to the sports medicine research lab for a pretest. In an attempt to minimize the effect of fatigue on the testing procedures, joint position sense testing was performed first, followed by balance testing. A practice session was immediately followed by the test session. Six weeks following the pretest, a posttest was conducted in the same manner.

Joint position sense Each subject was positioned supine on an examination table that had been modified to accommodate positioning of the ankle on the KinCom II ankle inversion/eversion footplate. The subject's foot was aligned with the axis of the dynamometer according to manufacturer's specifications with subtalar neutral designated as the "neutral" position. An Elastifoam wrap (low-density foam-padded elastic wrap) was placed around each subject's foot to reduce cutaneous receptor input. A total of seven test positions was assessed for active and passive joint repositioning. Three test positions (15° of inversion, 0° of neutral, and 10° of eversion) were performed at 0° and 25° of plantar flexion. An additional test position, maximum inversion, was performed in the plantar flexion (25°) position. The maximum inversion test position was set at —5° of each individual's maximum inversion active range of motion. This position was determined by having each subject actively invert the foot to a maximum position of inversion, where the range of motion in degrees was recorded from the internal goniometer of the KinCom.

Each subject performed a practice session followed by a 30-second rest. The test protocol followed with two trials for each test position. The average score of two trials was used for the analysis. A counterbalancing scheme was used for plantar flexion position, active/passive mode, and test position (inversion, neutral, eversion, and maximum inversion) to avoid an order effect. Subjects were blindfolded throughout the examination. For passive testing, the investigator moved the subject's foot at the dynamometer's set speed of 5°/sec. First, the subject's foot was moved through complete inversion and eversion range of motion. The investigator then moved the foot to the test position, where it was held for 15 seconds. Each subject was instructed to concentrate on the position of the foot. The foot was then brought to the extreme opposite range of motion (ie., to inversion for neutral and eversion test positions and to eversion for inversion and maximum inversion test positions). The investigator then moved the foot back toward the test position. The subject indicated when he/she felt the test position had been attained by performing a quick contraction of the antagonistic muscle group, causing a force curve to be recorded. The corresponding angle of movement was taken at the point of the initiation of the force curve. Measurements were recorded as degrees of error for each test position. This was repeated for two trials at each test position in both the 0° and 25° of plantar flexion positions. The active test was performed in the same manner, except, after being passively placed in the test position and moved to the opposite range of motion, the subject moved his/her foot actively back to the test position.

Postural stability Subjects were positioned on the force plate of the Balance System with the nonweight-bearing limb flexed at the knee to approximately 75° and the weight- bearing limb fully extended at the knee.

The subject's foot was positioned on a force plate adjusted to foot length. The subjects were asked to cross their arms over their chests. Two trials were performed

$$\text{Equilibrium Score} = \frac{\text{theoretical limit - actual sway}}{\text{theoretical limit}}$$

$$(12 - 3.9) / 12 = .68$$

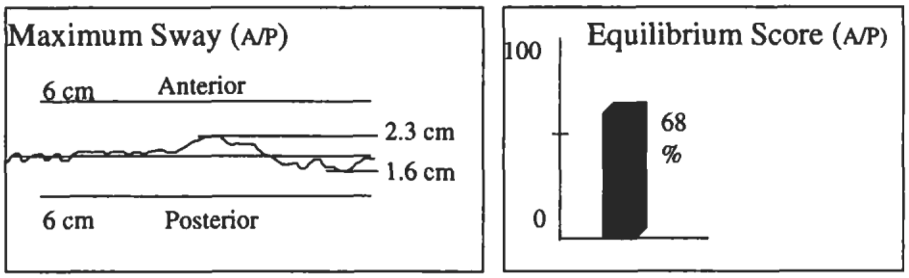


FIGURE 1. *Calculation of modified equilibrium score. A/P = Anterior/posterior.*

for each test. The average of the two trials was used for data analysis. Data were collected at an effective sampling rate of 15 Hz for a period of 20 seconds.

All subjects performed a practice session immediately followed by the test session. The test conditions were stable platform with eyes open (Condition 1), stable platform with eyes closed (Condition 2), inversion/eversion tilting platform with eyes open (Condition 3), and inversion/eversion tilting platform with eyes closed (Condition 4).

Sway index and modified equilibrium score were used as the dependent measures. Sway index is defined as a numerical value of the standard deviation of the distance the subject spent away from his/her center of balance. It is calculated by the following formula:

x cm = value which indicates the distance from the balance point in the X direction, where negative values indicate left, positive values indicate right, and 0 is direct center.

y cm = value which indicates the distance from the balance point in the Y direction, where negative values indicate heel direction, positive values indicate toe direction, and 0 is direct center.

Modified equilibrium score is a unitless measure of the actual anterior/posterior or medial/lateral sway in relation to the theoretical limits of stability (Figure 1). The theoretical limit of stability is a center of gravity sway angle and is based on height and weight (47). In this case, the limit was the maximum sway possible in a given direction, determined by the manufacturer. The Balance Sys- tern does not measure center of gravity; thus, the term "modified" equilibrium score is used here. Scores near 100% indicate little sway, where scores of 0 mean complete loss of stability. If an individual suffers a loss of balance and must touch the other foot down, a score of 0 is recorded for that trial. Modified equilibrium score = (B — A)/B X 100, where A represents actual anterior/posterior sway, and B represents the theoretical limits of stability (47).

Training Procedure

The training protocol consisted of 6 weeks of balance training, progressing from the most simple to the

Sway index =

$$\sqrt{\frac{SD(x\ cm^2 \times y\ cm^2)}{\text{number of points collected}}}$$

where:

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
1. Fixed surface, eyes open (FEO)	Same as week 1	FEO	FEC	FEC	FEC
2. Fixed surface, eyes closed (FEC)		FEC	FPO	FPO	FPO
3. Fixed surface, picking up objects (FPO)	Add wobble board	FPO	TEO2 ×2	TEO2	TEO2
4. Tilt board, dorsi/plantar, eyes open (TEO1)		TEO2	TEC2 ×2	TEC2	TEC2
5. Tilt board, dorsi/plantar, eyes closed (TEC1)	10. Wobble eyes open	TEC2	WEO ×2	WEO ×2	WEO
6. Tilt board, inversion/eversion, eyes open (TEO2)	(WEO) × 2	TEO3	WEC ×2	WEC ×2	WEC
7. Tilt board, inversion/eversion, eyes closed (TEC2)		TEC3		12. FHO × 2 (Functional	FHO ×2
8. Tilt board, diagonal placement, eyes open (TEO3)		WEO ×2		hop, eyes open)	13. FHC ×2 (Functional hop,
9. Tilt board, diagonal placement, eyes closed (TEC3)		11. Wobble eyes closed (WEC)			eyes closed only after
					landing)

Week 1: 15 seconds each, 45 seconds of rest between exercises.
Week 2: 20 seconds each, 40 seconds of rest between exercises.
Week 3: 25 seconds each, 35 seconds of rest between exercises.
Week 4: 30 seconds each, 30 seconds of rest between exercises.
Week 5: 30 seconds each, 30 seconds of rest between exercises.
Week 6: 30 seconds each, 30 seconds of rest between exercises.

TABLE 1. *Training protocol.*

most complex sessions. This protocol was designed based on a compilation of rehabilitation protocols (1,5,6,15, 18,23,36,38,40,42,51,54,63,69) to reflect current practices in treating functionally unstable ankles. Subjects in the experimental group trained three times per week for 10 minutes each day. The protocol is described in Table 1. Subjects stood on the affected limb with the contralateral knee flexed to approximately 75° and arms crossed over the chest. Strategies were performed with eyes open and eyes closed. Strategies 1-3 involved balancing on a fixed surface (the floor) with eyes open, eyes closed, and while picking up objects (eyes open) from the floor. Strategies 4-9 involved balancing on a 14-inch square tilt board (Figure 2), which allowed uniplanar motion only. Three different foot placements included a straight ahead placement to allow dorsiflexion and plantar flexion (strategies 4-5), a 90° placement which allowed inversion and eversion (strategies 6-7), and a diagonal placement such that inversion/plantar flexion and eversion/dorsiflexion were allowed (strategies 8-9). Strategies 10-11 allowed multiaxial movement using a circular wobble board constructed with a sphere on the undersurface (Figure 3), allowing motion in all ranges. In strategies 12-13, subjects performed a functional hop series, pausing to balance between each hop for a period of 5 seconds. The pattern of hopping included straight ahead, left, right, and diagonal left and right hops (Figure 4).

For the functional hop with eyes closed, the trial was performed by having subjects close their eyes immediately after performing each hop while attempting to gain their balance. They then opened their eyes prior to the next hop and repeated the same sequence until all six hops were complete.

Data Analysis

SPSS for Windows [Version 6.01, SPSS, Inc., Chicago, IL) was used for statistical analysis. An alpha level of .05 was used throughout the data analysis. For joint position sense, a mixed model, one between, three within repeated measures analysis of variance (ANOVA) was used to determine if differences existed between pre- and post-test measures for joint position sense. The dependent variable was error, recorded in degrees. The independent variables were Group (1,2,3), mode (active, passive), test (pre, post), and test position [plantar flexion (0°)—inversion, neutral, and eversion, and plantar flexion (25°)—inversion, neutral, eversion, and a maximum inversion). For postural stability, separate repeated measures ANOVAs with one between and three within variables were used to analyze the dependent measures' sway index and modified equilibrium scores in the anterior/posterior and medial/lateral direction. Independent measures were group (1,2,3), platform (stable, dynamic), eye condition (open, closed), and test (pre, post). Post hoc analyses for each sig-

FIGURE 2. *Subject performing exercises using square tilt board with diagonal foot placement.*

FIGURE 3. *Subject performing exercises using round wobble board.*

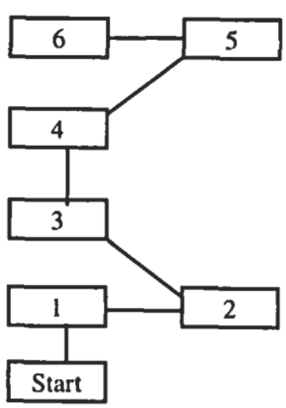


FIGURE 4. *Functional hop pattern (Strategies 12–13).*

Position		Control				Sham				Treatment			
		Active		Passive		Active		Passive		Active		Passive	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Pre	0/inversion	7.21	5.33	5.03	4.16	8.04	4.56	6.71	4.56	5.38	3.11	5.85	3.60
Post	0/inversion	7.28	6.26	4.46	3.12	6.21	4.76	5.79	3.17	5.26	3.70	5.85	4.35
Pre	0/neutral	4.17	3.12	4.17	3.12	5.39	3.67	5.39	3.67	5.41	3.53	5.41	3.53
Post	0/neutral	4.00	3.32	4.89	2.80	5.57	2.45	4.39	2.35	5.76	3.94	3.62	2.13
Pre	0/eversion	7.25	4.38	5.07	3.47	7.82	4.54	5.86	1.90	7.09	4.24	5.88	4.01
Post	0/eversion	5.85	3.46	5.50	3.96	4.14	2.81	4.25	2.68	5.56	3.58	3.79	3.04
Pre	25/inversion	8.75	6.00	6.46	3.57	8.71	6.08	6.71	4.20	6.38	4.45	4.47	2.98
Post	25/inversion	7.61	3.96	4.29	3.51	7.54	4.63	6.39	3.63	5.24	4.61	4.44	4.35
Pre	25/neutral	6.54	4.24	5.46	4.18	6.82	4.99	3.64	4.31	5.26	2.97	6.71	4.85
Post	25/neutral	5.14	2.82	5.32	4.40	6.71	4.67	8.07	6.28	4.76	2.81	5.74	3.95
Pre	25/eversion	6.43	4.70	4.89	3.23	6.93	3.68	4.79	2.99	7.97	4.87	7.00	4.76
Post	25/eversion	5.61	3.69	5.11	2.87	7.71	5.80	5.25	3.62	6.18	3.70	4.74	2.87
Pre	25/maximum inversion	9.36	6.82	3.57	2.81	7.82	4.95	5.29	4.07	8.47	7.71	4.71	2.87
Post	25/maximum inversion	7.54	5.78	4.64	3.81	6.68	3.19	4.71	2.57	7.24	5.95	4.29	2.76

0 = Indicates tests in the 0° of plantar flexion position. 25 = Indicates tests in 25° of plantar flexion.

TABLE 2. *Means and standard deviations for joint position sense (degrees of error).*

nificant interaction were conducted using the Tukey HSD procedure.

RESULTS

Two subjects from the control group and one from the sham group did not return for the posttest. Thus, 45 subjects completed the study and were included in the data analysis.

Joint Position Sense

Means and standard deviations for passive and active joint position sense are presented in Table 2. Analysis of variance revealed no main effect or interactions involving group. There was, however, a main effect for test, $F(1,42) = 5.46$, $p = .024$, with the posttest scores better than the pretest. A main effect was also present for mode, $F(1,42) = 15.75$, $p < .001$, with active position sense ($X = 6.57 \pm 4.41$) greater than passive ($X = 5.21 \pm 3.56$). A significant interaction for mode by position, $F(6,252) = 3.52$, $p = .002$, was also present. Tukey post hoc analysis revealed that passive position sense was significantly better than active position sense in the maximum inversion position ($P < .05$).

Postural Stability

Sway index The means for sway index are presented in Table 3. The ANOVA for sway index revealed no differences between groups. Significant main effects for test, $F(1,42) = 11.07$, $p = .002$; platform, $F(1,42) = 461.96$, $p < .001$; and eyes, $F(1,42) = 1267.89$, $p < .001$, were demonstrated.

Modified equilibrium score The mean modified equilibrium scores for anterior/posterior and medial/lateral are presented in Table 4. The ANOVA for modified equilibrium score anterior/posterior revealed significant main effects for test, 11,42) = 6.63, p .014; condition, $F(1,42) = 56.64$, $p < .001$; and eyes, $F(1,42) = 1118.18$, $p < .001$. The ANOVA for modified equilibrium score anterior/posterior also revealed a significant group by test by condition by eyes interaction, $F(2,42) = 5.19$, .01 (Figure 5). Tukey post hoc analysis revealed that the posttest for Group 3 during Conditions 2 and 3 was significantly improved ($p < .05$) over that of the pretest for all three groups as well as the posttest for Groups 1 and 2.

The ANOVA for modified equilibrium score medial/lateral also revealed significant main effects for test, $F(1,42) = 7.59$, $p = .009$; condition, $F(1,42) = 89.2$, $p < .001$; and eyes, $F(1,42) = 1212.81$, $p < .001$. Additionally, there was a group by test by condition by eyes interaction, $F(2,42) = 6.90$, $p = .003$ (Figure 6). Tukey post hoc analysis revealed that the posttest scores for the treatment group (Group 3) were also significantly improved on Condition 2 and

	Pretest		Posttest	
	$\bar{X}$	SD	$\bar{X}$	SD
Condition 1: Stable/eyes open				
Control	.64	.20	.63	.11
Sham	.71	.13	.69	.16
Treatment	.72	.17	.60	.12
$Mean_{Total}$	.69	.16	.64	.13
Condition 2: Stable/eyes closed				
Control	1.82	.32	1.77	.33
Sham	1.88	.40	1.87	.42
Treatment	1.82	.35	1.68	.42
$Mean_{Total}$	1.84	.36	1.78	.40
Condition 3: Dynamic/eyes open				
Control	.84	.25	.80	.20
Sham	.95	.22	.90	.24
Treatment	.90	.20	.75	.20
$Mean_{Total}$	.90	.22	.82	.21
Condition 4: Dynamic/eyes closed				
Control	2.49	.40	2.27	.38
Sham	2.48	.29	2.36	.25
Treatment	2.45	.27	2.32	.42
$Mean_{Total}$	2.47	.32	2.14	.36

TABLE 3. *Means and standard deviations for sway index under the four test conditions (cm).*

	Pretest				Posttest			
	Anterior/Posterior		Medial/Lateral		Anterior/Posterior		Medial/Lateral	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Condition 1: Stable/eyes open								
Control	74	15	74	15	78	13	79	12
Sham	77	5	79	3	77	4	81	3
Treatment	78	5	81	4	81	4	82	3
$Mean_{Total}$	76	8	78	9	79	7	81	7
Condition 2: Stable/eyes closed								
Control	18	23	18	25	12	15	12	14
Sham	7	11	9	13	5	14	6	17
Treatment	9	18	9	18	32	24	34	27
$Mean_{Total}$	12	18	12	19	16	18	19	24
Condition 3: Dynamic/eyes open								
Control	63	30	59	27	67	29	64	27
Sham	63	23	65	22	65	24	62	23
Treatment	69	17	65	13	78	5	75	7
$Mean_{Total}$	66	24	63	21	70	19	68	21
Condition 4: Dynamic/eyes closed								
Control	0	0	0	0	0	0	0	0
Sham	0	0	0	0	1	5	1	6
Treatment	0	0	0	0	3	9	3	9
$Mean_{Total}$	0	0	0	0	2	5	2	7

TABLE 4. *Means and standard deviations for modified equilibrium score (%).*

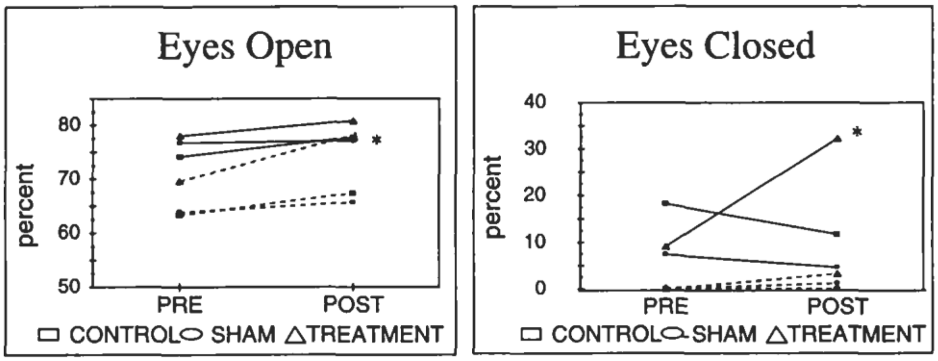


FIGURE 5. *Modified equilibrium score (anterior/posterior). Group by test by platform condition by eyes interaction. Solid lines indicate stable platform and dotted lines indicate dynamic platform. *Significantly greater than pretest for all three groups and posttest for Group 1 and Group 2 for Condition 3 ($p < .05$).*

gests the presence of a learning effect (41). Future studies should include a more in-depth training session prior to the testing sessions.

Our study also revealed that passive position sense was significantly better than active position sense for all three groups. Gross (30) examined both the injured and uninjured ankles of unilateral ankle-injured subjects as well as a group of noninjured controls for inversion and eversion joint position sense. He reported no differences between groups; however, he did report a significant main effect for mode. Consistent with our study, Gross (30) reported that passive inversion and eversion positioning at the ankle was significantly better than active positioning in both the injured and uninjured subjects.

Muscle proprioceptors may be best suited to sense rapid changes in body position (10-12,49), such as those evident in postural maintenance corrections. We tested joint position sense at 5°/sec. If muscle mechanoreceptors are best suited to sense quick changes, this would explain why active joint position sense was worse than passive. Passive joint position sense testing at a slow speed may act to isolate joint proprioceptors by limiting input from muscle proprioceptors. An extremely slow speed, such as the one used in our study during active joint positioning, may cause an interference with normal functioning of muscle proprioceptors. If active position sense testing is a measure of interest, perhaps a test which is more physiological in nature, such as a self-selected speed, would produce more meaningful results.

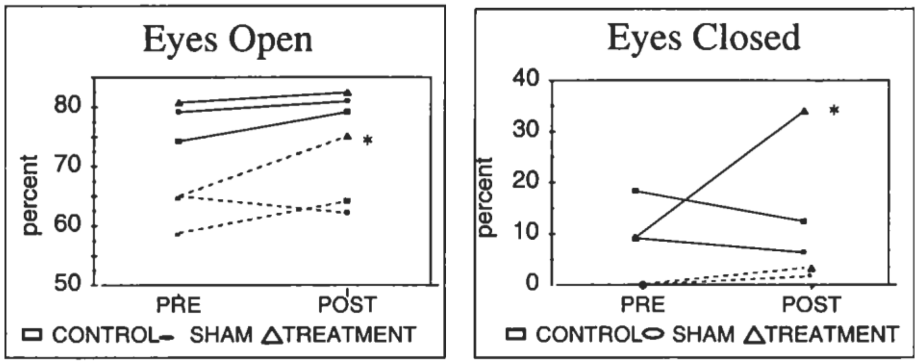
Another potential explanation for the difference in mode became evident during testing. Although the foot plate was adjusted for foot length and width and the foot was securely strapped in place, the subject's foot was still able to move slightly on the foot plate. During passive testing, this was not a problem. However, when an active contraction Condition 3 than the pretest for all three groups and the posttest for Groups 1 and 2.

DISCUSSION

The major finding of this study was that 6 weeks of coordination and balance training had a significant effect on the modified equilibrium scores of balance in both the anterior/posterior and medial/lateral direction. There was, however, no effect observed on sway index or joint position sense of the ankle. In the following sections, the main effects are discussed with the exception of the main effects for eyes and platform condition on the postural sway measures. It is expected that eye closure would significantly impair measures of sway, as would a dynamic platform condition.

Joint Position Sense

We found that the posttest scores for joint position sense were significantly improved over the pretest scores for all three groups. This sug-



IGURE 6. *Modified equilibrium score (medial/lateral). Group by test by platform condition by eyes interactio olid lines indicate stable platform and dotted lines indicate dynamic platform. *Significantly greater than prete or all three groups and posttest for Group 1 and Group 2 for Condition 3 ($p < .05$).*

began, the foot "slipped" in the direction of the movement. This meant that the anatomical angle of the subject's foot may have preceded the dynamometer's test angle. Some subjects reported that they felt like they were waiting for the machine "to catch up" to their foot prior to indicating that they were at the desired angle. We strongly suggest that future studies which assess active position sense, in which control of velocity is an issue, do so by using active positioning to show the subjects the initial position. We also suggest that the amount of force produced during the trials be limited. Although research has shown that the amount of force does not directly affect position sense (55), it was evident that a more forceful contraction produced greater tissue and padding compression. This, in turn, added to the discrepancy between the movement of the dynamometer and the actual joint movement.

The lack of a significant improvement in joint position sense for the training group in our study could be due to a number of factors. First, it could have been related to a lack of specificity between the training and assessment procedures. Secondly, it may be that 10 minutes per day, 3 days per week, for 6 weeks is simply insufficient to cause any physiological changes in the peripheral afferents.

We found that the maximum inversion position was better during passive testing than active testing. This is inconsistent with the findings of Glencross and Thornton (25), who found greater error in reproduction of joint position angles with the largest angles of movement. They tested four positions of plantar flexion and dorsiflexion for passive joint position sense and reported a linear trend between the degree of error and the test angle. As the test angle approached the limit of range of motion, the error in reproduction became greater. In our study, the maximum inversion position had the lowest mean score when tested passively and the highest mean score when tested actively.

In a concurrent study (64), we assessed the intertester reliability of our joint position sense measures and found them to range from good (.87) to poor (.03), depending on mode and position. Passive inversion (.87), passive eversion (.70), active eversion (.50), and active maximal inversion (.51) positions yielded the highest ICCs, while active inversion (.03), passive maximal inversion (.08), passive (.14), and active (.12) neutral positions yielded the poorest ICCs. Certainly, these findings affect our results; however, these ICC measures were intertester measures. All data for this study were collected by the same individual, and intratester reliability was not assessed. We suggest future studies investigate methods of assessing joint position sense, which will produce higher reliability estimates

The absence of a significant group by test interaction could be due to the specificity or type of training. All of the coordination and balance training activities were conducted in a weight-bearing position (single limb stance). Joint position sense was assessed with subjects supine in a nonweight-bearing position. Although the surface of the foot was in contact with the foot plate, the tibia served as the proximal, fixed segment, while the distal segment, the foot, served as the moving segment. The mechanical stresses imposed on a joint vary greatly between weight-bearing and nonweight-bearing activity (52,59). Perhaps a training program designed to include nonweight-bearing activities as well as weight-bearing activities on uneven surfaces would serve to improve joint position sense. Additionally, the assessment of joint position sense in a weight-bearing position may have merit.

Postural Sway

A significant main effect for test was present for all of the postural sway measures. This suggests that, regardless of the inclusion of a practice session, a learning effect was present.

Sway index There were no significant group by test interactions for sway index. A previous study by Cox et al (9) revealed similar results of no improvement following a training period in normal subjects. In their study, no significant improvement was shown in the sway index of uninjured individuals who trained 5 minutes per day for 6 weeks on either a firm surface or a compliant foam- rubber surface. Subjects were tested using the Chattecx Dynamic Balance System (Chattanooga Group Inc., Hixson, TN) for 10-second trials. The authors (9) attributed the lack of improvement in postural sway to the amount of time of the training and to the fact that subjects were uninjured, normal subjects. They reported that perhaps 5 continuous minutes of training was too demanding and that a shorter period of training could possibly produce a better quality of training. Additionally, they felt that it was possible that the uninjured subjects simply had no room for improvement. Another potential problem is that data were only collected over a 10-second period. This may not be long enough to detect changes in a healthy population. Furthermore, sway index was the only dependent measure analyzed. One disadvantage of using the sway index as the dependent measure is the Chattecx Dynamic Balance System's lack of sensitivity to touch downs. When the subject completely loses balance and touches the contralateral limb down or reaches for a hand rail, no measurement is recorded by the force plate. The investigator must choose to ignore the touch clown or repeat the trial. Neither option allows for reliable test results. The use of sway equilibrium allows the investigator to assign the score of zero for complete loss of balance in the instance when subjects must touch down.

Mattacola et al (44) measured postural sway (cm) in 12 subjects to determine intertester reliability using the Chattecx Dynamic Balance System. Subjects were tested for dual limb and single limb stance under static and dynamic conditions with eyes open and eyes closed. For single limb stance, ICCs (2,1) were reported to range from .41 to .57 for stable platform and from .63 to .90 for a dynamic platforms. Reliability of the Chattecx Dynamic Balance System was also tested by Irrgang and I.ephart (37). Thirteen subjects, ranging in age from 22 to 41 years, were measured using the sway index as the dependent measure under four test conditions: prescribed stance eyes open and eyes closed and choice stance eyes open and eyes closed. Data were collected over a 10-second period. Reliability was not affected by the different stance protocols. Moderate to high reliability was reported (.47—.81). Intraclass correlation coefficients were calculated by Ghent et al (24) for the Chattecx Dynamic Balance System. Fifty-four subjects (age = 15-79) were tested in a posture of their choice and a prescribed posture. Tests were performed over 10 seconds under four conditions: stable platform eyes open and eyes closed and moving platform eyes open and eyes closed. The dependent measure was not reported. Their results were also moderately reliable (r = .45—.63). These results indicate the need for further study of reliability as it relates to various testing protocols and careful planning and execution of testing procedures.

Modified equilibrium score The highest order interaction for modified equilibrium score in the anterior/posterior and medial/lateral directions revealed the same results; thus, the interactions will be discussed together. We found that the training group improved for Condition 2, eyes closed on a stable platform, and for Condition 3, eyes open on the inversion/eversion tilting platform. In contrast to the Hoffman and Payne study (33), our study did not reveal improvements in postural sway in the stable platform, eyes open (Condition 1). Hoffman and Payne (33) studied 28 healthy subjects who were divided into control and training groups. The subjects were pretested for standard deviations of sway in the anterior/posterior and medial/lateral directions using a Kistler force plate (Kistler Instrumentation Corporation, Amherst, NY) in an eyes open condition. The training group participated in 10 weeks of training using the Biomechanical Ankle Mat- form System (Spectrum Therapy Products, Jasper, MI). The training took place 3 days per week for a period of 10 minutes each day. Following the 10-week period, subjects were posttested to determine if postural sway had improved over the control group, which had been excluded from any training. Mean gain scores were analyzed with a single-factor ANOVA, which revealed a significant improvement in the experimental group for the X (-1) = .033) and for the Y parameters (1) = .019) over that of the control group (33).

A number of reasons exist as to why we did not see the same results as Hoffman and Payne (33). In their study (33), the sway index was not used; rather, they assessed postural sway in the anterior/posterior direction independently of medial/lateral sway. Additionally, both the testing and treatment instrumentation varied between studies. The treatment protocols varied both in type of exercise and length of study (10 weeks vs. 6 weeks). Finally, Hoffman and Payne's study trained healthy individuals, while our study included subjects with functional ankle instability.

Stable platform When looking at the results of the stable platform conditions in our study, only scores during the condition with eyes closed were significantly changed for Group 3. Nashner and Peters (49) reported that when somatosensory input is intact, removing visual input should only increase sway minimally. Therefore, in the injured individual, if somatosensory input is improved through training, the eyes closed condition should be the condition that would reveal improvements. The results of the modified equilibrium score in our study indicated that this "somatosensory" input can be improved in the functionally unstable ankle.

Dynamic platform When looking at the dynamic testing platform conditions, only the eyes open condition scores were improved in Group 3. It was expected that both of the dynamic tests would be improved. It appeals that Condition 4 (dynamic, eyes closed) was just too challenging, and most subjects were forced to

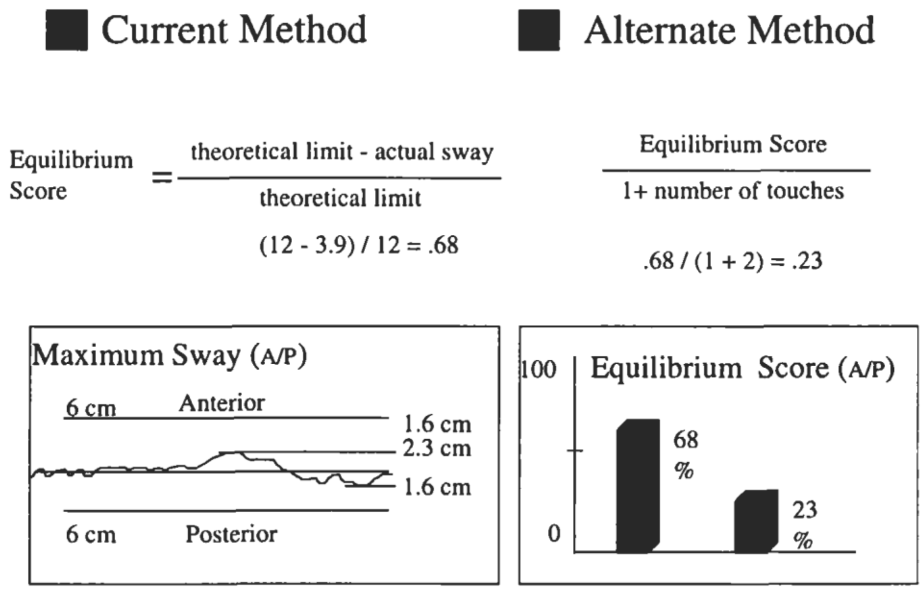


FIGURE 7. *Alternative method of calculating modified equilibrium score. The modified equilibrium score is calculated as previously described but then divided by [1 + number of touchdowns]. A/P = Anterior/posterior.*

touch down with the other foot. When looking at modified equilibrium score, a touch down yields a score of zero whether the subject touches once or 10 times. Modified equilibrium score is probably not the best tool to assess balance when extremely challenging conditions are imposed (ie., single limb, moving platform with eyes closed). Perhaps a new method could be used that would incorporate the limits of stability and the actual sway as well as take into account the number of touch downs.

To account for the number of touch downs, an alternate method of calculating the modified equilibrium score is presented in Figure 7. The modified equilibrium score is calculated as previously described but then divided by [1 + number of touch downs]. The same modified equilibrium score as shown in Figure 1 would be 33% if the subject scored one touch down and 23% if two touch downs were scored.

Clinical Implications

The results of the present study indicate that the use of a 6-week bal ance and training coordination program can increase the control of postural sway in individuals with functional instability of the ankle when sway is measured using a modified equilibrium score. The use of sway index appears to be limited in its ability to detect differences among groups. When assessing postural sway, clinicians should include multiple measures, such as center of balance, center of balance distance, modified equilibrium score, maximum sway in the anterior/posterior direction, and medial/lateral direction.

Balance and coordination training performed in a weight-bearing position does not appear to have an effect on passive and active position sense. Based on the reports from previous studies (26,62) that ankle joint injury may be due to an improper positioning of the foot at heel strike, it is clear that nonweight-bearing pro-prioception remains an integral sense that must be of concern. Although it is unclear whether, joint position sense can be improved, it is suggested that nonweight-bearing coordination exercises also be included in the retraining of functionally unstable ankles, and that future studies assess the efficacy of such programs on joint position sense.

Ankle joint proprioception or kinesthetic sensibility are often assessed with a constant velocity. It is clear that muscle, tendon, joint, and cutaneous receptors do not work independently of each other (7,19,20, 27-29,45,57,58,65,71). Perhaps proprioceptive deficits are not caused by selective damage to one or the other of these systems. Perhaps it is the combination or, more specifically, the interpretation of these inputs that becomes distorted. In recent years, joint mechanoreceptors have been the focus of ankle joint proprioception studies (21,25,30,32). These studies have led to varying results, introducing more questions. Isn't it possible that muscle and tendon mechanoreceptors could also become damaged following joint injury? Nitz et al (50) reported damage to the tibial and peroneal nerves following grade II and III ankle inversion sprains. If these large nerves are damaged, wouldn't neuromuscular interaction be affected? Isn't it also possible that the afferents arising from the muscles and tendons could become damaged during similar injury? If so, it might make sense to assess proprioception in a manner that would combine the use of joint, skin, and muscle mechanoreceptors rather than selectively assessing each. Since it is impossible to selectively assess different receptors without anesthetizing them, it might make more sense to assess the coordination or the interpretation of the various types of receptors (such as those that sense movement, velocity, or position). This could be accomplished by measuring joint position sense at clinically relevant velocities in weight- bearing and nonweight-bearing positions and with varying amounts of force. The use of a motion analysis system would allow nonweight-bearing assessment at self-selected velocities.

The overall results of an improvement in postural sway and no improvement in joint position sense can be discussed by looking at central motor control and peripheral motor control. Gaufin et al (23) refuted the theory of Freeman et al (18) that a peripheral deficit is the cause of functional instability. In the study by Gaufin et al (23), subjects trained for 8 weeks on an ankle disc. They measured postural sway while simultaneously recording body movements with two cameras (23). Not only did they report a decrease in postural sway, but also an improved pattern of balance control. This was evident in the injured limb as well as in the uninjured, untrained limb. Gaufin et al (23) proposed that this improvement implicated central motor control rather than peripheral proprioceptive control. If this theory holds true, it would be expected that the balance and coordination training in our study would improve measures of balance but would have no effect on the peripheral afferent receptors of the ankle and, thus, no effect on joint position sense.

SUMMARY

Based on the results of this study, it is evident that postural sway can be improved in subjects with functional instability of the ankle following 6 weeks of coordination and balance training. Balance and coordination training should continue to be an integral part of rehabilitation protocols.

The lack of a significant improvement in joint position sense following the coordination and training program indicates the need for further study in the area of training for nonweight-bearing proprioception. It is still unclear if joint position sense can be improved in the functionally unstable ankle.

ACKNOWLEDGMENTS

The authors wish to thank the following people for their time and valuable input to this project: Dr. Joe Gieck, Dr. Ethan Saliba, Dr. Donald Ball, and Dr. Christopher Vaughan. We'd also like to thank Dr. Lydia Burak and Claire Robson for their editorial comments.

REFERENCES

1. Arnheim DA, Prentice WE: Principles of Athletic Training (8th Ed), St. Louis: Mosby-Year Book Inc., 1993
2. Berne RM, Levy MN: Physiology (2nd Ed), St. Louis, MO: C.V. Mosby Company, 1988

3. Bosien WR, Staples S, Russell SW: Residual disability following acute ankle sprains. J Bone Joint Surg 37:1237-1243, 1955
4. Cahill BR: Chronic orthopedic problems in young athletes. J Sports Med 3:36-39, 1973
5. Case WS: Ankle injuries. In: Sanders B (ed), Sports Physical Therapy, pp 456464. Norwalk, CT: Appleton and Lange, 1990
6. Chen SC: Foot and ankle injuries. In: Helal B, King JB, Grange WI (eds), Sport Injuries and Their Treatment, pp 421426. Cambridge: Chapman and Hall Ltd., 1986
7. Clark FJ, Burgess PR, Chapin JW: Proprioception with the proximal interphalangeal joint of the index finger: Evidence for a movement sense without a static position sense. Brain 109:11951208, 1986
8. Cornwall MW, Murrell W: Postural sway following inversion sprain of the ankle. Podiatr Med Assoc 81:243-247, 1991
9. Cox ED, Lephart SM, Irrgang JJ: Unilateral training of non-injured individuals and the effect on postural sway. J Sport Rehabil 2:87-96, 1993
10. Diener HC, Dichgans J, Bootz F, Bacher M: Early stabilization of human posture after a sudden disturbance: Influence of rate and amplitude of displacement. Exp Brain Res 56:126-134, 1984
11. Diener HC, Dichgans J, Guschlbauer B, Bacher M: Role of visual and static vestibular influences on dynamic posture control. Human Neurobiol 5:105-113
12. Diener HC, Dichgans J, Guschlbauer B, Mau H: The significance of proprioception on postural stabilization as assessed by ischemia. Brain Res 296:103-109, 1984
13. Doman J, Fermie GR, Holliday P1: Visual input: Its importance in the control of postural sway. Arch Phys Med Rehabil 59:586-591, 1978
14. Evans G, Hardcastle P, Frenyo A: Acute rupture of the lateral ligaments of the ankle. J Bone Joint Surg 668:209-212, 1984
15. Freeman MAR: Coordination exercises in the treatment of functional instability of the foot. Physiotherapy 51:393-395, 1965
16. Freeman MAR: Instability of the foot after injuries to the lateral ligament of the ankle. J Bone Joint Surg 478:669677, 1965
17. Freeman MAR: Treatment of ruptures of the lateral ligament of the ankle.] Bone Joint Surg 478:661-668, 1965
18. Freeman MAR, Dean MRE, Hanham IWF: The etiology and prevention of functional instability of the foot. J Bone Joint Surg 478:678-685, 1965
19. Freeman MAR, Wyke B: The innervation of the ankle joint. Acta Anat 68: 321-333, 1967
20. Gandevia SC, McCloskey DI, Burke D: Kinesthetic signals and muscle contraction. Trends Neurosci 15:62-65, 1992
21. Gam SN, Newton RA: Kinesthetic awareness with multiple ankle sprains. Phys Ther 68:1667-1671, 1988
22. Garrick The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. Am J Sports Med 5:241-242, 1977
23. Gaufin H, Tropp H, Odenrick P: Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. Int J Sports Med 9:141-144, 1988
24. Ghent R, Probst J, Denegar CR, Clemente FR: Assessment of the reliability of the Chattecx Balance System. Phys Ther 72:S57, 1992 (abstract)
25. Glencross D, Thornton E: Position sense following joint injury. Am J Sports Med 21:23-27, 1981
26. Glick JM, Gordon RB, Nishimoto D: The prevention and treatment of ankle injuries. Am I Sports Med 4:136-141, 1976

27. Goodwin GM, McCloskey DI, Matthews PB: The contribution of muscle afferents to kinesthesia shown by vibration-induced illusions of movement and by the effect of paralyzing joint afferents. Brain 95:705-748, 1972
28. Grigg P, Finerman GA, Riley LH: Joint position sense after total hip replacement. J Bone Joint Surg 55A:10161025, 1973
29. Grigg P, Hoffman A: Properties of Ruffini afferents by stress analysis of isolated sections of joint capsule. J Neurophysiol 47:41-54, 1982
30. Gross MT: Effects of recurrent lateral ankle sprains on active and passive judgments of joint position. Phys Ther 67:1505-1509, 1987
31. Guyton AC: Textbook of Medical Physiology, Philadelphia: W.B. Saunders Company, 1981
32. Hertel JN, Guskiewicz KM, Kahler DM, Perrin DH: Effect of lateral ankle joint anesthesia on joint position sense, postural sway and center of balance. J Sport Rehabil 5:111-119, 1996
33. Hoffman M, Payne GV: The effects of proprioceptive ankle disk training on healthy subjects. I Orthop Sports Phys Ther 21:90-93, 1995
34. Honrubia V, Hoffman LF: Practical anatomy and physiology of the vestibular system. In: Jacobson GP, Newman CW, Kartush JM (eds), Handbook of Balance Function Testing, pp 261-279. St. Louis, MO: Mosby-Year Book, Inc., 1993
35. Horak FB, Nashner LM, Diener HC: Postural strategies associated with somatosensory and vestibular loss. Exp Brain Res 82:167-177, 1990
36. Hutson M: Sports Injuries: Recognition and Management, pp 133-135. New York: Oxford University Press, 1990
37. Irrgang JJ, Lephart S: Reliability of measuring postural sway in normal individuals using the Chattecx Dynamic Balance System. Phys Ther 72:S66, 1992 (abstract)
38. Irrgang JJ, Whitney SL, Cox ED: Balance and proprioceptive training for rehabilitation of the lower extremity. J Sport Rehabil 3:68-83, 1994
39. Jackson DW, Ashley RD, Powell JW: Ankle sprains in young athletes. Clin Orthop 101:201-214, 1974
40. Konradsen L, Ravn JB: Ankle instability caused by prolonged peroneal reaction time. Acta Orthop Scand 61:388-390, 1990
41. Kottke FJ, Halpern D, Easton JKM, Ozel AT, Burrill CA: The training of coordination. Arch Phys Med Rehabil 59:567-572, 1978
42. Kulund DN: The Injured Athlete, Philadelphia: J.B. Lippincott, 1988
43. Lentell GL, Katzman LL, Walters MR: The relationship between muscle function and ankle stability. J Orthop Sports Phys Ther 11:605-611, 1990
44. Mattacola C, Lebsack D, Perrin DH: Intertester reliability of assessing postural sway using the Chattecx Balance System. I Athl Train 29:170, 1994 (abstract)
45. McCloskey DI: Kinesthetic sensibility. Phys Rev 58:763-820, 1978
46. Nashner LM: Adapting reflexes controlling the human posture. Exp Brain Res 26:59-72, 1976
47. Nashner LM: Practical biomechanics and physiology of balance. In: Jacobson GP, Newman CW, Kartush JM (eds), Handbook of Balance Function Testing, pp 261-279. St Louis, MO: Mosby-Year Book, Inc., 1993
48. Nashner LM, Cordo PJ: Relation of automatic responses and reaction-time voluntary movements of human leg muscles. Exp Brain Res 43:395-405, 1981
49. Nashner LM, Peters JF: Dynamic posturography in the diagnosis and management of dizziness and balance disorders. Neuro Clinics 8:331-349, 1990
50. Nitz AI, Dobner JJ, Kersey D: Nerve injury and grades II and III ankle sprains. Am J Sports Med 13:177-181, 1985
51. O'Donohue DH: Treatment of Injuries to Athletes, Philadelphia: W.B. Saunders Company, 1984

52. Palmitier R, An KN, Scott S, Chao EYS: Kinetic chain exercise in knee rehabilitation. Sports Med 11:402-413, 1991
53. Perry J: Anatomy and biomechanics of the hindfoot. Clin Orthop 177:9-15, 1983
54. Pincivero D, Gieck J, Saliba E: Rehabilitation of a lateral ankle sprain with cryokinetics and functional progressive exercise. J Sport Rehabil 2:200-207, 1994
55. Rymer WZ, D'Almeida A: Joint position sense: The effects of muscle contraction. Brain 103:1-22, 1980
56. Sammarco J: Biomechanics of the ankle. I. Surface velocity and instantaneous center of rotation in the sagital plane. Am J Sports Med 5:231-234, 1977
57. Schultz RA, Miller DC, Kerr CS, Micheli L: Mechanoreceptors in human cruciate ligaments: A histological study. J Bone Joint Surg 66A:1072-1076, 1984
58. Schutte MJ, Dabezies El, Zimny ML, Happel LT: Neural anatomy of the human anterior cruciate ligament. J Bone Joint Surg 69A:243-247, 1987
59. Solomonow M, Barata R, Zhou BH, Shoji H, Bose W, Beck C, D'Ambrosia R: The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. Am J Sports Med 15:207-213, 1987
60. Staples 0: Result study of ruptures of lateral ligaments of the ankle. Clin Orthop 85:50-58, 1972
61. Staples 0: Ruptures of the fibular collateral ligaments of the ankle. J Bone Joint Surg 57A:101-107, 1975
62. Stormont DM, Morrey BF, An K, Cass JR: Stability of the loaded ankle: Relation between articular restraint and primary and secondary static restraints. Am J Sports Med 13:295-300, 1985
63. Subotnick SI: Sports Medicine of the Lower Extremity, New York: Churchill Livingstone Inc., 1989
64. Szczerba JE, Bernier IN, Perrin DH, Gansneder BM: Intertester reliability of active and passive ankle joint position sense testing. J Sport Rehabil 4:282291, 1995
65. Tamburello M: Effect of a small knee effusion. Unpublished doctoral dissertation, University of Virginia, Charlottesville, VA, 1992
66. Tropp H: Pronator muscle weakness in functional instability of the ankle joint. Int] Sports Med 7:291-294, 1986
67. Tropp H, Askling C, Gillquist I: Prevention of ankle sprains. Am J Sports Med 13:259-262, 1985
68. Tropp H, Ekstrand J, Gillquist J: Factors affecting stabilometry recordings of single limb stance. Am J Sports Med 12: 185-188, 1984
69. Tropp H, Ekstrand J, Gillquist J: Stabilometry in functional instability of the ankle and its value in predicting injury. Med Sci Sports Exerc 16:64-66, 1984
70. Wilkerson GB: Ankle injuries in athletes. Primary Care 19:377-392, 1992
71. Zimny ML, Albright DJ, Dabezies EJ: Mechanoreceptors in the human medial meniscus. Acta Anat 133:35-40, 1988