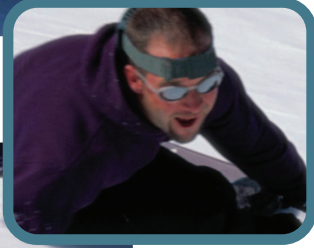


"The Clinical Advantage"TM



Biodex Balance System SD

(#950-300)

Clinical Resource Manual 945-308



BIODEX

Biodex Medical Systems, Inc.

20 Ramsay Road, Shirley, New York, 11967-4704, Tel: 800-224-6339 (In NY and Int'l, call 631-924-9000), Fax: 631-924-9338, Email: sales@biodex.com, www.biodex.com

REFERENCE MANUAL

table of contents



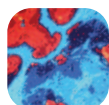
OVERVIEW	1
-----------------------	----------



DATA	2
-------------------	----------



SUPPORTING ARTICLES	3
----------------------------------	----------



BIBLIOGRAPHY	4
---------------------------	----------



Biodex Balance System SD

Reference Manual

1) Overview

- Introduction to Balance
- Theory of Operation
- Assessing Static Balance
- Assessing Dynamic Balance
- Clinical Applications



BIODEX BALANCE SYSTEM SD

introduction to balance

Maintaining postural balance while standing is a motor skill most people take for granted. Postural balance, however, requires complex coordination and integration of multiple sensory, motor and biomechanical components¹. An individual senses body position in relation to gravity and environmental surroundings by combining vestibular, visual and proprioceptive (somatosensory) inputs¹. Body position and smooth functional movement patterns result from these coordinated actions along with integration of graded ankle, knee and hip movements along the kinetic chain².

COMPONENTS OF BALANCE

The dynamic process of postural balance involves special sensory receptors that provide information in regards to various environmental and physiological conditions that may affect a person's ability to maintain equilibrium. They are as follows:

- **Vestibular Apparatus:**

The vestibular apparatus (VA) consists of three semicircular canals and provides sensory information in regards to head position and gravitational changes. This information is used in three distinct ways.

1. Assisting with maintaining upright posture, these organs are referred to as "sense organs of balance". They provide a sense of space via gravitational stimuli. This is apparent when the eyes are closed and the subject must rely on VA input.
2. Controlling the movement of the eye muscles via the vestibular-ocular reflex (VOR), which allows the eyes to remain fixed during movement or perturbation. The VOR is important for maintaining a frame of reference and providing spatial information regarding the environment around the person. When the VA is disturbed, the eyes will exhibit nystagmus in order to fix a reference point, otherwise the movement of the eyes is equal and in the opposite direction of head movement.
3. Provides conscious awareness in regards to the body's position and acceleration. This information is provided after stimuli has been relayed by the thalamus to the cerebral cortex.

- **Visual Input:**

Visual input is important to integrate the stimuli of the VA with the subject's physical environment. It occurs as follows:

1. The eyes function to detect a focal point on an object long enough for them to gain a clear image of that point.
2. When the head is moved, the endolymph in the semicircular canals specific to that plane of movement bends the tiny hairs located in the semicircular canals and sends the message to the 8th cranial nerve, assisting to elicit a vestibular-ocular reflex, in turn rotating the eyes in an equal and opposite direction of the head. This movement allows for a fixed reference point. (Guyton, A. A Textbook of Medical Physiology (7th ed.). Philadelphia: Saunders, 1986).

References:

1. Nashner, L., Practical Biomechanics and Physiology of Balance. Handbook of Balance Function and Testing, 1993
2. Irrgang, JJ, Whitney SL. Cox ED: Balance and Proprioceptive Training for Rehabilitation of the Lower Extremity. J Sports Rehabilitation 3:68-83, 1994
3. Vander, A., Sherman, J., Luciano, D. Human Physiology: "The Mechanisms of Body Function" [5th Ed.], 1990

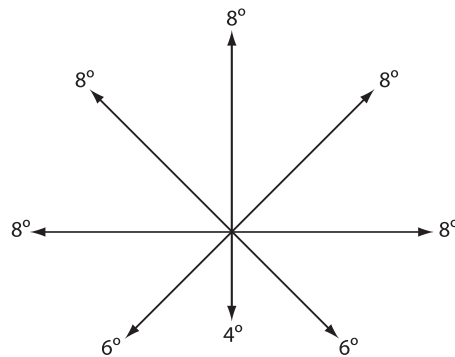
- **Proprioception and Kinesthetic Input:**

The proprioceptive component of balance involves mechanoreceptors located within the skin, muscle tendons and ligaments surrounding a joint. These structures play an important role in providing sensory information relating to touch, body position and rate of movement from external cues or conscious movement patterns associated with daily living. They also assist with providing adequate response to perturbations or noxious stimuli via reflex loops within the spinal cord to protect the body from injury.

Two such mechanoreceptors of importance to postural balance are: muscle spindle fibers and Golgi Tendon Organs. They consist of afferent nerve fibers and provide the nervous system with continual impulses regarding the status of a muscle at rest and during movement. They are crucial to maintaining postural balance.

LIMITS OF STABILITY

Limits of stability (LOS) for standing balance is defined as the maximum angle a person's body can achieve from vertical without losing balance. Basically, how well can a person control their center of gravity (COG) once it comes outside their base of support (BOS). Maintaining LOS is the result of integration of the sensory and motor control aspects of balance and plays an important role in activities of daily living. Once the LOS is exceeded, a corrective strategy must take place in order to prevent a fall or stumble. LOS for bilateral stance in normal adults is eight degrees anterior, four degrees posterior and eight degrees laterally in both directions.



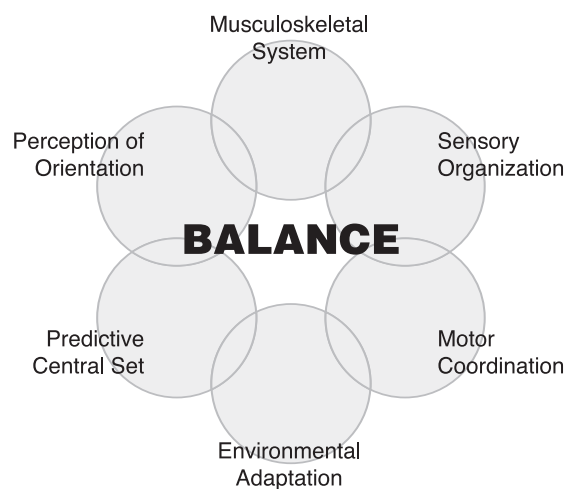
GOLGI TENDON ORGANS

- Located in the tendon near the musculotendinous junction.
- Serve as the protective mechanism to relax an overstretched muscle.
- Senses tension within the prospective muscle and transmit the information to the CNS, and through polysynaptic reflexes.
 1. Inhibits the motor neurons of the contracting muscle (Vander, Sherman, Luciano, 1990).
 2. Muscle tension is monitored throughout the range of motion by the GTO, this is crucial to preventing muscle strains and tears.

According to Horstmann and Dietz (1988), under normal conditions people rely most on visual and somatosensory inputs to maintain balance.

Maintaining balance involves a series of complex actions in the various stations of the Central Nervous System, as graphically represented below (see figure1). When one action does not function accordingly, equilibrium become altered, thus, disrupting the ability to maintain balance. A variety of consequences can occur due to poor balance; therefore, clinicians need to address each component in order to prevent re-injury or further trauma. The Biodex Balance System SD is important for the objective assessment of neuromuscular control and the somatosensory input important to balance.

Figure 1.



References:

1. <http://w3.ouhsc.edu/dthompso/balance/home.htm>
Fay Horak (1991, p.23) depicts the subsystems that influence balance behavior as interlocking circles.

BIODEX BALANCE SYSTEM SD | theory of operation

WHAT DOES THE BIODEX BALANCE SYSTEM SD DO?

- Provides valid, reliable and repeatable objective measures of a patient's ability to balance on stable and unstable surfaces. Documents neuromuscular control in safe environments.
- During static and dynamic stability exercise and testing, the Balance System SD provides visual biofeedback of a patient's ability to control their center of gravity (COG).
- During static and dynamic limits of stability exercises and testing, the Balance System SD provides visual biofeedback of the patient's ability to control their limits of stability (LOS).

THE BIODEX BALANCE SYSTEM SD CAN BE THE CORNERSTONE FOR THE FOLLOWING PROGRAMS:

- Fall Risk Assessment and Conditioning Program
- Fall Screening Program
- Athletic Screening Program
- Movement Disorders associated with neuromuscular control
- Amputee prosthetic rehabilitation
- Orthopedic rehabilitation associated with ligament sprains and poor neuromuscular control
- Sports Medicine and Conditioning Programs
- Core and Lumbar Stabilization Strategies
- Pre and Post Head Injury Screening
- Upper extremity closed chain activities

HOW IS THE BIODEX BALANCE SYSTEM SD EFFECTIVE?

By targeting the somatosensory and neuromuscular control aspects of balance, the Biodex Balance System SD can assist patients with controlling their COG over their base of support (BOS). Since the Biodex Balance System SD permits up to 20° of support surface tilt, the patient is challenged to maintain their COG over their BOS by trying to keep the platform level. The performance of this task is dependent upon neuromuscular mechanisms of proprioception, strength, and power. The Biodex Balance System SD is effective in the assessment and training of the somatosensory and neuromuscular control aspects of balance as it challenges the mechanoreceptors found around the joints of the lower extremity.

The Biodex Balance System SD has a wide range of clinical applications and provides objective measures from testing that can be used to establish progressions and discharge criteria, as well as be part of a comprehensive Fall Risk Assessment or Fall Screening Program. Balance ability can be assessed either statically or dynamically, as well as bilaterally and unilaterally. It also allows for bilateral comparisons between involved and uninvolved limbs.

DYNAMIC BILATERAL STANCE ASSESSMENT

When the default testing protocol is performed (5 trials x 20 seconds, 30 seconds rest) the reported Overall Stability Index can be compared to age related Predictive Values that were developed at the University of Southern Connecticut. The results of the five trials are collected and averaged by the software and displayed to the right of the age related Predictive Value. The Stability Index represents the variance of platform displacement in degrees from level in both the anterior/posterior and medial/lateral directions. A high number is indicative of poor neuromuscular control, which may increase the potential for orthopedic injury or falling.

The protocol used is as follows, and should be used during patient assessments:

TEST DURATION: 20 seconds

LEVEL: 8

TRIALS: 5

REST BETWEEN TRIALS: 30 seconds

STANCE: Bilateral

***NOTE:** The above protocol is an integral part of the Biodex Fall Risk Assessment Program

UNILATERAL STANCE ASSESSMENT

Using the same protocol as above, bilateral differences can be recorded and compared as an effective method to prevent acute injury and for setting rehabilitation goals with unilateral injuries such as ankle, knee sprains or post surgical intervention. The software will report percent difference between the uninvolved and involved side for the Overall, Anterior/Posterior and Medial/ Lateral Stability Indices.

References:

1. Finn, et al, Southern Connecticut State Univ. Stability Performance Assessment Among Subject of Disparate Balance Abilities, 1999

HOW ARE CLINICIANS USING THE BIODEX BALANCE SYSTEM SD WITH SPORTS MEDICINE AND ORTHOPEDIC PATIENTS?

- Lower Extremity Patients:

- ACLs
- Total Knee
- Total Hip
- Ankle Sprain
- Fractures
- Amputees - weight bearing and balance with the prosthesis
- High Tibal Osteotomies
- Risk for Fall
- Athletic Balance Assessment

These patients can work AROM either non weight bearing, or full weight bearing .They can work on weight shifting, proprioceptive and stabilization drills with or with out perturbation. Also some clinicians are using the Balance SystemSD for high level agilities.

- Spine Patients:

- Ankle, knee and hip movement strategies for improving posture and mechanics.
- Core Stabilization using a gym ball on the Balance System SD platform.

- Upper Extremity Patients:

- Scapular stabilization drills, where the patient uses his arms to manipulate the platform.

- Geriatric Patients: Both Neurological and Orthopedic

- Balance and weight shift training as part of rehabilitation from a total hip or knee replacement, or a stroke.
- Kinesthetic Balance Training
- Weight Bearing ROM

HOW ARE CLINICIANS USING THE BIODEX BALANCE SYSTEM SD WITH NEUROLOGICAL PATIENTS

- Stroke or Cerebrovascular Accident (CVA) Patients
- Parkinson Disease
- Amyotropic Lateral Sclerosis (ALS/ Lou Gehrig's Disease)
- Multiple Sclerosis
- Spinal Cord or Head Trauma
Any head or spinal cord injury resulting in loss of balance or ambulatory motor skills.

- Rehabilitation with these patients involves:
Restoration of effected motor skills by retraining new neural pathways.
Restoration of kinesthetic sense for proper body positioning to maintain balance and weight transfer for ambulation.

- The Biodex Balance System SD is effective because:
The instant biofeedback makes it easy for the patient to relate to and repeat the motions.
Safe controlled environment that allows the patient to progress from non weight bearing to weight bearing.
Objectives and reproducible so that progress can be monitored as well as rehab sessions documented.
Perfect precursor to gait training on parallel bars or the Biodex Rehabilitation Treadmill.

BIODEX BALANCE SYSTEM SD applications

ORTHOPEDIC AND SPORTS MEDICINE PROGRAM

- **Goal:**
To assess overall dynamic stability and balance for pre-season baseline, injury pre-disposition or return to activity. In addition, use for balance and proprioceptive training.
- **Method:**
Provides dynamic balance assessment of single-leg and two-leg stance. Test results compared to age and gender dependent normative values. Balance Training designed to improve postural stability, weight shift, proprioception and center of gravity control.
- **Results and Benefits:**
Test provides an objective score, "stability index", that if higher than the predicted value indicates a strength, proprioception, and vestibular or visual impairment.
- **Balance Assessment**
Two-leg stance, age dependent normal ranges:

Age	Stability Index
17-35	.82 – 2.26
36-53	1.23 – 3.03
54-71	1.79 – 3.35
72-89	1.90 – 3.50

- **Knee Injury Pre-disposition**
Single-leg stance, Stability Index by gender for healthy collegiate level athletes (Age: 19.6 ± 1.5 years):

Women	3.27 (+/- 1.43)
Men	6.00 (+/- 3.06)
- Objective data confirms presence or absence of a dynamic stability or balance problem – increases patient confidence and provides a tangible rehabilitation goal.
- Baseline measure to manage return to activity determination.
- Patients with ACL deficiency have decreased stability vs. controls in both limbs.
- Simple, efficient, reproducible balance screening and training tool.

References:

1. Finn JA, Alvares MM, Jett RE, Axtell RS, DS Kemler. Biodex Balance Assessment among subjects of disparate balancing abilities. Presented at 1999 American College of Sports Medicine Annual Meeting.
2. Hewett T. Balance Perspectives: Neuromuscular Training to Prevent Injuries. 1999 Advances on Knee and Shoulder Cincinnati Sportsmedicine and Orthopedic Center.
3. Rozzi SL, Lephart SM, Gear WS, FuFH. Knee Joint Laxity and Neuromuscular Characteristics of Male and Female Soccer and Basketball Players. Am J Sports Med 27:312-319, 1999.

FALL RISK ASSESSMENT, MOVEMENT DISORDERS AND NEUROLOGICAL PATHOLOGIES

- **Goal:**
To assess overall balance as a preliminary balance screening test or as an integral component of a Fall Risk Assessment Evaluation. In addition, use as an objective balance performance baseline in conjunction with balance training program.
- **Method:**
Dynamic balance assessment. Test results compared to age dependent normative values. Balance Training designed to improve postural stability, proprioception, range of motion, weight shift, and center of gravity control.
- **Results and Benefits:**
Test provides an objective score, "stability index", that if higher than the predicted value indicates a strength, proprioception, and vestibular or visual impairment.
- **Age dependent normal ranges**

Age	Stability Index
17-35	.82 – 2.26
36-53	1.23 – 3.03
54-71	1.79 – 3.35
72-89	1.90 – 3.50

- Objective data confirms presence or absence of a balance problem – increases patient confidence and provides a tangible rehabilitation goal.
- Baseline measure to manage effects of balance impairing medications.
- Real time visual representation of dynamic balance in a safe, controlled environment without the patient feeling self-conscious.
- Simple, efficient, reproducible balance screening and training tool.

ALTERNATIVE APPLICATIONS



1. By placing the physio ball on the Balance System SD, you can add various levels of difficulty to core stabilization exercises.



2. Closed Chain Scapular stabilization exercises can be performed using the Balance System SD in pushup or kneeling positions.



3. Tilting the Balance System SD allows the patient to do seated multiplanar Active Range of Motion activities.

References:

1. Finn JA, Alvares MM, Jett RE, Axtell RS, DS Kemler. Biodex Balance Assessment among subjects of disparate balancing abilities. Presented at 1999 American College of Sports Medicine Annual Meeting.
2. Guidelines for Prevention of Falls in Older Persons, American Geriatrics Society, British Geriatrics Society and American Academy of Orthopedic Surgeons Panel on Fall Prevention. JAGs 49:664-672, May 2001.

Biodex Balance System SD

Reference Manual

2) Data

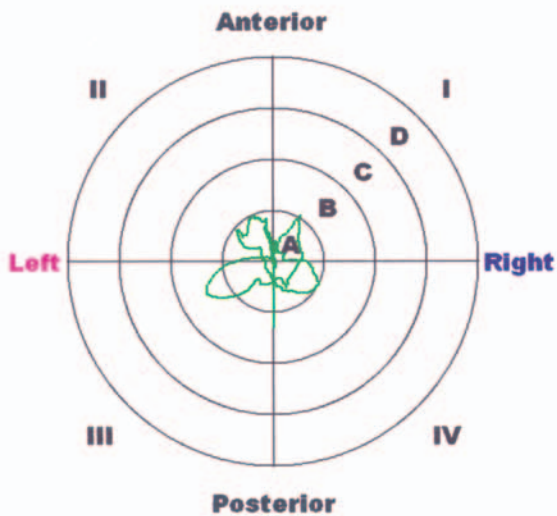
- Balance Testing
- Balance System
 - Reports
 - Parameters Defined
 - Stability Index



theory of operation

Postural Stability Test Results

Name: <u>Joe Blodex</u>		Date: <u>04/25/2006 9:33 AM</u>
Height: <u>65"-73"</u>	Age: <u>43</u>	
<u>Foot Placement</u>		<u>Protocol</u>
Foot Angle:		Platform Setting <u>STATIC</u>
Heel Position:		Test Trial Time <u>20</u>
		Test Trials <u>3</u>

[illegible]

Comments:

Clinician:

Limits of Stability Test Results

Name: Joe Blodex
Height: 65"-73"

Age: 43

Date: 04/25/2006 9:37 AM

Foot Placement

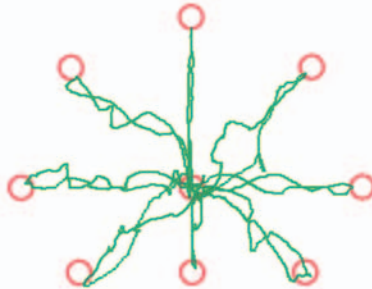
Protocol

Foot Angle:
Heel Position:

Platform Setting STATIC
Test Trial Time -1
Test Trials 3

Skill level: Medium
Time to Complete Test: 59

Direction Control	Actual	Goal
Overall:	78	>65
Forward:	96	>65
Backward:	72	>30
Right:	87	>65
Left:	78	>65
Forward/Right:	73	>65
Forward/Left:	83	>65
Backward/Right:	72	>65
Backward/Left:	78	>65



Comments:

Clinician:

Fall Risk Test Results

Name: Joe Biodex
Height: 65"-73"

Age: 85

Date: 04/25/2006 10:19 AM

Foot Placement

Protocol

Foot Angle:
Heel Position:

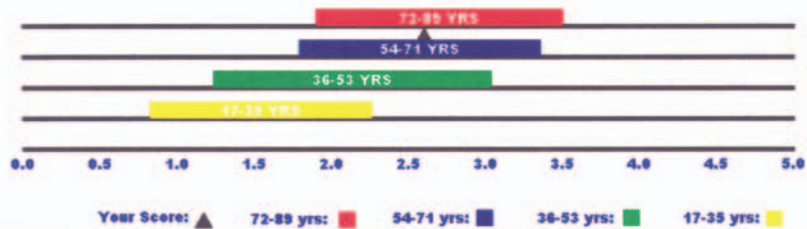
Platform Setting 8
Test Trial Time 20
Test Trials 3

Overall Stability Index:

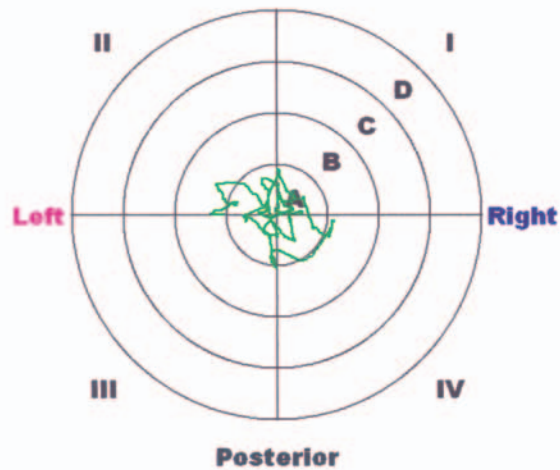
Actual
Score
2.6

STD
Dev.
1.78

Your score compared to age group of healthy people



Anterior



Comments:

Clinician:

Athletic Single Leg Stability Test Results

Name: Joe Biodesx
Height: 65"-73"

Age: 43

Date: 04/25/2006 9:40 AM

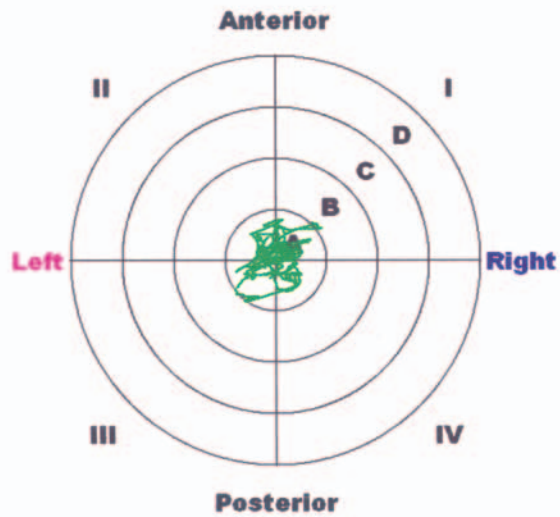
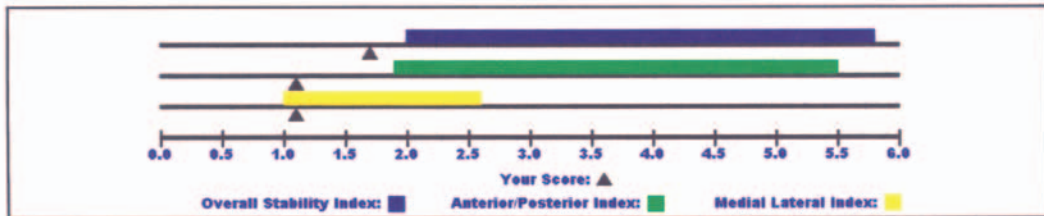
Foot Placement

Protocol

Foot Angle:
Heel Position:

Platform Setting 4
Test Trial Time 20
Test Trials 3

	Actual Score	STD Dev.	Normal Score	STD Dev.
Overall Stability Index:	1.7	1.00	3.9	1.9
Anterior/Posterior Index:	1.1	0.91	3.7	1.8
Medial Lateral Index:	1.1	0.92	1.8	0.8



Comments:

Clinician:

Postural Stability Training

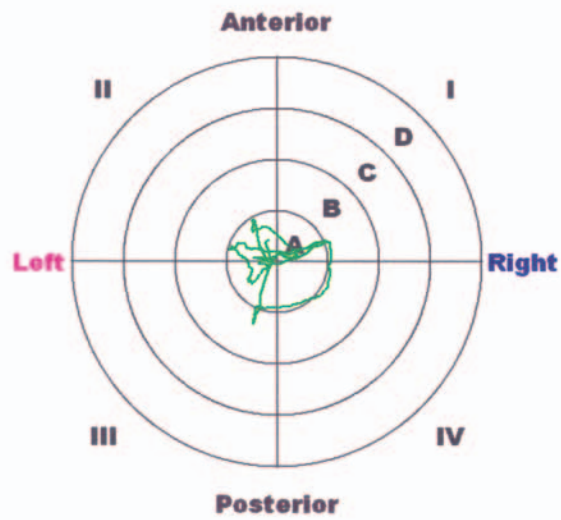
Name:
Height: 65"-73"

Date: 04/25/2006 9:56 AM

Protocol
Platform Setting 12

Time: 10

Score: 0



Comments: _____

Clinician: _____

Postural Stability Training

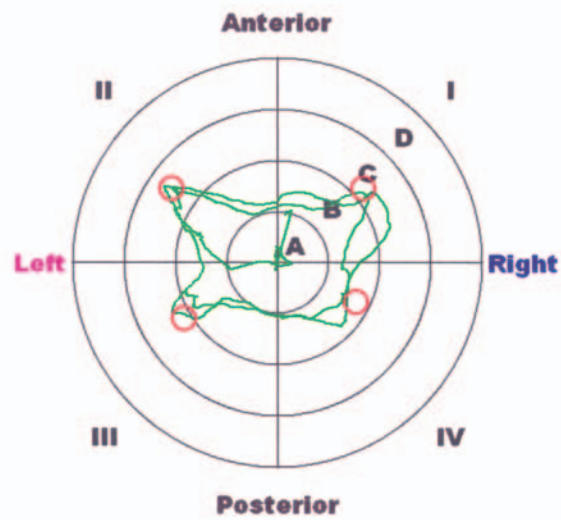
Name:
Height: 65"-73"

Date: 04/25/2006 9:55 AM

Protocol
Platform Setting 12

Time: 19

Score: 8



Comments:

Clinician:

Weight Shift Training

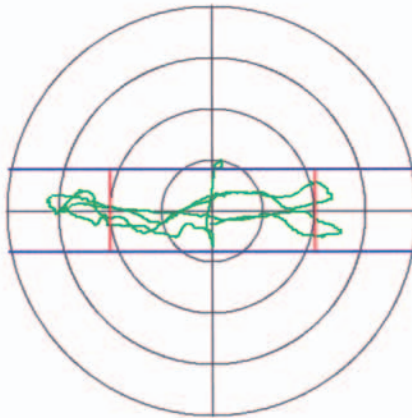
Name:
Height: 65"-73"

Date: 04/25/2006 9:58 AM

Protocol
Platform Setting **STATIC**
Skill Level **Hard**

Time: 18

Score: 75



Comments:

Clinician:

Weight Shift Training

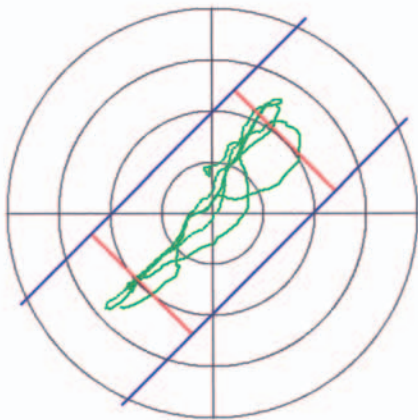
Name:
Height: 65"-73"

Date: 04/25/2006 9:59 AM

Protocol
Platform Setting **STATIC**
Skill Level Medium

Time: 17

Score: 100



Comments:

Clinician:

Weight Shift Training

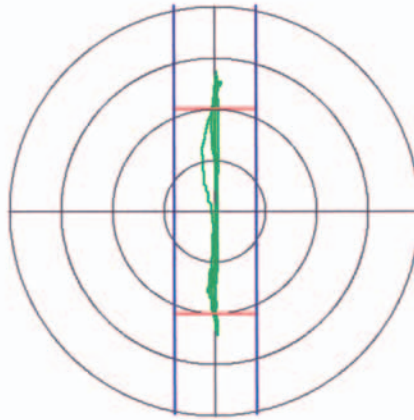
Name:
Height: 65"-73"

Date: 04/25/2006 9:59 AM

Protocol
Platform Setting STATIC
Skill Level Hard

Time: 17

Score: 100



Comments:

Clinician:

Random Control Training

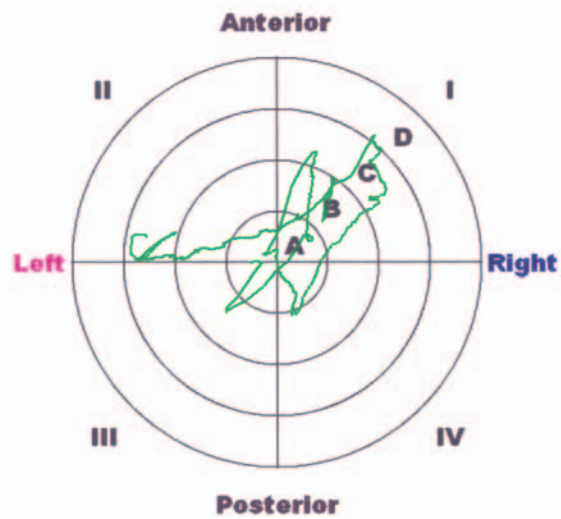
Name:
Height: 65"-73"

Date: 04/25/2006 10:01 AM

Protocol
Platform Setting **STATIC**
Skill Level **Easy**

Time: 24

Score: 100%



Comments: _____

Clinician: _____

Maze Control Training

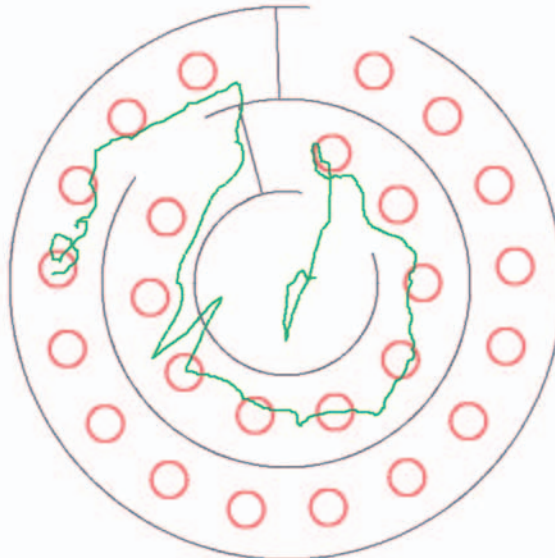
Name:
Height: 65"-73"

Date: 04/25/2006 10:00 AM

Protocol
Platform Setting **STATIC**
Skill Level **Medium**

Time: 14

Score: 84%



Comments: _____

Clinician: _____

Limits of Stability Training

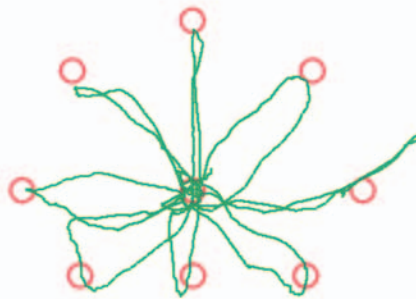
Name:
Height: 65"-73"

Date: 04/25/2006 9:57 AM

Protocol
Platform Setting 10
Skill Level Medium

Time: 28
Stance: Both

Score: 88



Comments: _____

Clinician: _____

BIODEX BALANCE SYSTEM SD reports

DYNAMIC BALANCE ASSESSMENTS

Once a Dynamic Balance Test is completed, reports can be generated in one of the following formats:

■ Biodex Balance System SD Dynamic Balance Report Parameters

	Predictive Values Bilateral	Comprehensive Bilateral	Comparative Unilateral	
Overall Values				
Stability Index	x	✓	R	L
Predictive Normative Value	x			
Mean Deflection		✓		
Standard Deviation	x	✓	R	L
Deflection Graph	x	✓	Yes	Yes
Percent Difference			Yes	Yes
Anterior/Posterior Values				
Stability Index	x	✓	R	L
Mean Deflection		✓		
Standard Deviation	x	✓	R	L
Deflection Graph	x	✓	R	L
Percent Difference				
Medial/Lateral Values				
Stability Index	x	✓	R	L
Mean Deflection		✓		
Standard Deviation	x	✓		
Deflection Graph	x	✓	R	L
Percent Difference			R	L
Percent Time In				
Zone		✓		
Quadrant		✓		

BIODEX BALANCE SYSTEM SD parameters defined

STABILITY INDEX

The Stability Index represents displacement from a level platform position. A high Stability Index is indicative of the subject having difficulty maintaining a level platform position and may represent poor neuromuscular control. This can be observed in both the Bilateral and Unilateral Stance evaluations. Further evaluation should be performed to specifically target the neuromuscular deficiency.

The Unilateral Stance evaluation presents the percent difference between the Uninvolved and Involved side, this can be used to support intervention decisions in regards to treatment progression and discharge.

The Stability Index is represented in the following formats:

▪ Overall

The Overall Stability Index takes into account the displacement from level in the following directions:

1. Anterior/Posterior (A/P)-Sagittal Plane
2. Medial/Lateral (M/L)-Frontal Plane

The Overall Stability Index can be compared to Predictive Values, which are age related normative ranges, useful for determining a subject's balance ability as compared to their peer group.

The following equation is used to calculate the Overall Stability Index:

$$(DI)^2 = \sqrt{\frac{\sum(O-X)^2 + \sum(O-Y)^2}{\text{number of samples}}} \quad (DI) = \sqrt{(DI)^2}$$

Predictive Normative Values

The Predictive Values Report allows the clinician to compare the subject's actual Overall Stability Index with age-related normative values which are expressed in a range. The Normative Values were developed at Southern Connecticut State University; the article can be found in the Source Book Section of this text. Should a patient perform outside the normative range, specific to the age, this may be indicative of poor neuromuscular control requiring further in-depth evaluation.

▪ Anterior/Posterior (A/P)

The Anterior/Posterior Stability Index represents platform displacement in a sagittal plane. A high score in this direction may indicate poor neuromuscular control of:

1. The Quadriceps and/or Hamstring muscles
2. The Anterior/Posterior compartment muscles of the lower leg

The following equation is used to calculate the Anterior/Posterior Stability Index:

$$DI_y = \sqrt{\frac{\sum(O-Y)^2}{\text{number of samples}}}$$

▪ **Medial/Lateral (M/L)**

The Medial/Lateral Stability Index represents platform displacement in the frontal plane. A high score in this direction may be indicative of:

1. Bilaterally - Poor neuromuscular control of the inversion or eversion muscles of the lower leg.
2. Unilaterally - Poor neuromuscular control of the inversion or eversion muscles of the lower leg, especially following an ankle sprain.

$$Dl_x = \sqrt{\frac{\sum (0-X)^2}{\text{number of samples}}}$$

The following equation is used to calculate the Medial/Lateral Stability Index:

DEFLECTION

This measurement is very similar to the Stability Index in that it measures displacement of the platform, however deflection measures variance of the platform from the patient's actual position. For example, during the centering procedure the clinician will center the subject so the platform is level. Once data collection starts, the patient may change the position of their center of gravity on the platform so they feel steadier. This can result in the following situations:

1. High Stability Index- platform position was not level.
Low Standard Deviation-patient is able to maintain platform position although not necessarily at zero degrees of platform tilt.
2. High Stability Index- platform position was not level.
High Standard Deviation-Patient was not able to maintain platform position

Deflection is useful for providing information in regards to the subject's body awareness. They may feel that their COG is over their BOS, however this may not actually be the case. This is typically seen in stroke and other neurologically compromised patients.

Muscle fatigue is apparent with long duration and multiple set evaluations, and can easily be observed using the deflection graphs which represent the amount of angular deflection from the starting position.

▪ **Mean Deflection**

Mean Deflection is first presented for the combination of the Anterior/Posterior and Medial/Lateral Deflection. This number takes into account the average deflection of platform position based on the subject's starting position.

▪ **Medial/Lateral Deflection**

Average position of side-to-side motion for the patient throughout the test.

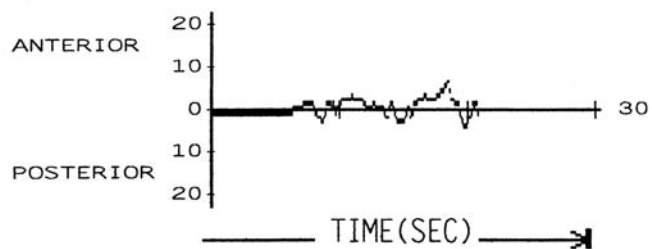
$$\text{Mean Deflection} = \frac{\sum_n |X_n, Y_n|}{n}$$

$$|X_n, Y_n| = \sqrt{X_n^2 + Y_n^2} \text{ (position vector magnitude)}$$

- Anterior/Posterior Deflection

Average position of forward and backward motion for the patient throughout the test.

$$A/P \text{ Mean Deflection} = \frac{\sum Y_n}{n} \quad \begin{array}{l} n = \# \text{ of samples} \\ Y_n = \text{nth sample} \end{array}$$



STANDARD DEVIATION (SD)

This is the amount of variability in the statistical measure between data points. A low standard deviation demonstrates that the range of values from which the mean was calculated were close together. Standard Deviation should be relatively low.

$$\text{Standard Deviation} = \frac{\sum \sqrt{(X_n - \bar{X})^2}}{n} \quad \begin{array}{l} n = \# \text{ of samples} \\ X_n = \text{nth sample} \\ \bar{X} = \text{mean deflection} \end{array}$$

ZONES AND QUADRANTS

The Target Display shown during testing for biofeedback is included on the output report and is broken down into Zones and Quadrants to assist with making a clinical diagnosis as to potential neuromuscular deficits.

- **Zones**

1. Represent the amount of degrees from level the platform has traveled.
2. Each Zone represents five degrees of travel.

Zone A = 0-5° from level
Zone B = 6-10° from level
Zone C = 11-15° from level
Zone D = 16-20° from level

- **Quadrants**

1. Represent position of the platform tilt.
2. Target divided into four quadrants as follows:

Bilateral Stance Protocol:

Quadrant 1 = Right Anterior
Quadrant 2 = Left Anterior
Quadrant 3 = Left Posterior
Quadrant 4 = Right Posterior

Unilateral Stance Protocol:

Quadrant 1 = Lateral Anterior
Quadrant 2 = Medial Anterior
Quadrant 3 = Medial Posterior
Quadrant 4 = Lateral Posterior

Zones and Quadrants are important when considering the rehabilitation of patients. Poor neuromuscular control can be easily conveyed to the patient in a graphical format using the reported information regarding how much time they spent in each Zone and/or Quadrant. A patient with weak hamstrings for example may exhibit more time in Quadrant 3 and 4, in a bilateral stance condition; while a patient with a lateral ankle sprain may spend more time in Quadrant 1 in a unilateral stance condition. The less control a patient is capable of, the further from level they are likely to go. More compromised patients will exhibit increased time in Zones farther from level.

DATA INTERPRETATION FOR THE DYNAMIC LIMITS OF STABILITY

Since the Biodex Balance System SD measures angular displacement from center, it can be used to assess a patient's LOS in two ways.

- **Method 1:**

Using the Stability Index (SI) gained from a Dynamic Balance Report it can be determined how well a patient controls their balance within their LOS in both an Anterior/Posterior (A/P) direction and a Medial/Lateral (M/L) direction. For example, an A/P SI of 6.8 would mean that a patient remains within 57% of their A/P LOS.

$$\text{A/P LOS} = 12$$

$$\text{A/P SI} = 6.8$$

therefore:

$$6.8/12 = .566 \text{ or } .57 \times 100 = 57\%$$

The same method can be used to determine the M/L LOS control. They are both important for determining a patient's potential risk for falling. Rehabilitation exercises can be properly prescribed from these results to effectively assist the patient to better control their LOS.

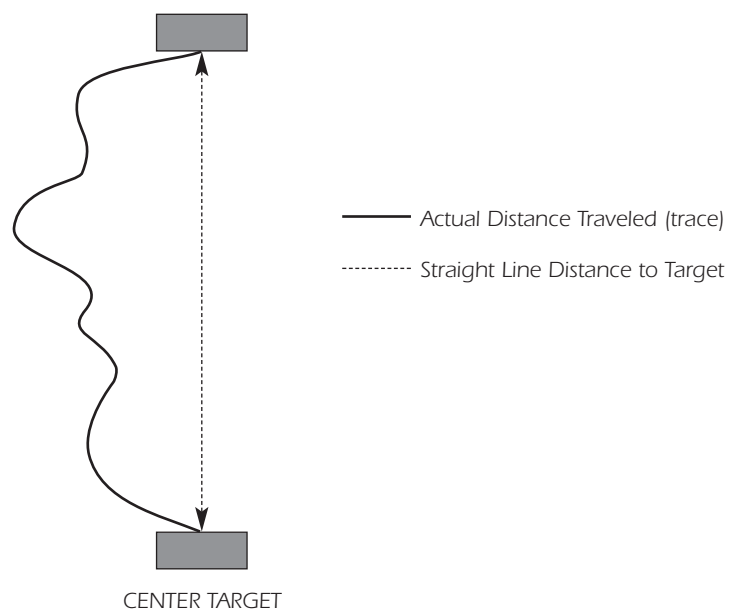
- **Method 2:**

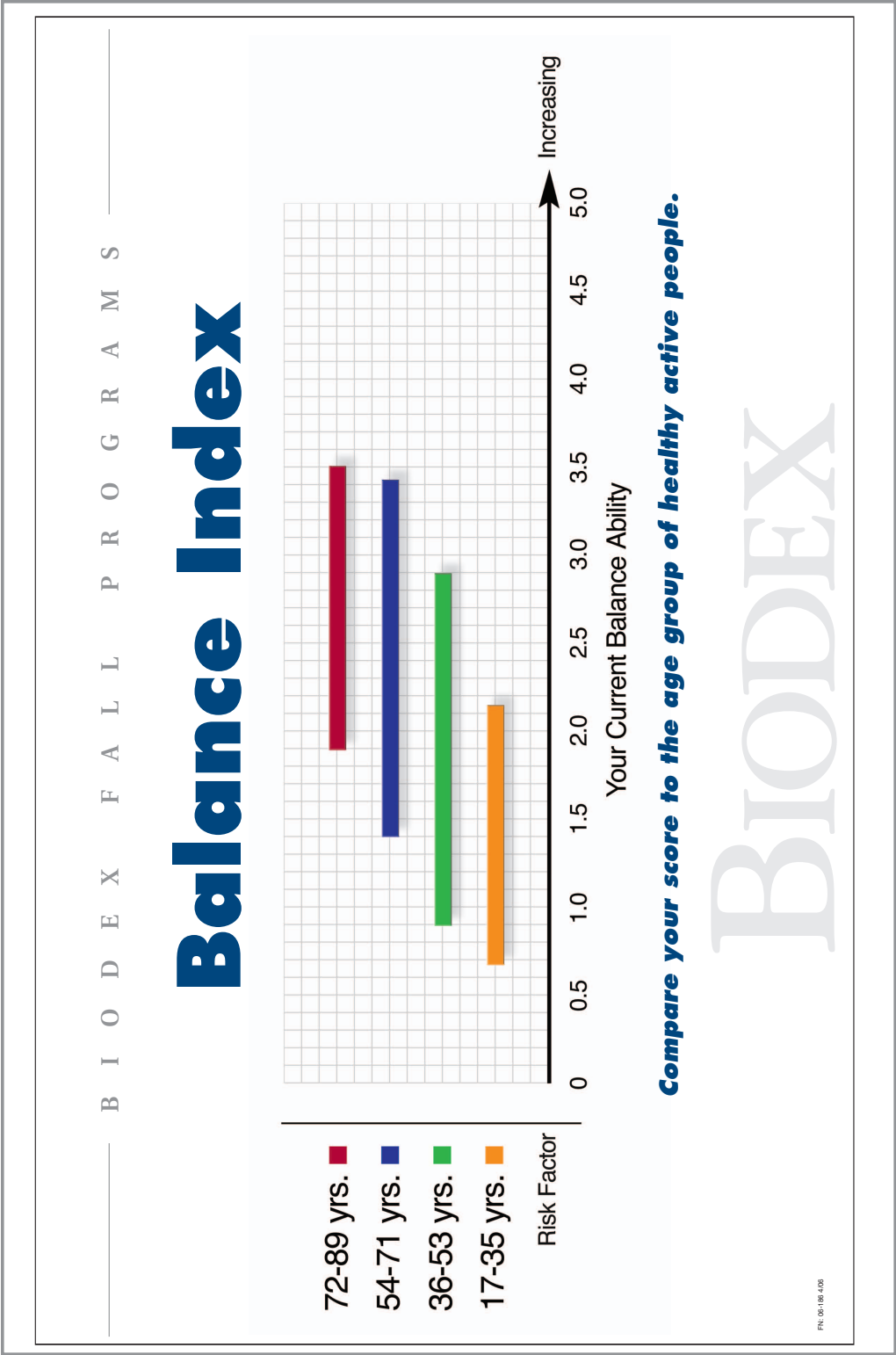
By using the Limits of Stability Test protocol it can be determined exactly in which direction a patient might have more trouble controlling their LOS. The test results are based on 100, with 100 being a perfect score. The patient's score is based on their ability to accurately move the display cursor to a target 10° from a level platform position and back to level again. The more direct the path to the target and back to center, the higher their score will be. Lower Scores may be indicative of poor neuromuscular control.

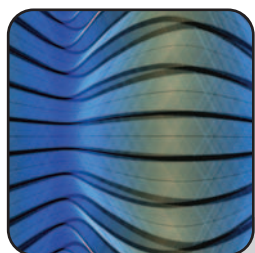
Parameters for this assessment can be found on the report for the Biodex Balance Assessment: Dynamic Limits of Stability Test. The formula found on the following page is used to calculate the score for each individual direction. The overall Dynamic Limits of Stability Test score is calculated by taking the average of the eight individual scores. From the results it can be determined how well the subject was able to control their Center of Gravity over their Base of Support. Higher numbers represent better control, with lower numbers representing a poor control. The report also gives the total time it took the patient to complete the test, which can also be compared between sessions.

HOW THE DYNAMIC LIMITS OF STABILITY SCORE IS CALCULATED

$$\text{Score \%} = \frac{\text{Straight Line Distance to Target}}{\text{number of samples}} \times 100$$







Biodex Balance System

Reference Manual

3) Supporting Articles



PRODUCT PROFILE: THE BIODEX BALANCE SYSTEM

By Thurman Ballard

INTRODUCTION

The Biodex Dynamic Postural Balance Assessment and Training Device is designed to evaluate and train postural balance and dynamic postural stability. Postural Balance is best described as the ability to maintain the body's center of gravity within the area of support provided by the feet. Postural Stability is the neuromuscular control required to stabilize the joints of the lower extremity, and to continually adjust the body's center of gravity (COG) to restore postural balance when displaced beyond the base of support.

From a physiological standpoint there are three factors contributing to maintenance of balance. The first of these is the visual component; how we react to what we see. The second factor is the vestibular component; how the inner ear senses and reacts to changes in the body position in space. The third factor is the neuromuscular component of balance known as proprioception.

PROPRIOCEPTION A KEY

In orthopedics the primary concern is with this proprioceptive component of balance as joint stability (dynamic joint integrity) is of critical importance. And this is exactly the task for which the Biodex Balance System has been designed: evaluation and training of the neuromuscular component of balance, with some influence from the visual system as the patient attempts to maintain a cursor in the target display for visual biofeedback.

This neuromuscular component of balance begins with sensory input from specialized nerve endings called *mechanoreceptors*, which are located in the joint capsules, ligaments, muscles, tendons, and skin. The mechanoreceptors pick up mechanical distortion of tissue and transmit that information through an afferent signal to the Central Nervous System. We call this process *proprioception*. The CNS interprets the messages from the mechanoreceptors, responding with an efferent signal of coded instructions to the muscles. This complex series of messages and responses is known as neuromuscular coordination.

Ligaments, attaching bones to bones, function as static stabilizers to the joints. Muscles and tendons, crossing joints as they travel from origin to insertion, function as dynamic stabilizers. People run into trouble when they have to rely on the static stabilizers in a dynamic situation. It is in this situation where ligament injuries usually occur. A primary use of the Biodex Balance System is to train the patient's neuromuscular coordination through enhancement of proprioception so that the muscles and tendons stabilize the joints, thus avoiding reliance on the static stabilizers and reducing the risk of ligamentous injury.

FULLY STIMULATE MECHANORECEPTORS

Operation of the Biodex Balance System is very straightforward. The system utilizes a dynamic platform which allows up to 20 degrees of deflection in any direction. This generous degree of deflection is essential because to stimulate the mechanoreceptors joint excursion must be allowed

to nearly the end range of motion. The patient begins each session by simply attempting to maintain postural balance on the platform. Platform stability can be altered to eight different levels, each progressively less stable than the last. The less stable the platform, the more difficult it will become to maintain postural balance. The patient is forced to exercise neuromuscular coordination by working to maintain the body in an upright position while on the unstable surface.

To gain insight into the vital role that the neuromuscular component of balance, proprioception, plays in joint stability and function, let's take a look at a familiar clinical scenario of two patients with the same injury or pathology. For arguments sake, let's say that both patients have a ruptured Anterior Cruciate Ligament. The ACL is the static or structural stabilizer for the tibia about the femur, preventing anterior translation of the tibia. Without the ACL the patient must rely on the secondary restraints and dynamic stabilizers, both of which are directly influenced by proprioception.

TALE OF TWO ACL'S

Now recalling that both patients have the same pathology and intact secondary restraints, why is it that one patient may be able to run, jump, downhill ski, play racquetball and even basketball with no episodes of instability — perhaps without even wearing a brace — while the other patient has trouble descending a flight of stairs, can not run and may even experience episodes of instability in which his knee "gives way" while walking quickly?

What is the difference between these patients? Is one patient a great athlete and the other an uncoordinated oaf? Well, there's probably more to it than that. In all likelihood, the patient who can actively participate in sports and functional daily activities without his knee giving way has developed the proprioception and neuromuscular coordination necessary to compensate for the loss of static stabilizers and decreased or altered joint afference. This enables his muscles and tendons to stabilize the joint in dynamic or functional situations. The other patient most likely lacks this neuromuscular sophistication, and perhaps also muscle strength. Consequently he must rely on the static stabilizers to stabilize the knee. A tough situation since, in this instance, the static stabilizers are already compromised.

TRAIN PROPRIOCEPTION, COORDINATION

In sum, there are three factors that contribute to chronic joint instability: ligament laxity, muscle weakness, and impaired proprioceptive mechanisms. Through the use of the Biodex Balance System patients with chronically unstable or reconstructed joints can effectively train their proprioception and neuromuscular coordination. The development of these vital mechanisms will enhance the ability of the muscles and tendons to dynamically stabilize the joints, greatly reducing stress to the ligaments, connective tissues and, ultimately, the joints themselves.

THE BIODEX BALANCE SYSTEM WORKS WONDERS WITH STROKE VICTIMS, AMPUTEES, NEUROLOGICALLY IMPAIRED AND MORE

Many clinicians think of the Biodex Balance System as a training device used mostly to address neuromuscular control and postural stability problems associated with orthopedic and sports medicine or geriatric rehabilitation. But now, as the system has gained wide acceptance in the mainstream of physical medicine, clinics around the country are discovering many more useful applications with truly gratifying results.

"I'm really excited about this device" says one clinician at a leading Northeast hospital. "And I think its usefulness will far surpass what we ever expected. It certainly has a wide application outside of the sports medicine area that many people associate it with. So far, we've used the system to work with everyone from stroke victims and amputees to pulmonary disease, acute-care geriatric patients and patients with transverse myelosis. I couldn't be more pleased with the results."

According to this source, the Biodex Balance System has played its most surprising role in working with stroke victims. In fact, the progress with some patients has been "absolutely striking."

"I have one stroke victim here for which the Biodex Balance System proved to be *the only* means that could get her to weight shift. This patient suffered a stroke on her left side. She has some cognitive difficulties due to the stroke but she can walk on her own to a degree. She is a business woman who is very goal orientated, very analytical, and this technology has really worked for her."

Using the Balance System platform grid and biofeedback training screens is helping this patient overcome perceptual problems in addition to regaining the ability to weight shift and balance. The patient begins each session by positioning her feet on the platform using the grid coordinates as landmarks to ensure her foot placement is consistent from session to session. This simple positioning chore, notes her clinician, can be a very difficult task for stroke victims in the early stages of rehab as the simple concept of moving left and right, forward and back, can be very tough to conquer. The grid on the platform allows the patient to assume basic responsibility for foot positioning and to work on coordination.

Like many stroke victims, this patient has the sensation that one leg is lighter than the other and she tends to lean toward the lighter side. Prior to her sessions on the Balance System, the only way attending clinicians could get her to weight shift properly was through manual hand cues. On the Balance System, however, the clinicians were able to begin with the hand cues and show the patient how her weight shifting was mirrored by the cursor on the training screen. This provided the patient with a visual cue as to what was happening and as soon as she realized this her progress took off rapidly.

"In the first session, we still had to provide manual clues to the patient to get her to move the cursor around the training screen

as she tried to make the connection that the cursor reflected her weight shifts," states the lead clinician involved in this case. Once she realized that she *was* the cursor, she immediately began to make great strides. By her second session, she was initiating movement on her own."

"I've got to tell you, we tried many different modalities with this patient but this was the only thing that worked. The opportunity to visualize her weight shifting on the training screen was exactly what she needed. She still has some challenges to overcome, but we now see marked improvement every time she comes in for therapy. In her first session, she was fatigued after two minutes. Now she can move the cursor where we ask and even keep it inside a selected concentric circle on the screen. - and she can do this for over five minutes. She still has very real cognitive problems that you might not notice in conversation - she still has to think about movement direction, for example - but now, at least, we have a way to work with her."

The Biodex Balance System is rapidly gaining favor in the field of physical medicine and, with astute clinicians always on the lookout for new and better approaches to treat their patients, there can be no doubt that the number of applications for this device will continue to increase rapidly. In addition to its already well-established use in orthopedic, sport medicine and geriatric rehabilitation, where the system is generally used for balance training, cutting edge clinicians and researchers are currently probing its value as a tool for head trauma injury, as well as fall risk assessment and intervention. Additional avenues may include work to establish norms for low-back patients and baselines for amputee balance.

"As you can tell, I really believe the Biodex Balance System can help many of my patients," states the lead clinician who was involved with the stroke victim described above. "Later this week I'll be using it with some of our amputees. Many of these patients have difficulty learning to put pressure on their new prosthesis. They'll walk on it but, when standing still, they tend to strongly lean on their good leg and that equates to a loss of stability. I have one patient here with whom we're having great difficulty getting the message across but I'm sure - I know - this system will help him. I'm going to put him on the platform and let him see on the screen how his center of gravity is affected when he favors his good side. It should be a real eye-opener."

"It's great to see how this system is really helping people," summarizes Ed Behan. "The possibilities as to what it can do in the fields of intervention and rehabilitation are very exciting."

EVALUATION OF ANKLE INSTABILITY USING THE BIODEX BALANCE SYSTEM

Chris Testerman, M.D., and Robert Vander Griend, M.D.
Knoxville, Tennessee, and Gainesville, Florida

ABSTRACT

Ten patients with chronic unilateral functional lateral instability of the ankle were evaluated using the Biodex Balance System. This system uses a multi-axial testing platform which can be set at variable degrees of instability. Patients are then tested for their ability to "balance" the platform during single-limb stance, and a balance index is electronically generated. This balance index is believed to be an objective measurement that correlates with proprioceptive status of the ankle.

Instability of the ankle was confirmed in all 10 patients, using stress radiographs. Two levels of platform balance were tested. With the platform in its most stable configuration, there was minimal difference between the previously injured and the uninjured ankle. With the platform set to permit up to 20° of tilt in any plane, 6 of 10 patients had more difficulty balancing the platform with their injured ankle (higher balance index). This preliminary study suggests that the Biodex Balance System may be a useful tool in trying to objectively measure proprioceptive function.

INTRODUCTION

Chronic lateral ankle symptoms occur in up to 30% of patients after an inversion ankle sprain. These symptoms may include swelling, pain, instability, and repeat ankle injury. The cause of these chronic problems is often attributed to instability, muscle weakness, and proprioceptive deficits.

Ankle instability is often characterized as being mechanical or functional. Mechanical instability results from laxity of the ligamentous and pericapsular soft tissues. The resultant increased mobility of the ankle is greater than the physiologic range and can be demonstrated by an abnormal anterior drawer or talar tilt at clinical or radiographic examination, or both (1). Functional instability is a sensation that the ankle will "give way," or feels unstable to the patient. This can occur either with or without actual mechanical instability (3).

Peroneal muscle weakness is believed to contribute to chronic instability. This was suggested in studies done using manual muscle testing. However, recent work using more objective measuring techniques suggests that muscle weakness, although present, is not a primary factor in either the cause of instability or the outcome of rehabilitation (10, 11).

Freeman (3,4) and others (2,9,16) have attributed functional instability to a proprioceptive deficit. Proprioception is a specialized sensory modality that includes both the sensation of joint movement and joint position. Mechanoreceptors in the skin, muscle, tendons, and joint provide input to the central nervous system. Vestibular and visual input is also involved in this complex pathway of proprioception and neuromuscular response.

Damage to mechanoreceptors in the pericapsular tissue is believed to result in proprioceptive deficits. Garn and Newton (5) demonstrated that a patient's ability to detect joint movement was less in an ankle which had been previously sprained than in an uninjured ankle. Similarly, differences in the ability to actively identify and reproduce a passive foot position and in peroneal reaction time have been found between a previously sprained and the uninjured ankle (6,8,12).

A number of studies have tried to identify methods of measuring proprioception in a clinically useful way. Although proprioceptive "retraining" has been shown to be an important part of ankle rehabilitation programs, there is currently no objective method to measure either deficits in proprioception that occur after injury or recovery of deficits after rehabilitation. Most reported studies have centered on assessing the effects of injury on balance or postural sway in an attempt to quantify both the static and dynamic components of proprioception (1,7,13). Subjective evaluation, such as a Romberg test or the ability to maintain a single limb stance, has been used to demonstrate these proprioceptive changes in the ankle. These evaluations are based on the concept that injury to the mechanoreceptors of the lateral ankle decreases the afferent feedback and, consequently, the neuromuscular response, resulting in changes in postural or balance control.

The Biodex Balance System (Biodex Medical Systems, Shirley, NY) was designed to evaluate problems relating to balance, proprioception, and neuromuscular control. The purpose of this study was to use the Biodex Balance System to evaluate patients with chronic unilateral instability of the ankle.

BIODEX BALANCE SYSTEM

This testing machine consists of a multiaxial standing platform which can be adjusted to provide varying degrees of platform tilt or platform instability (Fig. 1). A maximum of 20° of platform surface tilt can be selected. With this degree of surface tilt, a dynamic situation is created, similar to actual functional activities that result in instability. The ability of the patient to maintain dynamic postural balance on this unstable tilting platform is assessed. The patient stands on the platform and is instructed to try to balance or hold the platform in level position. A chosen level of platform instability is tested for a selected period of time. The patient's ability to control the angle of tilt of the platform is quantified as a variance from the neutral position (zero-zero) center over time. Three indices are electronically generated: (1) anterior/posterior index (fore and aft movement in the sagittal plane), (2) medial/lateral index (side-to-side movement in the frontal plane), and (3) balance index (dispersive index of balance performance). The balance index is believed to be the best indicator of the overall ability of the patient to balance the platform. The output from this machine is such that the larger the numerical value of the balance index, the greater the degree of difficulty or "instability" in balancing the platform. In theory, this "instability" should correlate with proprioception and neuromuscular response.

This dynamic tilting platform system differs from a static force plate system in that the center of pressure resulting from the vertical ground reaction force remains constant (14). In a static platform system as the foot is supinated, the center of gravity moves laterally, and the vertical ground reaction force and center of pressure must follow. Patients must move their center of gravity (sway) to maintain balance, and this shift is what is measured in the static platform systems. In a dynamic tilting platform, only a small amount of surface tilt is needed to stress the joint mechanoreceptors without changing the center of pressure or the vertical ground reaction force. As the table tilts, the patient should be able to realign the joint and "resolve" the resulting forces of gravity with only a few degrees of joint motion.



Fig 1. The Biodex Balance System

MATERIALS AND METHODS

Ten otherwise healthy, athletic patients with unilateral chronic ankle instability were tested on the Biodex Balance System. There were nine men and one woman. All were <30 years of age. The initial injury in all patients was an inversion injury with no associated fracture. The initial treatment varied from no treatment to cast immobilization. The rehabilitation after the initial injury also varied from no rehabilitation to combinations of muscle strengthening, range of motion exercises, and proprioceptive training. Eight of the ten patients had one or more episodes of repeated instability after the initial injury (Table 1).

Stress radiographs of both ankles were obtained in all of the patients. The Telos radiographic stress system (Telos Device; Austin and Associates, Falston, MD) was used, and stress radiographs were performed without anesthesia because all of the patients could tolerate stress exams of the ankle. All of the patients included in this study had at least 3° of increased talar tilt and at least 3mm of increased anterior translation (stress anterior drawer) compared with the uninvolved side.

Table 1.

Patient	Side/sex	Date/injury	# Episodes of instability	Last episode instability	Rehab	Stability index: level 8 (INJ/NL)	Stability index: level 2 (INJ/NL)
1CB	R/M	6/94 BB	1	2 yrs	1st None 2nd TB	1.6/1.6	5.7/6.5
2 BG	L/M	5/95 Run	3	1 mos	None	1.6/1.6	6.7/6.5
3 CK	L/M	1992	Many	1 mos	PSE	3.7/2.3	10.9/10.5
4 MM	L/M	9/95 Soccer	0	0	ROM	2.3/3.4	7.0/6.3
5 KH	R/M	3/95 BB	0	0	ROM	1.3/1.6	4.5/4.6
6 JF	R/M	1986 FB	Many	1 yr	None	2.0/2.3	10.1/8.6
7 AF	R/F	1982 Gymnst	5	3 mos	ROM PSE	1.5/1.4	2.3/2.6
8 JH	L/M	1989 Soccer	3	3 yrs	TB	1.5/1.3	6.9/4.6
9 KJ	R/M	1990 Soccer	3	1 yr	None	1.5/1.4	8.1/6.9
10 PW	R/M	1986	Many	1 yr	ROM PSE	1.4/1.7	3.8/5.3

BB, basketball; FB, football; TB, theraband; ROM, range of motion; PSE, peroneal muscle strengthening exercise; INJ/NL, injured ankle/normal; level 8, most stable; level 2 almost 20° tilt.

Our testing protocol was based on previous studies using the Biodex Balance System (15). To demonstrate use of the machine, each patient first stood on one leg for 20 sec with the platform in its most stable position. This was repeated with the contralateral leg. The foot position on the platform was recorded and remained constant throughout each test. Once the patient had acclimated to the platform, three tests were done at each of the two levels of instability. The most stable test (level 8) permitted minimal movement of the platform, the unstable level chosen (level 2) permitted almost 20° of tilt in all directions. A 1-min test period was given between trials. The initial leg tested was randomized, and the uninvolved leg served as a control. During the test, the contralateral leg was held in a flexed position off of the platform and arms were placed across the chest. No patient had difficulty with balance or maintaining a single limb stance posture on the platform.

Muscle strength testing was performed after the balance tests were complete. The Cybex II Isokinetic Dynamometer (Cybex Int., Medway, MA) was used to measure eversion and inversion strength at speeds of 30°/sec, 90°/sec, and 120°/sec.

RESULTS

The results were based on an average of the three tests recorded at each balance level (Fig. 2). At the higher level of platform balance (level 8), the balance index was greater (indicating more difficulty in controlling the platform) on the injured side in only four patients. None of these differences were statistically significant using the paired t-test.

EVALUATION OF ANKLE INSTABILITY BIODEX BALANCE RESULTS

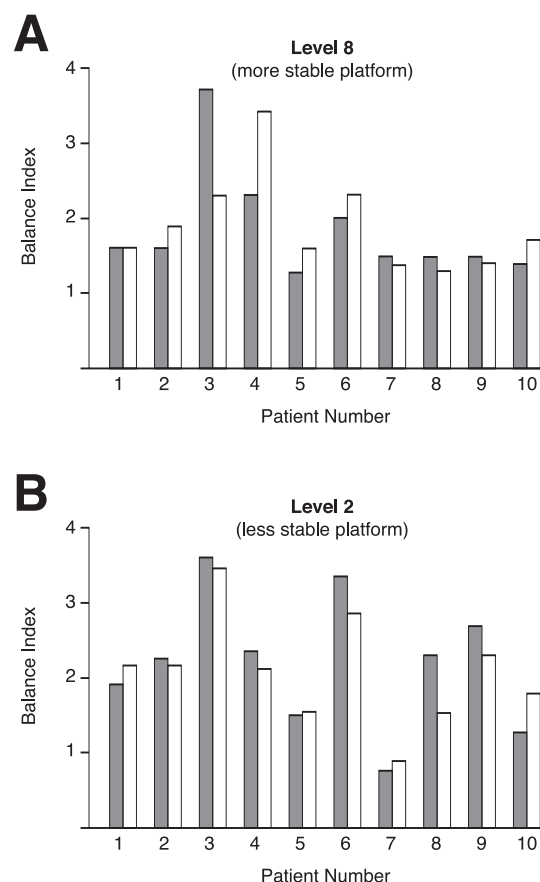


Fig 2. Results of balance testing. The injured and uninjured side are compared on both the more stable (A) and less stable (B) platforms

With the platform in a more unstable position of (level 2), six of the patients had a balance index which was greater on the injured side than the normal side. Five of these six patients had at least three or more episodes of instability since their initial injury. Three of these six patients had no rehabilitation after any episode of injury, one had a home program consisting of theraband exercises and two received a range of motion or strengthening program. In the five patients with three or more episodes of instability, the differences in the balance index between the injured and normal ankle were statistically significant. However, when the cumulative differences in the balance index between the injured and normal sides at level 2 were compared for all 10 patients, these differences were not statistically significant using the paired t-test.

An interesting finding was that the lowest balance index in this study (i.e., the best ability to control the platform) at both levels of balance tested was in the only woman tested (patient 7). She was a physical therapist and had continued with an ongoing rehabilitation program. She continued to be active in gymnastics and ballet dancing, despite intermittent symptoms of functional instability.

The results of Cybex II testing showed only three patients with <80% eversion strength of the injured compared with the normal extremity. Only one of these three (patient 8) had a significantly higher balance index of the injured ankle.

DISCUSSION

Although both the extent of loss and the degree of recovery of proprioception is an important factor in determining outcome after ligamentous injuries of the ankle, an objective method of measuring ankle and foot proprioception has remained elusive.

The Biodex Balance System uses a multiaxial tilting platform in an attempt to quantitate joint proprioception. This was a pilot study to determine whether this system could be used to objectively quantify a proprioceptive deficiency in patients with chronic ankle instability. Differences between the injured and normal ankles were seen in 60% of patients when tested at an increased level of platform instability. Patients with a history of multiple episodes of instability also had differences between the injured and normal ankles. As in previous studies, our patients did not have significant weakness between the injured and uninjured ankles, as measured by Cybex testing.

The significance of these finds needs further study. The number of patients tested was small, and a number of variables could not be controlled. For example, there were differences in the rehabilitation that these patients received and in their perceived degree of balance. This, however, is not different from most clinical studies that have shown that there is variability in long-term functional outcomes among patients having similar injuries and similar degrees of measured radiographic instability. Additional questions raised by our preliminary study including the following:

1. What is actually being measured: proprioception, neuromuscular response, or both?
2. Is the balance index a measurement of anything clinically relevant?
3. Are side-to-side differences or absolute measurements more indicative of normal proprioception?
4. How well does the balance index correlate with clinical instability?
5. Will a rehabilitation program improve the balance index?
6. Will surgical stabilization improve the balance index?

Although this study has generated as many questions as answers, we believe this system shows promise in the evaluation of proprioception abnormalities of the ankle.

REFERENCES

1. **Cornwall MW and Murrell P:** Postural sway following inversion sprain of the ankle. *J. Am. Podiatr. Med Assoc.*, 81:243-247, 1991.
2. **DeCarlo MS, and Talbot RW:** Evaluation of ankle joint proprioception following injection of the anterior talofibular ligament. *J. Orthop. Sports Phys. Ther.*, 8:70-76, 1986.
3. **Freeman MAR and Wyke B:** Articular reflexes at the ankle joint: an electromyographic study of normal and abnormal influences of ankle joint mechanoreceptors upon reflex activity in the leg muscles. *Br. J. Surg.*, 54:990-1001, 1967.
4. **Freeman MAR, Dean MRE, and Hanham IWF:** The etiology and prevention of functional instability of the foot. *J. Bone Joint Surg.*, 47B:676-685, 1985.
5. **Garn SN and Newton RA:** Kinesthetic awareness in subjects with multiple ankle sprains. *Phys. Ther.*, 68:1667-1671, 1988.

6. **Glencross D and Thorton E:** Position sense following joint Injury. J. Sports Med. Phys. Fitness, 21:23-27, 1982.
7. **Gross MT:** Effects of recurrent lateral ankle sprains on active and passive judgments of joint position. Phys. Ther., 67:1505-1509, 1987.
8. **Konradson L and Ravn JB:** Ankle instability caused by prolonged peroneal reaction time. Acta. Orthop. Scand., 61:388-390, 1990.
9. **Konradsen L, Ravn JB, and Sorensen AI:** Proprioception of the ankle: the effect of anaesthetic blockade of ligament receptors. J. Bone Joint Surg., 75B:433-436, 1993.
10. **Lentell GI, Baas B, Lopez D, McGuire L, Sarrels M and Snyder P:** The contributions of proprioceptive defects, muscle function, and anatomic laxity to functional instability of the ankle. J. Orthop. Sports Phys. Ther., 21:206-214, 1995.
11. **Lentell GI, Katzman BS, and Walters MR:** The relationship between muscle function and ankle balance. J. Orthop. Sports Phys. Ther., 11:605-611, 1990.
12. **Lovenberg R, Karrholm J, Sundelin G, and Ahlgren O:** Prolonged reaction time in patients with chronic lateral instability of the ankle. Am. J. Sports Med., 23:414-417, 1995.
13. **Tropp H and Odenrick P:** Postural control in single-limb stance. J. Orthop. Res. 6:833-839, 1988.
14. **Wilkerson GB and Behan E:** The Advanges of a Dynamic Balance System Compared to a Static Force Plate System for Orthopedic and Musculoskeletal Rehabilitation, Shirley, New York, Biodex Medical Systems, 1994.
15. **Wilkerson GB and Behan E:** Biodex Integrated Physical Rehabilitation, Shirley, New York, Biodex Medical Systems, 1994.
16. **Wilkerson GB and Nitz AJ:** Dynamic ankle balance: mechanical and neuromuscular interrelationships. J. Sports Rehab, 3:43-57, 1994.

STABILITY PERFORMANCE ASSESSMENT AMONG SUBJECTS OF DISPARATE BALANCE ABILITIES.¹

J.A. Finn, M.M. Alvarez, R.E. Jett, R.S. Axtell, D.S. Kemler, Exercise Scientist Department, Southern Connecticut State University, New Haven, CT.

Previous studies have repeatedly demonstrated that poor balance is a risk factor for falls among elderly subjects. The purpose of this study was to determine the effectiveness of the Biodex Stability System (BSS) in identifying subjects with disparate dynamic balance abilities. Two hundred men and women, ranging in age from 18 to 89 years, were study participants. After a brief ergometer cycle warm-up, subjects completed a practice period becoming familiar and comfortable on the moveable platform of the BSS. Subjects completed five, 20 second trials attempting to maintain their balance at stability level eight, the most stable level. Average balance index was calculated after the best and worst scores were discarded. Subjects 50 years of age and older completed the Guralnik Functional test which included a: 1) 50 foot timed walk, 2) ten second, single leg stand performed once on the right and left foot, 3) timed pencil pick-up, 4) ten second tandem stand (eyes open/eyes closed), 5) ten step tandem walk, and 6) timed chair stand test. Stepwise discriminant function and MAVOVA analysis identified differences between genders, among age groups, and among stability groups. Males (N=106) were less stable than females (N=94) with means and standard deviations of 2.70 ± 0.08 and 1.94 ± 0.80 , respectively. Young subjects were most stable than older subjects with each age group being different, as shown in Table 1. Four dis-

parate balance groups were identified, as shown in Table 2.

Table 1: Stability Index Differences among Age groups

Group 1 (N=31)	Group 2 (N=44)	Group 3 (N=78)	Group 4 (N=47)
17-35 yrs.	36-53 yrs.	54-71 yrs.	72-89 yrs.
X=1.54	X=2.13	X=2.57	X=2.70
s.d.=0.72	s.d.=0.90	s.d.=0.78	s.d.=0.80

Table 2: Stability Index Differences among Balance groups

Group A (N=36)	Group B (N=79)	Group C (N=63)	Group D (N=21)
Best			Worst
X=1.08	X=1.95	X=3.17	X=4.42
s.d.=0.19	s.d.=0.36	s.d.=0.34	s.d.=0.35

A stepwise discriminant function analysis was used to determine Guralnik scores most important in predicting subjects' stability score. Single leg stand left (SSL), single leg stand right (SSR) and Walk 3 (speed pace) were identified as statistically significant and most important predictors of balance. These three variables identified 0.40 of the variance. These findings indicate that BBS was effective in distinguishing between and among subjects regarding gender, age groups and balance ability.

CORRELATIONS BETWEEN DYNAMIC BALANCE PERFORMANCE AND ISOKINETIC FUNCTIONS OF KNEE FLEXOR/EXTENSOR MUSCLES IN THE ELDERLY²

P. G. Siudmak, J.F. Signorile, M.H. Campbell, and A. Perry, University of Miami, Human Performance Lab, Coral Gables, FL

Corporeal balance is a multifaceted activity with visual, vestibular and musculoskeletal systems interacting synchronously. The importance of muscular performance was evaluated by correlating anthropometric and isokinetic knee functions with dynamic balance in a group of active elderly. Thirty-eight participants (22 females, 16 males, ages 62-77) were tested on the Biodex stability system at two stability levels assessing overall stability and deflections in the anterior/posterior and medial/lateral planes. A stable center of gravity/base condition with feet together and arms at the sides was established. Two practice and four test trials were given at each stability level (8=most stable, 2=least stable). Visual feedback was provided on a LCD screen. Concentric isokinetic work (TW), power (AP), and torque (PT) (90°/s, 180°/s, 300°/s) for the

flexors/extensors were measured during 5 repetitions. Strong negative correlations were observed between body weight (BW), and stability levels 2 and 8 ($R=-.74$, $P<.0001$ and $R=-.72$, $P<.0001$, respectively). When BW was partialled out, PT, AP, TW, PTBW, and TWBW were significant ($P<.05$) for all three stability planes at level 8, yet, not at level 2. A by gender analysis with BW included confirmed the importance of BW since the highest correlations were with isokinetic variables corrected for BW (PTBW, TWBW). These data indicate that as an individual's mass increases it is more difficult to recover balance. In addition, training designed to reduce the incidence of falls should concentrate on improving knee flexor/extensor strengths per unit body weight as opposed to absolute strength.

LEARNING EFFECTS AND RELIABILITY OF THE BIODEx STABILITY SYSTEM

Scott M. Lephart, PhD, ATC
Danny Pincivero, MEd
Timothy Henry, MS, ATC

Sports Medicine and Neuromuscular Laboratory
University of Pittsburgh
Pittsburgh, Pennsylvania

INTRODUCTION

Ligaments play a major role in normal joint kinematics, providing mechanical restraint to abnormal joint movement when a stress is placed on the joint. Following injury to these tissues, there is an inherent loss of mechanical stability to the joint resulting in aberrations to normal kinematics. Management of these sports related injuries focuses on restoring joint kinematics either through surgical reconstruction, or by enhancing muscular reflex compensatory stabilization through rehabilitation. By restoring joint stability either mechanically or substituting with secondary stabilizers, it is speculated that sport activities can be resumed, recurrent injury will be minimized, and progressive joint degeneration can be avoided.

Kennedy (4) observed that in addition to their mechanical restraining function, articular ligaments provide important neurological feedback that directly regulates muscular reflex stabilization about the joint. The neuromuscular controlling mechanism is mediated by articular mechanoreceptors and provides the individual with the proprioceptive sensations of kinesthesia and joint position sense. The neurological feedback for the control of muscular actions serves to protect against excessive strain on passive joint restraints and provides a prophylactic mechanism to recurrent injury. Following joint injury, disruption to these articular mechanoreceptors inhibits normal neuromuscular reflex joint stabilization and contributes to repetitive injuries and the progress decline of the joint.

Therefore, ligament injury not only results in the loss of the mechanical stability of the joint, but also diminishes the capacity for secondary stabilizers (muscles to provide joint stability through reflex contraction). This proprioception mechanism has recently received considerable attention relative to the treatment of sports injuries.

PRINCIPLES PROPRIOCEPTION REHABILITATION AND ASSESSMENT

Developing a sports rehabilitation program that incorporates proprioceptively mediated muscular control of joints necessitates an appreciation for the central nervous system's (CNS) influence on motor activities. Joint afferents contribute to CNS function at three distinct levels of motor con-

trol (8). At the spinal level, reflexed subserve movement patterns that are received from higher levels of the nervous system. This provides for reflex splinting during conditions of abnormal stress about the joint and has significant implications for rehabilitation (5). The muscle spindles play a major role in the control of muscular movement by adjusting activity in the lower motor neurons. Partial differentiation of joint afferent receptors has also been shown to alter the musculature's ability to provide co-contraction joint stabilization by antagonistic and synergistic muscles, thus resulting in the potential for reinjury (4).

The second level of motor control is at the brain stem, where joint afference is relayed to maintain posture and balance of the body. The input to the brain stem about this information emanates from the joint proprioceptors, the vestibular centers in the ears, and from the eyes (8).

The final aspect of motor control includes the highest level of CNS function (motor cortex, basal ganglia, and cerebellum) and is mediated by cognitive awareness of body position and movement. Movements that are repeated can be stored as central commands, and can be performed without continuous reference to consciousness (8).

With these three levels of motor control established, mediated in part by joint and muscle afferents, one can begin to develop rehabilitation activities to address proprioceptive deficiencies. The objectives must be to stimulate the joint and muscle receptors in order to encourage maximum afferent discharge to the respective CNS level. At the spinal level, activities that encourage reflex joint stabilization should be addressed. Balance and postural activities, both with and without visual input, will enhance motor function at the level of the brain stem. Consciously performed programming activities, especially at joint end ranges, will maximally stimulate the conversion of conscious to unconscious motor programming. The BIODEx STABILITY SYSTEM provides a mode to both rehabilitate and assess these levels of motor control that are mediated by lower extremity.

BALANCE TRAINING AND TESTING

Balance is mediated by the same afferent mechanism that mediate joint proprioception, and is suggested to be totally dependent upon the inherent ability to integrate joint posi-

tion sense, kinesthesia, and neuromuscular control (7). Balance training using an unstable balance platform simultaneously integrates all of the aforementioned sensorimeter components responsible for modulating muscle function at the lower extremity. Preliminary evaluation on healthy knees has demonstrated significant improvements in balance proficiency after completing a balance training program using an unstable platform (1). Results also indicated a significant variation in balance indices between sport-specific individuals (1,7). Balance proficiency has been demonstrated to diminish in partially differentiated joints (3,7) and these deficits produce aberrations in the afferent feedback loop of the lower extremity, thus causing diminished neuromuscular function. Related studies have identified deficits in balance proficiency using similar assessment techniques for individuals diagnosed with ankle instability (3). The lower extremity functions in a closed kinetic chain necessitating neurosensory inputs from the ankle, knee and hip. In conditions such as ACL-deficiency and ankle instability, aberrations in sensory input will cause altered neuromuscular control. From these findings, it may be postulated that some aspect of the joint afferent pathway is altered as a result of trauma, surgery, or training, and can be identified by assessing balance proficiency.

The BIODEX STABILITY SYSTEM provides the clinician with the flexibility to train and test at each level of motor control both in a single leg or bilateral stance. The System provides up to 20 degrees of surface tilt which stimulates joint receptors and promotes reflex muscular contraction necessary for joint stability. The System also permits testing with and without visual cues and enhances motor programming. The System allows for progressive adaptations to occur as the platform stability varies to accommodate for the desired stimuli, necessary for each patient.

The purpose of these studies were to: (1) establish the trial exposures required to negate any effects of procedural learning or familiarization, and (2) establish the reliability of testing over multiple trials, subsequent to negating the effects of learning.

METHODS

Learning Effects Study: Subjects in this phase of the study included 10 healthy college age students. Stability indices were obtained under 2 conditions: bi-lateral stance and dominant single leg stance at two stability levels; level 2 and level 8. Subjects were tested without footwear and were positioned on the BIODEX STABILITY SYSTEM platform in a comfortable position. Foot position coordinates were recorded for consistency between trial tests. The subject's arms were folded across their chest and knees were flexed to approximately 10-15 degrees. All tests were performed with the subject's eyes open. Subjects were instructed to maintain a level platform for a duration of 20 seconds for each test. Six trials were performed under each condition and at both stability levels. The order of the tests were randomized.

Reliability Study: Subjects in this phase of the study included 20 healthy college age students, none of which participated in the Learning Effect Study. Stability indices were

obtained under 3 conditions: bi-lateral stance, dominant single leg stance, and non-dominant single leg stance at two stability levels; level 2 and level 8. Testing was performed in a similar fashion as described for the Learning Effect Study. Prior to three test trials one familiarization trial was performed at each condition and stability level. Two familiarization trials were performed for bilateral stance level 2. The familiarization trials were selected based on results from Phase 1 of the study to negate any learning effects.

Statistical Analysis: A one-way analysis of variance with repeated measures was employed to establish statistical mean differences between the six trials under each test condition for the Learning Effects Study. A one-way analysis of variance with repeated measures was also employed to establish statistical mean differences between the three test trials for the Reliability Study. Intra-class correlation coefficients were then calculated to determine reliability between the three tests trials under each condition at both stability levels.

RESULTS

Learning Study: The one-way analysis of variance revealed significant mean effects of learning under the Bilateral Stance Level 2 condition and the Bilateral Stance Level 8 condition. During the Bilateral Stance Level 2 condition the subjects' scores were significantly ($p < 0.05$) higher during trial 1 (mean=4.8) and trial 2 (mean=2.71) and the test of the trials 3-6 (Figure 1). Mean scores on trials 3-6 were not significantly different (means=1.87, 1.57, 1.73, 1.73). During the Bilateral Stance Level 8 condition only the first trial (mean=2.18) was significantly higher than the other 5 trials (means=1.3, 1.2, 1.03, 1.02, 1.01) (Figure 2). There were no significant mean differences between any of the 6 trials under the Dominant Limb Level 2 (Figure 3) or Dominant Limb Level 8 conditions (Figure 4).

Reliability Study: There were no significant mean differences revealed between any of the test trials under the 6 conditions during the reliability study. Intra-class correlations (ICC 1,1) ranged from 0.60 to 0.95.

The values for each of the conditions are listed below:

Dominant Limb Stability Level 8
ICC=0.95
Non-dominant Limb Stability Level 8
ICC=0.78
Dominant Limb Stability Level 2
ICC=0.60
Non-dominant Limb Stability Level 2
ICC=0.60
Bilateral Stance Stability Level 2
ICC=0.85
Bilateral Stance Stability Level 8
ICC=0.71

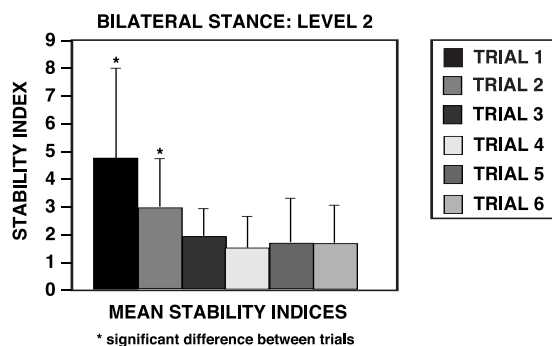


Figure 1.

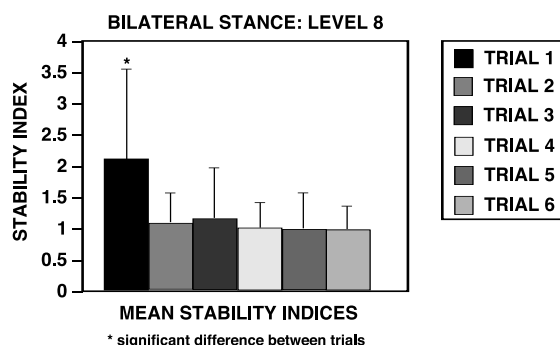


Figure 2.

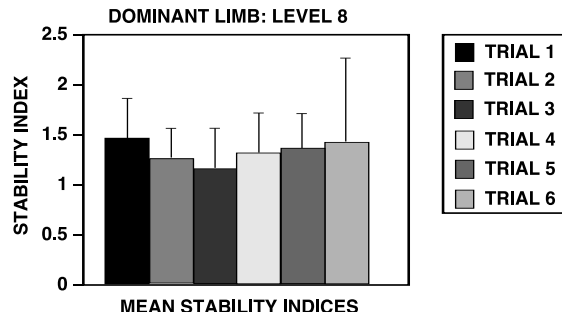


Figure 3.

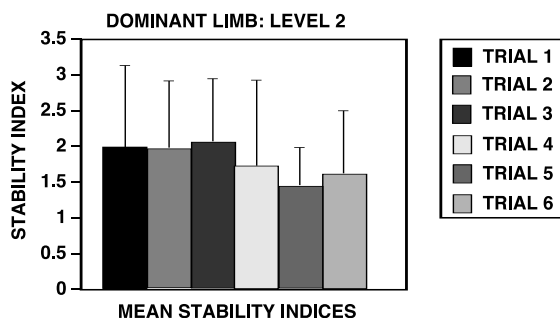


Figure 4.

DISCUSSION AND RECOMMENDATIONS

The BIODEX STABILITY SYSTEM appears to be a highly reliable assessment device across multiple test trials in healthy individuals. There appears to be a learning effect which was observed following two exposures to the device when testing Bilateral Stance at Stability Level 2 and one exposure learning effect when testing Bilateral Stance Level 8. Single leg testing did not reveal any significant learning effect from 6 exposures. Based on these results it is recommended that all subjects perform two trial tests for the purposes of instrument familiarity prior to data collection to ensure learning effects are negated, regardless of the test condition. Following these two trials the clinician can assume that all data acquired is reliable across the spectrum of stability levels and that data differences are not related to learning.

REFERENCES

1. France EP, Derscheid G, Irrgang JJ, Malone T, Peterson R, Tippet S, Wilk K: Preliminary clinical evaluation of the Breg K.A.T.: Effects of training in normals. *Isokinetics and Exerc Sci* 2(3), 133-139, 1992.
2. Gray GW: Chain reaction: A successful strategy for closed chain testing and rehabilitation. *Adrian, MI - Wynn Market Inc.*, 23: 1990.
3. Irrgang JJ, Whitney SL, Cox ED: Balance and proprioceptive training for rehabilitation of the lower extremity. *J Sport Rehabil* 3:68-83, 1994.
4. Kennedy JC, Alexander IJ, and Hayes KC: Nerve supply of the human knee in its functional importance. *Am J Sports Med*, 10:329-335, 1989.
5. Lephart SM, Kocher MS, Fu FH, Borsa PA, Harner CD: Proprioception following anterior cruciate ligament reconstruction. *J Sports Rehabil* 1:186-196, 1992.
6. Lephart SM: Re-establishing proprioception, kinesthesia, joint position sense, and neuromuscular control in rehabilitation. In: Prentice W.E. (2nd ed.) *Rehabilitation Techniques in Sports*. St. Louis: Times Mirror Mosby College Publishing, 118-137, 1993.
7. Losse GM, Howard ME, Cawley PW, Philipe J, Doubbit BE: Correlation of lower extremity injury to balance indices: An investigation utilizing an instrumented unstable platform. *American Orthopedic Society for Sports Medicine Specialty Day Meeting*. New Orleans, LA, 1994.
8. Tyldesley B, Grieve JJ: *Muscles and Nerves and Movement: Kinesiology in Daily Living*. Boston, MA, Blackwell Scientific Publications, 268-284, 1989.

THE ADVANTAGES OF A DYNAMIC STABILITY SYSTEM COMPARED TO A STATIC FORCE PLATE SYSTEM FOR ORTHOPEDIC AND MUSCULOSKELETAL REHABILITATION

Gary B. Wilkerson, EdD, ATC
University of Tennessee
Chattanooga, Tennessee

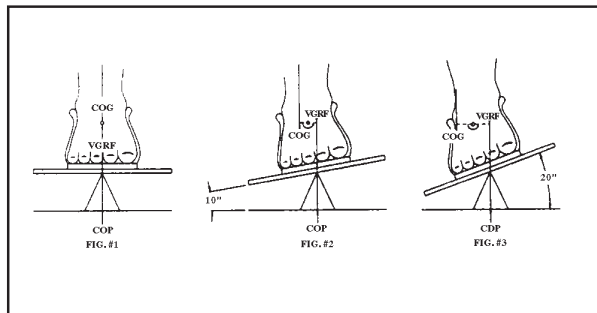
Ed Behan
Director of Market Development
Biodex Medical Systems

ABSTRACT

The Biodex Stability System, a new device by Biodex Medical Systems, was designed with a dynamic multi-axial tilting platform to aid in joint rehabilitation and enhance proprioceptive mechanisms. In contrast to a static force plate system, where the line of action of the vertical ground reaction force is not constant, the Biodex Stability System allows sufficient tilt to stress the joint mechanoreceptors without excessively displacing the ankle. This results in much greater ankle motion and stimulation of the joint mechanoreceptors, with decreased risk of re-injury.

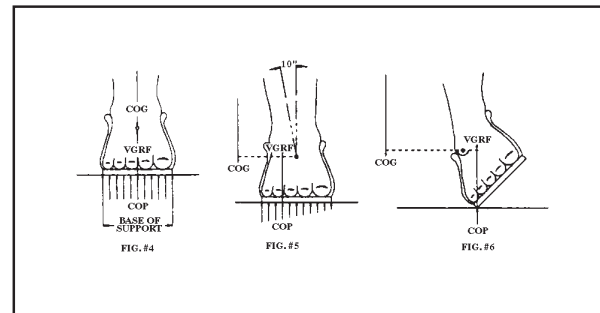
INTRODUCTION

Any movement of the body's center of gravity (COG) away from a perfectly balanced position (ie, directly over the central portion of the base of support) results in the creation of a force moment that must be counteracted by an appropriate muscle activation pattern and generation of sufficient muscular torque to prevent the support surface from tilting. These movements are governed by and stimulate proprioceptive mechanoreceptors. Such mechanoreceptors are stimulated most by movement of the joint toward the limit of its range. Thus, stimulation of mechanoreceptors to regain proprioceptive function is an important part of joint rehabilitation.



DYNAMIC STABILITY SYSTEM

With a dynamic multi-axial tilting platform such as the Biodex Stability System, the line of action (center of pressure, COP) resulting from the vertical ground reaction force (VGRF) remains constant. As the line of action moves away from the VGRF, the forces of gravity — COG and ground reaction — act on opposite sides of the subtalar axis of rotation. Because the COP remains in line with the VGRF, only a few degrees of joint motion are required to bring the joint and resulting forces back into alignment. For this reason, 20 degrees of support surface tilt is sufficient to stress the joint mechanoreceptors, while being limited enough to prevent excessive ankle displacement.



STATIC FORCE PLATFORM SYSTEM

With a static force plate system, the line of action (COP) of the vertical ground reaction force is not constant. As the COG moves laterally, the COP beneath the foot and the corresponding VGRF follow. The COG must be laterally displaced beyond the limits of stability, before the lateral border of the foot acts as a fulcrum to supinate the foot. This causes the VGRF to pass medial to the subtalar axis. As a consequence, the patient must move their COG considerably (sway widely) to get the VGRF opposite the axis of rotation. These are considered the limits of stability (LOS). By the time the LOS are reached, the patient will have fallen.

Neuromuscular Training Improves Single-Limb Stability in Young Female Athletes

Mark V. Paterno PT, MS, SCS, ATC¹

Greg D. Myer MS, CSCS²

Kevin R. Ford, MS³

Timothy E. Hewett, PhD⁴

Study Design: Controlled single-group pretest/posttest design.

Objective: The purpose of this study was to determine if a 6-week neuromuscular training program designed to decrease the incidence of anterior cruciate ligament (ACL) injuries would improve single-limb postural stability in young female athletes. We hypothesized neuromuscular training would result in an improvement in postural stability, with the greatest improvement taking place in the medial-lateral direction.

Background: Balance training has become a common component of programs designed to prevent ACL injury. Rehabilitation programs can improve postural stability following ACL injury and reconstruction; however, there is limited information available which quantifies improvement of postural stability following neuromuscular training designed to prevent ACL injuries in a healthy population.

Methods and Measures: Forty-one healthy female high school athletes (mean age, 15.3 years; age range, 13-17 years) participated in this study. Single-limb postural stability for both lower extremities was assessed with a Biodex Stability System. The neuromuscular training program consisted of three 90-minute training sessions per week for 6 weeks. Following the completion of the training program, each subject was re-evaluated to determine change in total, anterior-posterior, and medial-lateral single-limb stability. Two-way analysis of variance models were used to determine differences between pretraining and posttraining and between limbs.

Results: The subjects showed a significant improvement in single-limb total stability ($P = .004$) and anterior-posterior stability ($P = .001$), but not medial-lateral stability ($P = .650$) for both the right and left lower extremity following training. In addition, the subjects demonstrated significantly better total postural stability on the right side as compared to the left ($P = .026$).

Conclusions: A 6-week neuromuscular training program designed to decrease the incidence of ACL injuries improves objective measures of total and anterior-posterior single-limb postural stability in high school female athletes. *J Orthop Sports Phys Ther* 2004;34:305-317.

Key Words: anterior cruciate ligament, balance, knee, prevention, proprioception

Female athletes injure their anterior cruciate ligaments (ACLs) at a rate 4 to 6 times higher than that of male athletes participating in the same jumping and pivoting sports.^{7,10,23,25,34,47} Consequently, there is currently an increased emphasis in sports medicine on the development of training programs designed to decrease the incidence of noncontact ACL injury in female athletes.^{5,6,17,21} In addition to reducing the incidence of ACL injuries,^{6,17,21,23} these programs have been shown to also improve lower extremity biomechanics during athletic tasks, while increasing athletic performance.²³

Injury prevention training programs typically incorporate some combination of strengthening, flexibility, plyometrics, and balance components; however, what has not been fully determined is the mechanism of how these programs effectively reduce ACL injuries.^{5,6,17,21,23,32,45} Caraffa et al¹⁶ utilized balance board training and noted a 7-fold decrease in ACL injuries in male soccer players.

¹ Coordinator of Orthopaedic and Sports Physical Therapy, Sports Medicine Biodynamics Center and Department of Occupational Therapy and Physical Therapy, Cincinnati Children's Hospital Medical Center and Research Foundation, Cincinnati, OH.

² Sports Biomechanist, Sports Medicine Biodynamics Center and Human Performance Laboratory, Division of Molecular Cardiovascular Biology, Cincinnati Children's Hospital Medical Center and Research Foundation, Cincinnati, OH.

³ Research Biomechanist, Sports Medicine Biodynamics Center and Human Performance Laboratory, Division of Molecular Cardiovascular Biology, Cincinnati Children's Hospital Medical Center and Research Foundation, Cincinnati, OH.

⁴ Director, Sports Medicine Biodynamics Center and Human Performance Laboratory, Division of Molecular Cardiovascular Biology, Cincinnati Children's Hospital Medical Center and Research Foundation, Cincinnati, OH.

This study was approved by the Cincinnati Children's Hospital Medical Center Institutional Review Board.

Corresponding author Mark V. Paterno, Cincinnati Children's Hospital Medical Center, Sports Medicine Biodynamics Center, 3333 Burnet Avenue MLC 10001, Cincinnati, OH 45229-3039. E-mail: mark.paterno@cchmc.org

Wedderkopp et al⁴⁵ instituted an injury prevention program focusing on ankle disc training in young female handball players and compared injury rates of the trained group to a control group. The authors determined that the trained group experienced 79% fewer lower extremity injuries (including sprains, strains, and subluxations) than the control group over one 10-month competitive season. Hewett et al²¹ incorporated flexibility, strength training, plyometrics, and several single-leg balance drills in the overall training of female volleyball, basketball, and soccer players. They noted a 72% decrease in major knee injuries in the trained group. While differences exist among these training programs, the 1 common component shared among protocols is the utilization of some form of balance and proprioception exercise.

Balance training has been defined as exercises designed to focus on postural awareness and equilibrium maintenance without changing the base of support³⁷ and has been incorporated into a variety of training programs. There is a general consensus in the scientific community that balance training can improve postural stability, or the ability to maintain an upright posture under dynamic conditions, in a population with lower extremity injury such as an ACL tear.^{2,11,13,39,46} However, this has not been verified in populations with mechanically stable knees.

Stabilometry is an objective and quantitative method for evaluating postural stability.^{14,16,35,43} In the past, stabilometry studies were performed on a static force plate with measurement of center of pressure displacement or angular displacement of the platform in the sagittal and coronal planes. More recently, dynamic mobile platforms that also measure center of pressure displacement in 2 dimensions have been developed. These measures of stability can be reported as total stability, stability in the anterior-posterior (AP) direction, and stability in the medial-lateral (ML) direction. Arnold et al³ studied an uninjured population of male and female athletes utilizing the Biodex Stability System (Biodex Corp., Shirley, NY) and determined that there is a close relationship between total stability and AP stability, but not between total stability and ML stability. The authors concluded that there is a need for individual evaluation of each component of postural stability to determine deficits in each plane.

Two recent studies^{12,33} have evaluated gender differences in lower extremity kinematics with athletic tasks such as a jumping, landing, and cutting maneuvers, and have found significant differences in coronal plane motion between uninjured male and female athletes. Based on these results, the authors hypothesized that this difference in coronal plane movement may be a risk factor for ACL injury. If there are differences in coronal plane kinematics that increase risk of ACL injury and assessment of total stability is not an accurate indicator of coronal plane

stability, then there is a need to individually evaluate both AP and ML stability following a training program designed to decrease ACL injury risk to determine changes that occur in each plane.

Several studies have utilized stabilometry to evaluate subjects following lower extremity injury in an attempt to quantify deficits in stability or ability to regain dynamic joint control after rehabilitation.^{8,20,22,35,43,45} Assessment of change in postural stability and proprioceptive ability in these populations was quantified through the assessment of joint position sense, joint kinesthesia, and stabilometry, and has supported the role of postural stability training in the functional stability of the lower extremity following injury.^{1,2,13,31,32,38,39}

With respect to patients with mechanically stable knees following ACL reconstruction, proprioception and postural stability can improve over the first 9 to 12 months postoperatively as a result of rehabilitation focused on balance and proprioception.^{9,16,20,22,42} Therefore, published evidence demonstrates that rehabilitation with balance, proprioception, and agility training can restore dynamic functional stability in individuals with an ACL-reconstructed knee.

In contrast to the large amount of literature on the effects of neuromuscular rehabilitation focused on balance and proprioception in patients, there is little published data that demonstrate the potential to improve proprioception and postural stability in a healthy, athletic population.³⁶ Heitkamp et al¹⁸ attempted to determine if short-term balance training alone could improve strength. In doing so, the authors reported that improvements in balance and stabilometry were observed following a 6-week training program. In addition, at least 2 studies have confirmed superior proprioception in athletes participating in sports that require superior balance, such as gymnastics.^{30,44} The gymnasts studied either possessed inherent superior balance or developed it following a career of balance training specific to the sport. However, no study to date has quantitatively evaluated the effects of a short-term neuromuscular training program on measures of balance and proprioception and no study has attempted to determine if improvements in postural stability occur following a dynamic, multicomponent program designed to decrease ACL injuries. In addition, it is unknown if improvement in postural stability is the mechanism by which neuromuscular training programs may decrease the risk of ACL injuries in these athletes.

Lloyd³² suggests that cocontraction of the lower extremity musculature may be responsible for the increased joint stability in the knee during athletic maneuvers and may be a mechanism by which training programs help to decrease knee injury. This author also states that balance and stability training may help to improve the athlete's ability to cocontract lower extremity musculature and ulti-

mately improve lower extremity stability. However, Lloyd³² notes that no study to date has evaluated how balance and stability training have actually reduced the rate of ACL injury.

The purpose of this study was to determine if a 6-week, multicomponent neuromuscular training program designed to help decrease the incidence of ACL injuries in young female athletes improves single-limb postural stability. Our hypothesis was that, following a 6-week neuromuscular training program, we would see an objective improvement in postural stability as demonstrated by total stability on the Biodex Stability System. In addition, we hypothesized that greater improvement would be reported in the ML direction as compared to the AP direction.

METHODS

Subjects

Fifty-three female athletes from a local high school registered to participate in this study. We established an inclusionary compliance criterion mandating that each participant be present for at least two-thirds (12 of 18) of the training sessions for their data to be included in the results of the study. This criterion allows for an average minimum compliance of 2 sessions per week and has previously been documented in the literature.²¹ Forty-one female athletes (77%) met the compliance requirement. These subjects attended a mean of 15 training sessions (± 1.67). Twelve of the original 53 subjects (23%) were unable to complete the mandatory amount of training sessions due to conflicting obligations.

The mean age of the 41 subjects was 15.3 years (range, 13-17 years). Ten athletes reported basketball, 15 reported soccer, and 16 reported volleyball as their primary sport. Forty (97.6%) of 41 subjects had greater than 4 years of participation in their sport and 73.1% had greater than 6 years experience in their respective sport. One participant had 2 years experience in her sport. All training occurred in the summer, immediately prior to the soccer and volleyball seasons, so no organized team sport participation was occurring at the time of training; however, independent athlete participation in sport was not monitored or controlled.

Height and mass were assessed at the pretraining and posttraining test date. Parents or guardians signed informed consent prior to participation in the study. The testing protocol was approved by the Cincinnati Children's Hospital Medical Center Institutional Review Board.

Assessment

Prior to initiating training, single-limb postural stability was assessed on a Biodex Stability System

(Biodex, Shirley, NY). The Biodex Stability system is a multi-axial tilting platform that allows the examiner to objectively measure the ability of a subject to maintain dynamic single-limb postural stance on an unstable platform through the use of stabilometry.^{3,41} This stabilometric technique allowed assessment of total single-limb postural stability in addition to AP stability, and ML stability. The stability platform allows for varying levels of difficulty of stability testing, ranging from level 8 (most stable) to level 1 (least stable). Schmitz et al⁴¹ examined the intratester reliability of the Biodex Stability System and reported an intraclass correlation coefficient (ICC) value of 0.82 for total stability, using a descending stability test from level 8 to level 2 over a 30-second trial. Hinman et al²⁴ reported intratester reliability of 0.89 at level 3 based on 2 separate 30-second trials. Initial between-session reliability data collected in our lab on 5 female athletes (mean age, 16.9 ± 5.0 years) on 3 separate days at level 4 resulted in ICC_{3,1} values of 0.72 for total stability, 0.77 for AP stability, and 0.81 for ML stability.



FIGURE 1. Assessment of single-limb postural stability utilizing the Biodex Stability System.

Prior to testing, the subject was asked to center the foot on the platform in a position that was level and stable. This foot placement was maintained throughout all 3 trials for the test leg. This position was used as the level reference point from which degree of displacement was measured. The subject was instructed to stand on 1 foot with the knee slightly flexed on the free-moving stability platform, with the contralateral knee flexed to 90° for 20 seconds (Figure 1). The subject was then instructed to keep the platform as stable as possible. After reviewing the current literature regarding reliability,^{24,41} and considering the authors' own personal experience with testing on the Biodex Stability System, level 4 was selected for use during testing. The authors theorized that in addition to having lower reliability, level 2 would be too unstable for some participants. Conversely, levels 6 through 8 had superior reliability, but may not be sufficiently challenging to allow subtle differences in stability in athletic populations to be observed. Therefore, level 4 was utilized for all testing. The subjects were instructed to cross their arms at their chest to minimize their use in attaining balance, as per system operation procedures.⁴ No verbal feedback was given during the testing and while the subjects kept their eyes open, they were allowed no visual feedback regarding their performance during the test, as the control screen was covered during all testing. The Stability System was positioned facing the corner of the room and each subject was asked to look straight ahead and focus on a point on the wall in front of the subject. Each leg was tested 3 times, as done in previous studies utilizing the Stability System for an assessment of postural stability.^{40,41} The mean displacement from the referenced, level position during the 20-second trial was calculated for each trial.

The mean and standard deviation of the 3 trials was calculated by the Stability System. The data were analyzed and reported as total stability index, AP stability index, and ML stability index, which is the mean displacement of the platform in degrees, from a level position. A higher stability index from the reference point indicates a greater difficulty of the subject to maintain the platform in a stable position.

This indicates less postural stability demonstrated by the subject. Conversely, the lower the stability index, the more stable the platform, representing greater postural stability of the subject.

Training

The training program utilized in this study was a synthesis of exercises used in published research studies^{6,15,17,19,21,23,26-29} and prevention techniques developed through recent empirical and analytical evaluations of neuromuscular training programs. The 3 components of the dynamic neuromuscular training protocol utilized in this study include: (1) balance training and hip/pelvis/trunk strengthening, (2) plyometrics and dynamic movement training, and (3) resistance training. Each training component focused on regular instruction regarding appropriate technique from the instructor with continuous feedback to the athlete both during and following training.

General Guidelines to Training The training protocol stressed technique perfection for each exercise, especially in the early training sessions. Each session maintained a 1-to-4 instructor-participant ratio and was directed by a certified strength and conditioning specialist. The trainers were skilled in recognizing the desired technique for a given exercise and consistently encouraged the athlete to maintain proper technique performance for as long as possible. When the athlete fatigued to a point that she could not perform the exercise with near perfect technique, the exercise was stopped. The athlete recorded the duration of the exercises and number of repetitions completed. The goal of the next training session was to continue to improve technique, while increasing duration, volume, or intensity of the exercise. In addition to technique perfection, the neuromuscular training was progressed to ensure a continued challenge to the athlete and maximize potential for successful outcomes (Table and Appendix A). The neuromuscular training stressed performance of general athletic maneuvers in a powerful, efficient, and safe manner.

TABLE. Sample exercise progressions from the balance and hip/pelvis/trunk strengthening protocol.

Initial Phase (Weeks 1-2)	Intermediate Phase (Weeks 3-4)	Late Phase (Weeks 5-6)
Stable surface progression		
Broad jump, stick landing	Single leg, stick landing	Single leg crossover, stick landing
Box drop, stick landing	Box drop medicine ball catch	Box drop 180° medicine ball catch
Unstable surface (BOSU) progression		
Double-leg balance (Figure 3)	Single-leg balance	Single-leg balance (perturbation/sport)
Double-knee balance	Single-knee balance (Figure 2)	Hip-side balance
Targeted hip/pelvis/trunk strengthening		
Abdominal crunch	BOSU abdominal crunch	BOSU abdominal V-sit/toe touch
Lower back superman's	BOSU lower back superman's	Back hyperextensions

The athletes participated in the training program 3 days per week with at least 1 day of rest between each session. Each training session lasted for 90 minutes and began with an active warm-up that included jogging, backwards running, lateral shuffling, and carioca. During each training session, the athlete participated in 2 of the 3 components of the program, resulting in 2 exposures per week to each component of the program. At the end of each training session the athletes performed self-selected stretching exercises for 15 minutes. This cycle of training was repeated each week for the training period of 6 weeks.

Balance Training and Hip/Pelvis/Trunk Strengthening
The balance training and hip/pelvis/trunk strengthening component of the protocol followed an organized exercise selection specifically directed at strengthening the hip/pelvis/trunk stabilizing muscles. The training was structured to provide the appropriate intensity and progression of exercises. The training progression took the athlete through a combination of low- to higher-intensity maneuvers in a controlled situation (Table). The goal of the functional balance training and hip/pelvis/trunk strengthening was to improve hip/pelvis/trunk stability and coordination in an attempt to properly control force, maintain balance and posture, and subsequently regenerate force in the desired direction. The athletes did not train or practice on the Biodex Stability System.

The initial phase of the balance training and hip/pelvis/trunk strengthening component lasted 2 weeks and focused on development of baseline stability and good technique (Table). Early balance exercises included double-limb jumping activities with a focus on correct landing posture, which has been described by previous authors.^{21,23} In addition, low-intensity single-leg hops were introduced at this time, again with a focus on maintaining balanced landing. During the beginning stages, progressions were made from decreasing frequency of double-limb jumps and increasing frequency of single-limb hops. Balance on an unstable surface was also introduced using bilateral stance exercises on the "both sides up" (BOSU) balance device (DW Fitness, LLC, Madison, NJ). The BOSU (Figures 2 and 3) is a balance device with a circular platform on 1 side and an inflated half-sphere on the opposite side. It provides an unstable platform to further challenge the subject's balance and stability. The initial stages of training also included a component that focused on abdominal, mid-back, low-back, and hip strengthening.

The intermediate phase of the balance training and hip/pelvis/trunk strengthening portion of the neuromuscular training program occurred during the third and fourth week of training. During this time the athlete was progressed to more single-limb stance movements with a decrease in volume of double-limb



FIGURE 2. Example of hip/pelvis/trunk training with single-knee stance on unstable surface.

stance on stable surfaces. In addition, stable surface activities progressed into more multiple-plane movements. Trunk strengthening was also progressed during this phase to knee support balance drills (Figure 2) and unanticipated perturbations.

The late phase of the balance training and hip/pelvis/trunk strengthening exercises lasted 2 weeks and focused on training on an unstable surface with single-limb support. The training included static holds with upper extremity involvement, as well as dynamic activities such as jumping onto and off the unstable surface in multiple planes and rotational jumps on the unstable platform. Hip/pelvis/trunk strengthening was also continued with abdominal and trunk strengthening activities. The focus of the late stage was to develop stability in a single-limb stance position in unstable and unanticipated environments, with the goal of preparing the athlete to react appropriately in an athletic situation. Ultimately, the goal is to provide stability and avoid injury. Figure 3 demonstrates a typical exercise progression during the balance training.

Plyometrics and Dynamic Movement Training The plyometrics and dynamic movement training component emphasized a progression of jumping, pivoting, and cutting maneuvers from double-limb to single-limb movements throughout the training phases.

Resistance Training The resistance-training component of the protocol was periodized with an initial high-volume, low-intensity protocol. The goal of the resistance training component of the protocol was to strengthen all major muscle groups through complete range of motion and to provide complementary muscular strength and power to the plyometric and balance components of the protocol. Appendix A describes the specific exercises executed during each phase of training.



FIGURE 3. Demonstration of balance training exercise progression on unstable platform (BOSU) from double-limb stance to single-limb stance to double-limb stance with perturbation to single-limb stance with sports-specific perturbation.

Data Analysis

Mean and SD of height and mass were reported for all subjects pretraining and posttraining. A paired *t* test was used to determine significant changes in these variables ($P < .05$).

For assessment of postural stability, mean and SD of postural stability of the 3 single-limb trials for both legs of each subject was recorded at the pretraining and the posttraining sessions for total stability, AP stability, and ML stability. The group mean and SD for each leg pretraining and posttraining were calculated for descriptive purposes. Three separate 2×2 (side \times training) repeated-measures 2-way analyses of variance (ANOVAs) were conducted to determine if any difference existed between sides (right versus left) and time of testing (pretraining versus posttraining) for total stability, AP stability, and ML stability. A Pearson correlation coefficient was measured to determine the degree of association between total stability and AP and ML stability. Significance was set at $P < .05$. Statistical analyses were conducted in SPSS for Windows, Release 10.0.7 (SPSS, Inc., Chicago, IL).

RESULTS

Height and mass of the subjects were evaluated pretraining and posttraining. The initial height (mean \pm SD) of the participants was 171.2 ± 7.2 cm, and mass (mean \pm SD) was 64.8 ± 10.0 kg. Assessment of height and mass after 6 weeks of training revealed no change in mean height; however, a very small but statistically significant increase in mass (65.7 ± 6.7 kg) was noted ($P = .001$).

Mean and SD of single-limb postural stability pretraining and posttraining for total stability, AP stability, and ML stability are reported in Figures 4, 5, and 6 for the right and left lower extremities. The results of the ANOVA for total stability indicated a main effect for training ($F_{1,40} = 9.4$, $P = .004$), and for side ($F_{1,40} = 5.4$, $P = .026$), with stability posttraining being better than pretraining and stability on the

right side being better than stability on the left side. There was no interaction between the variables of side and training ($P = .674$).

The results of the ANOVA indicated a significant training main effect for AP stability ($F_{1,40} = 11.7$, $P = .001$), with posttraining values being better than the pretraining values (Figure 5). There was no significant difference for AP stability between the right and left lower extremity ($F_{1,40} = 3.1$, $P = .086$). There was also no significant interaction between the variables of side and training ($P = .866$).

No significant difference was found between pretraining and posttraining ($F_{1,40} = .2$, $P = .65$) and between lower extremities ($F_{1,40} = 2.5$, $P = .12$) for stability in the ML direction. There was no interaction between the variables of side and training ($P = .835$).

Finally, a strong correlation was observed between total stability index and AP stability index for the right leg ($r = .954$, $P < .001$) and the left leg ($r = .923$,

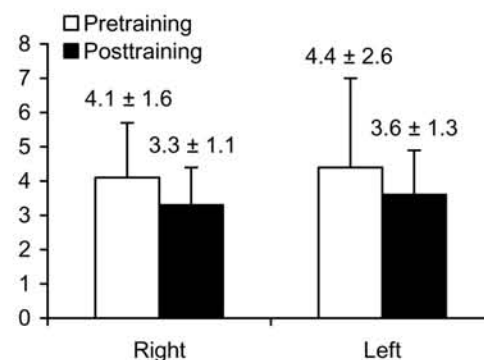


FIGURE 4. Mean total stability index pretraining and posttraining for the right and left lower extremity. Posttraining values are significantly better than pretraining values ($P = .004$) and stability on the right lower extremity is better than on the left side ($P = .026$). The error bars are 1 SD.

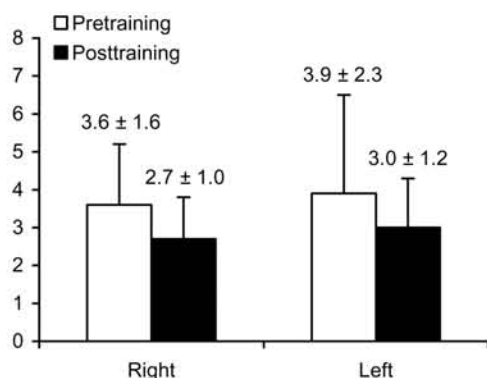


FIGURE 5. Mean anterior-posterior stability index pretraining and posttraining for the right and left lower extremity. Posttraining values are significantly better than pretraining values ($P = .001$). The bars are 1 SD.

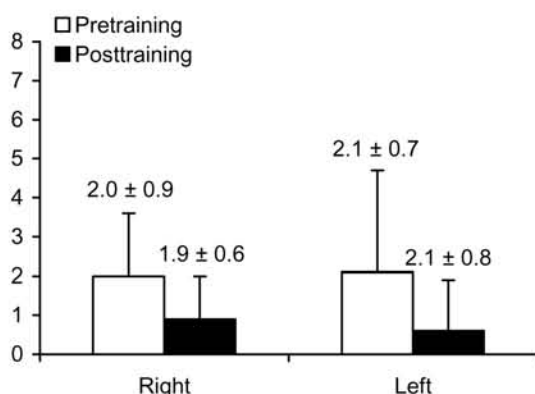


FIGURE 6. Mean medial-lateral stability index pretraining and posttraining for the right and left lower extremity. Medial-lateral stability did not change with training. The bars are 1 SD.

$P < .001$). There was only a moderate correlation between total stability index and ML stability index for the right leg ($r = .601$, $P < .001$) and the left leg ($r = .733$, $P < .001$).

DISCUSSION

Participation in a structured 6-week preseason neuromuscular training program designed to decrease ACL injury significantly improved total and AP direction single-limb postural stability measures in young female athletes. However, no change in stability in the ML direction was noted.

In the uninjured population, to our knowledge, the effect of short-term neuromuscular training designed to help decrease knee injuries on postural stability and proprioception has not been reported in the

published literature. Two authors have retrospectively evaluated the proprioceptive capacity of gymnasts who participated in long-term proprioceptive training as part of their sport. Lephart et al³⁰ and Vuillerme et al⁴⁴ found that gymnasts were better able to maintain postural stability when compared to nongymnasts. These studies both suggest improvement in proprioceptive ability and postural stability with long-term training; however they did not report the effects on proprioception of a short-term training program. Our findings suggest that in as little as 6 weeks of neuromuscular training there can be a significant improvement in total and AP postural stability in young female athletes.

Similar to the findings of Arnold et al,³ our results show a strong correlation between total stability index and AP stability index for the right leg ($r = 0.954$, $P < .001$) and the left leg ($r = .923$, $P < .001$), and only moderate correlation between total stability index and ML stability index for the right leg ($r = .601$, $P < .001$) and the left leg ($r = .733$, $P < .001$). This finding is, in part, the result of the higher magnitude of motion demonstrated in the AP direction as opposed to the ML direction and is supported by a few studies in the literature.^{3,22} These findings further substantiate the need to evaluate total stability and ML stability independent of each another.

With respect to ML movement, Ford et al¹² reported increased valgus knee motion in normal female basketball players when compared to males during a drop jump task. Malinzak et al³³ demonstrated increased knee valgus angles and decreased knee flexion angles in female athletes performing cutting tasks when compared to male controls. These gender differences in coronal plane kinematics in uninjured female athletes may represent an increased risk for ACL injury. Considering these gender differences, we hypothesized that following a training program designed to decrease ACL injury risk, there would be an improvement in coronal plane postural stability. However, our results demonstrated no significant improvement in stability in the ML direction.

A retrospective analysis of our training program design was conducted to determine if any bias existed to explain the significant improvement in AP stability and failure to demonstrate significant improvement in the ML direction. The training program utilized AP perturbations on an unstable platform without ML perturbations and may have failed to properly stimulate stability improvement in the ML direction. Further research is needed to investigate the potential of neuromuscular training focused on improving ML stability, specifically ML perturbations.

With respect to neuromuscular training, there have been a few studies documenting the importance of preseason training programs on the prevention of ACL injuries; however these have failed to investigate the changes in postural stability that may have oc-

curred. Caraffa et al⁶ conducted a prospective study of European male soccer players in an attempt to decrease the incidence of ACL injuries. The authors had the study group participate in progressive proprioceptive training that utilized balance board and disk training drills and found a 7-fold decrease in the incidence of ACL injuries when compared to a control group; however, the athlete's improvement in postural stability was not objectively measured. Wedderkopp et al⁴⁵ implemented a prospective intervention program designed to decrease injury rate in elite European female handball players. The authors reported an 80% decrease in injuries during games and a 71% decrease in injuries in practice for the intervention group when compared to the control group. Hewett et al²¹ reported a 72% decrease in serious knee injuries in female athletes following participation in a 6-week preseason training program including flexibility, strength training, plyometric training, and single-leg balance drills; however, no quantification of improvement in proprioception or postural stability was reported. Thus, it cannot be determined if the mechanism resulting in decrease injury rate was related to improved proprioception and postural stability or other unmeasured variables.

These previously reported findings, coupled with the results of the current study, provide a novel contribution to the scientific literature. Our findings help substantiate that the balance component is improved following preseason training designed to help decrease ACL injuries. In the work of Caraffa et al⁶ and Hewett et al,²¹ an athletic population is shown to have a marked decrease in noncontact ACL and MCL injury incidence following training. While our findings suggest that participation in such training will aid in the improvement of postural stability that may improve dynamic joint stability in the knee and decrease ACL injuries in female athletes, our study did not look at dynamic joint stability and the incidence of ACL injuries. Therefore, no conclusion can be reached at this time.

Future research should explore the possibility that deficits in total, AP, or ML postural stability may be a risk factor for ACL injury. If this is the case, then assessing postural stability in the preseason may help identify young female athletes who have deficits in postural stability, dynamic joint control at the knee, and ultimately are at higher risk for ACL injury. Identification of a high-risk group is the first step in determining what population of athletes should participate in preseason neuromuscular training to help decrease the incidence of knee injury. Prior studies by Tropp et al⁴³ demonstrated that an abnormal stabilometric score was predictive of future ankle injury. No study has associated deficits in postural stability to increased incidence of knee injury. Neuromuscular training programs implemented at the team level, such as those demonstrated by Caraffa

et al⁶ and Hewett et al,²¹ appear to be successful at decreasing the incidence of knee injuries, but they have not been effectively targeted towards individuals who may be at the highest risk.

This study has several possible limitations that need to be considered. First, the neuromuscular training we utilized was a multicomponent program including balance training, plyometrics, and resistance training. A single component of this program (ie, balance training) may have been solely responsible for the improvement seen in postural stability; however, we are unable to dissect out the separate effects of each of the components of the program. Secondly, there is a limit to the generalizability of the effects of training because the focus of this study was on young female athletes. The question, however, still remains if males would benefit equally from such a training program. Knowing the biomechanical differences between male and female athletes, it would be inappropriate to assume the same results would occur in male athletes. Thirdly, it is assumed that the improvements in postural stability seen following the 6-week preseason training persist through the season. However, this study is unable to determine if the changes seen at the end of training persisted throughout the season or if they deteriorate over time, because no repeat testing was performed postseason. Finally, there was no control group tested in the study, therefore we are unable to unequivocally determine if the changes noted in postural stability were in fact due to the intervention.

Future studies should attempt to further quantify the presence of other biomechanical and neuromuscular improvements that may be observed following structured preseason neuromuscular training designed to reduce the incidence of ACL injuries in female athletes. Methods to refine programs aimed at effectively reducing the rate of ACL injuries in female athletes need to be determined.

CONCLUSIONS

Single-limb postural stability and proprioception is a key component to the functional status of the lower extremity. This study shows that 6 weeks of neuromuscular training can improve single-limb postural balance as measured by an index of total stability and AP stability, but not ML stability.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Jeffrey Robbins, Division of Molecular and Cardiovascular Biology, and Rebecca Reder, Division of Occupational Therapy and Physical Therapy, for ongoing support of our work, and Melissa Mays for her assistance in the preparation of this manuscript.

REFERENCES

- Ageberg E. Consequences of a ligament injury on neuromuscular function and relevance to rehabilitation - using the anterior cruciate ligament-injured knee as model. *J Electromyogr Kinesiol.* 2002;12:205-212.
- Ageberg E, Zatterstrom R, Moritz U, Friden T. Influence of supervised and non-supervised training on postural control after an acute anterior cruciate ligament rupture: a three-year longitudinal prospective study. *J Orthop Sports Phys Ther.* 2001;31:632-644.
- Arnold BL, Schmitz RJ. Examination of balance measures produced by the Biodex Stability System. *J Athl Train.* 1998;33:323-327.
- Biodex System Operation and Service Manual (#945-300). Shirley, NY: Biodex Medical Systems, Inc.; 2002.
- Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of high school football knee injuries. *Am J Sports Med.* 1978;6:180-184.
- Caraffa A, Cerulli G, Proietti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc.* 1996;4:19-21.
- Chandy TA, Grana WA. Secondary school athletic injury in boys and girls: A three-year comparison. *Phys Sportsmed.* 1985;13:106-111.
- Co FH, Skinner HB, Cannon WD. Effect of reconstruction of the anterior cruciate ligament on proprioception of the knee and the heel strike transient. *J Orthop Res.* 1993;11:696-704.
- Denti M, Randelli P, Lo Vetere D, Moiola M, Bagnoli I, Cawley PW. Motor control performance in the lower extremity: normals vs. anterior cruciate ligament reconstructed knees 5-8 years from the index surgery. *Knee Surg Sports Traumatol Arthrosc.* 2000;8:296-300.
- Ferretti A, Papandrea P, Conteduca F, Mariani PP. Knee ligament injuries in volleyball players. *Am J Sports Med.* 1992;20:203-207.
- Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. *Phys Ther.* 2000;80:128-140.
- Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* 2003;35:1745-1750.
- Friden T, Roberts D, Ageberg E, Walden M, Zatterstrom R. Review of knee proprioception and the relation to extremity function after an anterior cruciate ligament rupture. *J Orthop Sports Phys Ther.* 2001;31:567-576.
- Friden T, Zatterstrom R, Lindstrand A, Moritz U. A stabilometric technique for evaluation of lower limb instabilities. *Am J Sports Med.* 1989;17:118-122.
- Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg.* 2000;8:141-150.
- Harrison EL, Duenkel N, Dunlop R, Russell G. Evaluation of single-leg standing following anterior cruciate ligament surgery and rehabilitation. *Phys Ther.* 1994;74:245-252.
- Heidt RS, Jr., Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med.* 2000;28:659-662.
- Heitkamp HC, Horstmann T, Mayer F, Weller J, Dickhuth HH. Gain in strength and muscular balance after balance training. *Int J Sports Med.* 2001;22:285-290.
- Hejna W, Rosenberg A, Buturusi D, Krieger A. The prevention of sports injuries in high school students through strength training. *Nat Strength Coaches Assoc J.* 1982;4:23-31.
- Henriksson M, Ledin T, Good L. Postural control after anterior cruciate ligament reconstruction and functional rehabilitation. *Am J Sports Med.* 2001;29:359-366.
- Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med.* 1999;27:699-706.
- Hewett TE, Paterno MV, Myer GD. Strategies for enhancing proprioception and neuromuscular control of the knee. *Clin Orthop.* 2002;76-94.
- Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24:765-773.
- Hinman MR. Factors affecting reliability of the Biodex Balance System: a summary of four studies. *J Sport Rehabil.* 2000;9:240-252.
- Huston LJ, Wojtys EM. Neuromuscular performance characteristics in elite female athletes. *Am J Sports Med.* 1996;24:427-436.
- Kraemer WJ. A series of studies: the physiological basis for strength training in American football: fact over philosophy. *J Strength Cond Res.* 1997;11:131-142.
- Kraemer WJ, Duncan ND, Volek JS. Resistance training and elite athletes: adaptations and program considerations. *J Orthop Sports Phys Ther.* 1998;28:110-119.
- Kraemer WJ, Hakkinen K, Triplett-McBride NT, et al. Physiological changes with periodized resistance training in women tennis players. *Med Sci Sports Exerc.* 2003;35:157-168.
- Lehnhard RA, Lehnhard HR, Young R, Butterfield SA. Monitoring injuries on a college soccer team: the effect of strength training. *J Strength Cond Res.* 1996;10:115-119.
- Lephart SM, Giraldo JL, Borsa PA, Fu FH. Knee joint proprioception: a comparison between female intercollegiate gymnasts and controls. *Knee Surg Sports Traumatol Arthrosc.* 1996;4:121-124.
- Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med.* 1997;25:130-137.
- Lloyd DG. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *J Orthop Sports Phys Ther.* 2001;31:645-654; discussion 661.
- Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon).* 2001;16:438-445.
- Malone TR, Hardaker WT, Garrett WE, Feagin JA, Bassett FH. Relationship of gender to anterior cruciate ligament injuries in intercollegiate basketball players. *J South Orthop Assoc.* 1993;2:36-39.
- Mizuta H, Shiraishi M, Kubota K, Kai K, Takagi K. A stabilometric technique for evaluation of functional instability in anterior cruciate ligament-deficient knee. *Clin J Sport Med.* 1992;2:235-239.
- Orchard J, Seward H, McGivern J, Hood S. Intrinsic and extrinsic risk factors for anterior cruciate ligament injury in Australian footballers. *Am J Sports Med.* 2001;29:196-200.
- Risberg MA, Mork M, Jenssen HK, Holm I. Design and implementation of a neuromuscular training program following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2001;31:620-631.

38. Roberts D, Friden T, Stomberg A, Lindstrand A, Moritz U. Bilateral proprioceptive defects in patients with a unilateral anterior cruciate ligament reconstruction: a comparison between patients and healthy individuals. *J Orthop Res.* 2000;18:565-571.
39. Roberts D, Friden T, Zatterstrom R, Lindstrand A, Moritz U. Proprioception in people with anterior cruciate ligament-deficient knees: comparison of symptomatic and asymptomatic patients. *J Orthop Sports Phys Ther.* 1999;29:587-594.
40. Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med.* 1999;27:312-319.
41. Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J Sport Rehabil.* 1998;7:95-101.
42. Shiraishi M, Mizuta H, Kubota K, Otsuka Y, Nagamoto N, Takagi K. Stabilometric assessment in the anterior cruciate ligament-reconstructed knee. *Clin J Sport Med.* 1996;6:32-39.
43. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recordings of single limb stance. *Am J Sports Med.* 1984;12:185-188.
44. Vuillerme N, Danion F, Marin L, et al. The effect of expertise in gymnastics on postural control. *Neurosci Lett.* 2001;303:83-86.
45. Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports.* 1999;9:41-47.
46. Zatterstrom R, Friden T, Lindstrand A, Moritz U. The effect of physiotherapy on standing balance in chronic anterior cruciate ligament insufficiency. *Am J Sports Med.* 1994;22:531-536.
47. Zelisko JA, Noble HB, Porter M. A comparison of men's and women's professional basketball injuries. *Am J Sports Med.* 1982;10:297-299.

Appendix

Athletes completed 2 sessions from each of the 3 protocol sections (hip/pelvis/trunk strengthening and balance training, plyometrics and dynamic movement training, and resistance training) each week during the 6 week training program. (Abbreviations: r, recommended exercise repetitions; s, recommended exercise time [seconds]).

Section 1: Hip/pelvis/trunk strengthening and balance training sessions.

Exercises	Training Sessions											
	1	2	3	4	5	6	7	8	9	10	11	12
BOSU superman (right-left)	1 x 15 r	1 x 17 r	1 x 17 r	1 x 15 r	1 x 20 r	1 x 20 r	1 x 20 r	1 x 20 r	2 x 25 r	2 x 25 r	2 x 25 r	2 x 25 r
BOSU crunches	2 x 35 r	2 x 40 r	2 x 40 r	2 x 35 r	1 x 55 s	1 x 55 s	1 x 55 s	1 x 55 s				
BOSU double-leg perturbations	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s				
BOSU double-leg pick	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r				
Broad jump-stick landing	1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r	1 x 4 r	1 x 4 r	1 x 4 r	1 x 4 r				
Single-leg x hop (right-left)	1 x 3 r	1 x 4 r	1 x 4 r	1 x 3 r	1 x 5 r	1 x 5 r	1 x 5 r	1 x 5 r				
180° jumps stick landing	1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r								
BOSU both knees deep hold	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s								
BOSU both legs deep hold	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s								
BOSU jump stick landing	1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r								
BOSU swivel crunch (feet planted)	2 x 40 r	2 x 40 r	2 x 40 r	2 x 40 r								
Box drop stick landing	1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r								
Hop-stick landing (right-left)	1 x 5 r	1 x 5 r	1 x 5 r	1 x 5 r	1 x 6 r							
BOSU single-leg deep hold					2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s
BOSU V-sit toe touches					1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r
Double crunch					2 x 25 r	2 x 25 r	2 x 25 r	2 x 25 r	1 x 25 r			
180° jumps stick landing, medicine ball catch					1 x 6 r	1 x 6 r	1 x 6 r	1 x 6 r				
BOSU both knees deep hold, medicine ball catch					2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s				
BOSU swivel crunch (feet up)					2 x 30 r	2 x 30 r	2 x 30 r	2 x 30 r				
Box drop medicine ball catch					1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r				
Crossover hop-stick						1 x 12 r	1 x 12 r	1 x 12 r	1 x 12 r	1 x 12 r	1 x 12 r	1 x 12 r
BOSU 180° jumps stick landing									1 x 15 r	1 x 15 r	1 x 15 r	1 x 15 r
BOSU jump stick landing, medicine ball catch									1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r
BOSU partner toss (feet up)									2 x 30 s	2 x 30 s	2 x 30 s	2 x 30 s
BOSU single-knee deep hold									2 x 20 s	2 x 20 s	2 x 20 s	2 x 20 s
BOSU single-leg deep hold, multiple switches									2 x 30 s	2 x 30 s	2 x 30 s	2 x 30 s
BOSU single-leg pick (right-left)									1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r
BOSU double crunch										1 x 25 r	2 x 25 r	
BOSU hop stick landing (right-left)											1 x 8 r	1 x 8 r
BOSU opposite knee to elbow											1 x 25 r	2 x 25r

Section 2. Plyometrics and dynamic movement training.

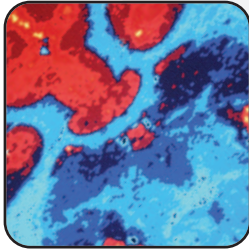
Exercises	Training Sessions											
	1	2	3	4	5	6	7	8	9	10	11	12
Wall jumps (ankle bounces)	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s
Squat jumps	1 x 10 s	2 x 15 s	1 x 15 s	2 x 15 s	1 x 15 s	1 x 15 s	1 x 10 s	1 x 10 s	1 x 10 s	1 x 10 s		
180° jumps (height)	1 x 15 s				1 x 15 s			1 x 15 s			1 x 15 s	
Barrier jumps (side to side)	1 x 10 s	1 x 10 s		1 x 10 s	1 x 10 s							
Bounding in place	1 x 20 s	1 x 20 s										
Box depth max vertical	1 x 10 r	1 x 10 r										
Box depth reaction	1 x 10 r	1 x 10 r										
Broad jump vertical	1 x 10 r	1 x 10 r										
Forward barrier hops with middle box	1 x 6 r	1 x 6 r										
Forward hops over barriers	1 x 6 r	1 x 6 r										
Lunge jump	2 x 10 s	2 x 10 s										
Tuck jump (with thighs parallel)	2 x 10 s	1 x 10 s	1 x 10 s	1 x 10 s								
180° jumps (speed)		1 x 15 s		2 x 15 s		1 x 15 s				1 x 15 s		1 x 15 s
Backward-forward box depth max vertical			1 x 10 r	1 x 10 r	1 x 10 r	1 x 10 r						
Barrier jumps (front to back)			1 x 15 s	1 x 15 s	1 x 15 s	1 x 15 s						
Bounding for distance			1 x 6 r	1 x 6 r	1 x 6 r	1 x 6 r						
Scissors jump			1 x 10 s	1 x 10 s								
Tuck jump (with butt kick)			2 x 10 s	1 x 10 s	1 x 10 s	1 x 10 s						
180° jumps, broad jump			2 x 15 s			1 x 15 s			1 x 15 s			
Forward barrier hops with staggered box			1 x 6 r	1 x 6 r			1 x 6 r	1 x 6 r				
Box depth max, vertical, reaction			1 x 10 r	1 x 10 r								
Broad jump, jump, vertical			1 x 10 r	1 x 10 r								
Zig-zag jumps over barriers			1 x 6 r	1 x 6 r								
Broad jump, jump, jump, vertical					1 x 10 r	1 x 10 r	1 x 6 r	1 x 6 r	1 x 6 r	1 x 6 r		
Hop, hop, hop-stick (right-left)					1 x 6 r	1 x 6 r	1 x 6 r	1 x 6 r				
Lateral barrier hops					1 x 6 r	1 x 6 r						
Lateral barrier hops with staggered box					1 x 6 r	1 x 6 r	1 x 6 r	1 x 6 r				
Power steps (right-left)					1 x 10 r	1 x 10 r						
Tuck jump (with abdominal crunch)					2 x 5 s	1 x 15 s	1 x 10 s	1 x 10 s	1 x 10 s	1 x 10 s		
Barrier jumps (front-to-back) speed							1 x 15 s	1 x 15 s				
Barrier jumps (side-to-side) speed							1 x 15 s	1 x 15 s				
BOSU 180° jumps stick landing							1 x 15 r	1 x 15 r				
Box depth 180°, box depth max, vertical							1 x 8 r	1 x 8 r	1 x 8 r	1 x 8 r		
Jump into bounding							1 x 6 r	1 x 6 r				
3 barrier hop, reaction (3-way)									1 x 9 r	1 x 9 r	1 x 9 r	1 x 9 r
Barrier hops flat (front-to-back) (right-left)									1 x 12 s	1 x 12 s	1 x 12 s	1 x 12 s
Barrier hops flat (side-to-side) (right-left)									1 x 12 s	1 x 12 s	1 x 12 s	1 x 12 s
Box depth, broad jump									1 x 8 r	1 x 8 r		
Crossover hop, hop, hop-stick (width)									1 x 10 r	1 x 10 r		
Multidirectional barrier hops									1 x 6 r	1 x 6 r		
Crossover hop, hop, hop-stick (distance)										1 x 0 r		1 x 10 r
Box depth, 180°, box depth, vertical, reaction											1 x 8 r	1 x 8 r

Section 2. Plyometrics and dynamic movement training. (cont'd.)

Exercises	Training Sessions											
	1	2	3	4	5	6	7	8	9	10	11	12
Box depth-180°-reaction											1 × 8 r	1 × 8 r
Broad jump, jump, jump, vertical, reaction											1 × 6 r	1 × 6 r
Forward/backward hops over barrier											1 × 6 r	1 × 6 r
Squat-tuck jumps											1 × 12 s	1 × 12 s

Section 3. Resistance training.

Exercises	Training Sessions											
	1	2	3	4	5	6	7	8	9	10	11	12
Lateral pulldown	2 × 12	2 × 12	2 × 12	2 × 12	2 × 10	2 × 10	2 × 8	2 × 8	1 × 8	1 × 8		1 × 8
Ankle, plantar-dorsi	1 × 12		1 × 12		1 × 12		1 × 12		1 × 12	1 × 12	1 × 12	1 × 12
Benchpress	2 × 12		2 × 12		2 × 12		2 × 12		3 × 12	3 × 12		3 × 12
Db hang snatch	2 × 12		2 × 12		2 × 10		2 × 8		2 × 8	2 × 5		3 × 5
Leg curl	2 × 12		2 × 12		2 × 10		2 × 8		3 × 8	3 × 5		3 × 5
Shoulder press	2 × 12		2 × 12		2 × 10		2 × 8		1 × 8	1 × 8		1 × 8
Squat	2 × 12		2 × 12		2 × 10		2 × 8		3 × 8	3 × 5		3 × 5
Back fly	2 × 12		2 × 12		2 × 12		2 × 12				1 × 12	
Bicep circuit	1 × 12		1 × 12		1 × 12		1 × 12				1 × 12	
Russian good mornings	2 × 12		2 × 12		2 × 12		2 × 15				1 × 15	
Ankle, eversion-inversion		1 × 12		1 × 12		1 × 12		1 × 12				
Cable rows		2 × 12		2 × 12		2 × 12		2 × 12				
Db incline		2 × 12		2 × 12		2 × 10		2 × 8			2 × 8	
Hang cleans		2 × 12		2 × 12		2 × 10		2 × 8			2 × 8	
Leg press		2 × 12		2 × 12		2 × 10		2 × 8			2 × 8	
Lunge circuit		1 × 12		1 × 12		2 × 10		1 × 8			1 × 8	
Shoulder circuit		1 × 12		1 × 12		1 × 10		1 × 8			1 × 8	
Straight-leg dead lift		2 × 12		2 × 12		2 × 12		2 × 12				
Tricep circuit		1 × 12		1 × 12		1 × 12		1 × 12				



Biodex Balance System SD

Reference Manual

4) Bibliography



STABILITY / BALANCE

ARNOLD, BL, et al.

NORMAL STABILITY PATTERNS AND RELATIONSHIP AS ASSESSED WITH THE BIODEX BALANCE SYSTEM

J of Athletic Training, Vol. 32 (2):S-25 / April-June 1997

Biodex #93-268

EXAMINATION OF BALANCE MEASURES PRODUCED BY THE BIODEX STABILITY SYSTEM

J of Athletic Training, Vol. 33(4):323-27, Dec. 1998

Biodex #93-287

AYDOĞ, E, et al.

EVALUATION OF DYNAMIC POSTURAL BALANCE USING THE BIODEX STABILITY SYSTEM IN RHEUMATOID ARTHRITIS PATIENTS

Abstract only - Clin Rheumatol, 2005, Oct 25:1-6

Biodex #93-104

DYNAMIC POSTURAL BALANCE IN ANKYLOSING SPONDYLITIS PATIENTS

Abstract only – Rheumatology (Oxford), 2005, Nov. 8

Biodex #93-105

BALLARD, T

PRODUCT PROFILE: THE BIODEX BALANCE SYSTEM

Biodex Medical Systems

Biodex #91-111

BEHAN, E

A COMPARISON OF A DYNAMIC BALANCE SYSTEM TO A STATIC FORCE PLAT SYSTEM FOR ORTHOPEDIC AND MUSCULOSKELETAL REHABILITATION

Biodex Medical Systems

Biodex #91-113

BLACKBURN, JT, et al.

BALANCE AND JOINT STABILITY:

THE RELATIVE CONTRIBUTIONS OF PROPRIOCEPTION AND MUSCULAR STRENGTH

J of Athletic Training, Vol. 34(2):S-30 / April-June 1999

Biodex #91-104

BLACKBURN, TA, et al.

SINGLE LEG STANCE: DEVELOPMENT OF RELIABLE TESTING PROCEDURE

Berkshire Institute of Orthopedic & Sports Physical Therapy, Wyomissing, PA

Biodex #93-207

CACHUPE, WJC, et al.

RELIABILITY OF BIODEX BALANCE SYSTEM MEASURES

Human Performance Dept. / San Jose State University / June 2000

Biodex #91-198

CAGGIANO, NA, et al.

THE RELATIONSHIP BETWEEN ANKLE KINESTHESIA AND PEAK TORQUE WITH
SINGLE LEG MULTIAXIAL PLATFORM STABILITY

J of Athletic Training, Vol. 34(2):S-31 / April-June 1999
Biodex #91-106

CAMPBELL, MH, et al.

THE CORRELATION BETWEEN ISOKINETIC STRENGTH MEASURES AND FUNCTIONAL PERFORMANCE IN AN ELDERLY
POPULATION

Biodex #93-293

CAVANAUGH, JT, et al.

BALANCE AND POSTOPERATIVE LOWER EXTREMITY JOINT RECONSTRUCTION

Orthopaedic Phys Therapy Clinics of No America; Vol.11:1, 75-99 - March 2002
Biodex #92-244

CLARK, S, et al.

GENERALIZABILITY OF THE LIMITS OF STABILITY TEST IN THE EVALUATION OF DYNAMIC BALANCE AMONG OLDER
ADULTS

Arch Phys Med Rehabil Vol 78:1078-1084, October 1997
92-269

DiCOSTANZA, K, et al.

EFFECT OF ADHESIVE MEDIAL LONGITUDINAL ARCH SUPPORT ON POSTURAL SWAY

J of Athletic Training / Vol. 36(2) (suppl) S66, April-June 2001
Biodex #92-227

DOVER, G, et al.

RELIABILITY OF INVERSION AND EVERSION PEAK TORQUE MEASUREMENTS FROM THE BIODEX SYSTEM 3 ISOKINETIC
DYNAMOMETER

J of Athletic Training / Vol. 35 (2) (suppl) / S-91 / April-June 2000
Biodex #91-185

FERRIS, CM, et al.

A COMPARISON OF STRENGTH, PROPRIOCEPTION, LAXITY, FLEXIBILITY, AND BALANCE BETWEEN BASKETBALL AND
NON-BASKETBALL COLLEGIATE FEMALE ATHLETES

J of Athletic Training / Vol. 35 No. 2 (suppl) / S38 / April-June 2000
Biodex #91-189

FINN, JA, et al.

STABILITY PERFORMANCE ASSESSMENT AMONG SUBJECTS OF DISPARATE BALANCING ABILITIES

Southern Connecticut State University, 501 Crescent St.,
New Haven, CT 06515 Phone: 203-392-6036
Biodex #93-286

FLYNN, WL, et al.

CHANGES IN DYNAMIC POSTURAL STABILITY FOLLOWING CRYOTHERAPY

J of Athletic Training, Vol. 32(2):S-6 / April-June 1997
Biodex #91-110

FREIDHOFF, G, et al.

PILOT ASSESSMENT OF THE BIODEX STABILITY SYSTEM WITH NORMALS:
TEST/RETEST AND DAY TO DAY RELIABILITY
University of Kentucky, Div. of P.T.,
(Med. Center Annex I, Lexington, KY)
Biodex #93-206

HINMAN, MR

FACTORS AFFECTING RELIABILITY OF THE BIODEX BALANCE SYSTEM:
A SUMMARY OF FOUR STUDIES
J of Sport Rehab, Vol. 9 (3):240-52, August 2000
Biodex #91-194

HORNYIK, ML, et al.

RELIABILITY OF LIMITS OF STABILITY TESTING: A COMPARISON OF TWO DYNAMIC POSTURAL STABILITY EVALUATION
DEVICES
J of Athletic Training, Vol. 36(2) (suppl) S78, April-June 2001
Biodex #92-229

HORODYSKI, MB, et al.

MEASUREMENTS OF DYNAMIC POSTURAL STABILITY, VISUAL SCANNING, AND MENTAL FLEXIBILITY IN COLLEGIATE
FOOTBALL PLAYERS
J of Athletic Training, Vol. 34(2):S85 / April-June 1999
Biodex #91-108

JORDEN, RA, et al.

THE INFLUENCE OF ANKLE ORTHOSES AND EXERCISE ON POSTURAL STABILITY
J of Athletic Training, Vol. 36(2) (suppl):S-78, April-June 2001
Biodex #92-228

LEONARD, K, et al.

CHANGES IN DYNAMIC POSTURAL STABILITY FOLLOWING CRYOTHERAPY TO THE ANKLE AND KNEE
J of Athletic Training, Vol. 34(2):S-68 / April-June 1999
Biodex #91-107

LEPHART, S, et al.

LEARNING EFFECTS AND RELIABILITY OF THE BIODEX STABILITY SYSTEM
Sports Medicine & Neuromuscular Laboratory,
Univ. of Pittsburgh / Pittsburgh, PA
Biodex #93-208

MAGILL, J, et al.

CHANGES IN DYNAMIC POSTURAL STABILITY WITH THE USE OF NEOPRENE SLEEVES
J of Athletic Training, Vol. 34(2), S-30 / April-June 1999
Biodex #91-103

MALLEY, C, et al.

THE EFFECTS OF THREE DIFFERENT ANKLE TRAINING PROGRAMS ON FUNCTIONAL STABILITY AND SINGLE-LIMB
STANCE
J of Athletic Training, Vol. 34(2), S-30 / April-June 1999
Biodex #91-105

NELSON, AJ, et al.

USING THE BIODEX UNWEIGHING SYSTEM, BALANCE SYSTEM AND GAIT TRAINER IN AN INTEGRATED REHABILITATION PROGRAM

Abstract, May 2001

Biodex #92-217

PATERNO, MV, et al.

THE RETURN OF NEUROMUSCULAR COORDINATION AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Biodex Medical Systems

Biodex #91-112

PATERNO, MV, et al.

NEUROMUSCULAR TRAINING IMPROVES SINGLE-LIMB STABILITY IN YOUNG FEMALE ATHLETES

JOSPT, Vol. 34 (6):305-316, June 2004

Biodex #92-245

PINTO, KK, et al.

THE EFFECTS OF ANKLE TAPING AND BALANCE ACTIVITIES ON BIODEX STABILITY MEASUREMENTS

J of Athletic Training, Vol. 34(2), 5-30 / April-June 1999

Biodex #91-102

RIEMANN, BL, et al.

COMPARISON OF THE ANKLE, KNEE, HIP, AND TRUNK CORRECTIVE ACTION SHOWN DURING SINGLE-LEG STANCE ON FIRM, FOAM, AND MULTIAXIAL SURFACES

Arch Phys Med Rehabil, Vol. 84: 90-95, January 2003

92-237

ROZZI, SL, et al.

KNEE JOINT LAXITY AND NEUROMUSCULAR CHARACTERISTICS OF MALE AND FEMALE SOCCER AND BASKETBALL PLAYERS

American J Sports Med, Vol. 27(3):312-319 / May-June 1999

Biodex #91-101

SCHMITZ, RJ, et al.

INTERTESTER AND INTRATESTER RELIABILITY OF A DYNAMIC BALANCE PROTOCOL USING THE BIODEX STABILITY SYSTEM

J of Sports Rehab 7:95-101, 1998

Biodex #93-271

SIERI, T and BERETTA, G.

FALL RISK ASSESSMENT IN VERY OLD MALES AND FEMALES LIVING IN NURSING HOMES

Disability and Rehabilitation: 2004, Vol. 26, No. 12:718-723

Biodex #93-106

SIUDMAK, PG, et al.

CORRELATIONS BETWEEN DYNAMIC BALANCE PERFORMANCE AND ISOKINETIC FUNCTIONS OF KNEE FLEXOR/EXTENSOR MUSCLES IN THE ELDERLY

Biodex #93-295

TESTERMAN, C, et al.

EVALUATION OF ANKLE INSTABILITY USING THE BIODEX STABILITY SYSTEM

Foot Ankle Int 1999 May, 20(5):317-21 (ISSN: 1071-1007)

Biodex #91-116

WILKERSON, GB

DYNAMIC JOINT STABILITY: MECHANICAL AND NEUROMUSCULAR INTER-RELATIONSHIPS

Biodex Medical Systems

Biodex #91-109

REV. 12/05-DV