STRENGTH TRAINING ON POSTURAL CONTROL IN OLDER ADULTS

INFLUENCE OF STRENGTH TRAINING ON POSTURAL CONTROL IN THE OLDER ADULT

BY

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ABSTRACT

The present study was designed to investigate the effects of a progressive strength training program on quiet postural sway and stability limits in healthy males (n=8) and females (n=12) aged 60-80 years. The ability of the subjects to utilize visual information (eyes open vs. eyes closed) to improve quiet postural sway and stability limits was also examined. Vision, was found to significantly improve quiet postural sway (lat and a-p) and stability limits (a-p). Vision improved stability limits (lat) for the male subjects but not for the female subjects. The strength training did not significantly improve any of the balance measures but a gender by training interaction was found for quiet postural sway (normalized to stability limits) in the a-p direction. The male subjects quiet postural sway decreased after the strength training and their stability limits increased. The greatest improvements in balance were noted for the subjects who had substantially higher baseline levels to begin with. Exercise was found to improve muscle strength and this increase may have contributed to the improvements in balance noted.

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INTRODUCTION

The effects of strength training on postural stability and balance in the older adult population has not been thoroughly investigated. With increasing age, balance becomes a major concern as the incidence of falls and instability increase. Poor balance control systems in the older adult have been equated with 1) large excursions of the centre of pressure of ground reaction forces beneath the feet in static balance tests and 2) decreased stability limits. The extent to which exercise or programs of physical activity and exercise can either prevent a decline in postural control or enhance balance is yet unclear (Berg, 1989). Subjects have been selected from the participants in a study of "Longitudinal Strength Training in the Elderly" at McMaster University (McCartney, et al., in press). The male and female subjects ranged from 60-80 years of age and were enrolled in a 22 month progressive weight-lifting training program. This study has both theoretical and clinical importance as it attempts to determine if an overall strength training program can improve the postural control in the older adult. If reduced strength is a factor in the deterioration of postural control then a strength training program may successfully improve balance and postural control in the older adult.

OBJECTIVES

The objectives of this study are to:
1) assess quiet postural sway and the effects of vision (eyes open and eyes closed) during normal quiet standing in the older adult;

2) determine the stability limits in the older adult and the influence of vision (eyes open and eyes closed) on stability limits;

3) assess the effects of a progressive weight-lifting program on quiet postural stance and stability limits in the older adult; and

4) assess the test-retest reliability of quiet postural sway and stability limits in the older adult.

SIGNIFICANCE

This will be the first study of postural control investigating the effects of a strength training program on balance in the older adult. The study will gain insight into the components and systems involved in balance control in the older adult. If strength training can improve postural control in this population, more comprehensive and effective programs can be designed and utilized to optimize balance and stability in the older adult.

HYPOTHESES

The hypotheses to be tested are:
1) the ratio of quiet postural sway to stability limits will decrease following the strength training program of the older adults, (i.e. stability limits will increase while quiet postural sway will decrease following the strength training program in the older adult) and

2) visual input will help the older adult to obtain greater stability limits and visual information will be stabilizing in quiet postural sway.

REVIEW OF LITERATURE

Balance is important for each person's independence as it is responsible for achieving upright posture and allows the body to move efficiently in the upright stance. An individual's balance control system must react and make adjustments to both voluntary movements and externally induced stresses. Independence, ability to perform activities of daily living, mobility and safety all rely upon the balance and balance control systems of the individual. The systems that contribute to balance are the sensory, cognitive, central integrative, neuromotor and musculoskeletal systems (Speechley & Tinetti, 1990).

With increasing age, after 60 years, balance becomes a major concern as there is an increase in the incidence of falls in the older adult population (Kippenbrock & Soja, 1993; Speechley & Tinetti, 1991; Prudham & Evans, 1981; Gryfe, Amies & Ashley, 1977). The steady increase in the number of falls with aging can be seen as one in every three individuals over the age of 65 and one in every two individuals over the age of 80 may experience a minimum of one fall per year (Tinetti, Speechley & Ginter, 1988; Campbell, et al., 1981; Prudham & Evans, 1981). The frequency of falls rise with increasing age and is higher in women than in men of the same age (Overstall, 1980; Overstall, et al., 1977; Droller, 1955). The magnitude of the problem of falling among the older adult is increasing as the number of older adults in the population is rising. A high rate of injury, morbidity and mortality are a result of falls in the older adult population (Pentland, Jones, Roy & Miller, 1986; Gryfe, Amies & Ashley, 1977). Falling may also result in psychological trauma, loss of self-esteem and/or fear of falling again. Both the physical and psychological effects of falling may lead to a decrease in mobility and a subsequent decline in activities of daily living and overall functional independence (Tideiksaar & Kay, 1986; Overstall, 1980). Clearly, the prevention of instability, loss of balance and falls, with their potential physical and psychological trauma, are of major concern to the older adult.

To prevent falls in the older adult population, one must understand the underlying reasons. Both intrinsic and extrinsic factors may precipitate a loss of balance. Extrinsic factors that may be to blame for a loss of balance are slippery surfaces, curbs, stairs, objects on the ground, pets, etc.. (Hayes, 1993). Intrinsic factors that contribute to the increased incidence of falls in the older adult include normal physiologic ageing, pathologic diseases and the effect of various medications (Kippenbrock & Soja, 1993).

The fundamental decrease in an individual's balance and postural control systems that lead to instability are often age-related. Examples of normal ageing changes that may adversely affect postural stability are decreased muscular strength and endurance, slowed reaction time, limited range of motion, and decreased sensory perception (Kippenbrock & Soja, 1993). Lipsitz et al. (1994) found an inverse relationship between falls and quadriceps muscle strength in the American subjects but not in the Japanese group. Muscle weakness may be an important predisposing factor leading to falls but may be compounded by other factors such as culture, environment, and pathology (Lipsitz et al., 1994). The changes in the balance control systems and factors leading to instability would operate in an additive fashion. Both the number of systems and the severity of the loss of the systems through ageing do correlate directly with instability and falls in the older adult population (Speechley & Tinetti, 1990). To improve any of the factors above may enhance the stability of older adults.

Static Balance Test

One of the most common techniques for assessing the postural control system has been the use of static balance tests. Static balance tests assess the ability of an individual to maintain an upright stance. The support configuration of the test may vary as the subjects may be asked to stand on both feet (feet together, feet a prescribed distance apart, Romberg Stance, etc.) or on one foot. Visual conditions of the test also may be altered as the subject may be required to stand with eyes open (EO) or eyes closed (EC) to assess the effects of vision. The maintenance of the upright posture depends on sensory input from vision, vestibular and somatosensory systems, muscular strength and central nervous system control.

Postural sway is the continuous shifting of the centre of gravity (CG) in the body that all human beings are subject to. Postural sway is often described by the displacement of the centre of pressure of ground reaction force beneath the feet (CP) obtained from standing on a force plate (Patla, Frank & Winter, 1990). Sheldon (1963) defined sway as a "well-known phenomenon which is caused by the constant small deviations from the vertical and their subsequent correction to which all human beings are subject when standing upright".

The displacement or excursion of the CP reflects the controlling element to correct the imbalance of the CG. The CP recordings are an expression of the motor signal which controls the moving CG. To maintain an upright stance the CP controls the CG so that the CG does not move outside the borders of the feet. If the CG is allowed to reach the borders of the feet the CP would not be capable of moving outside of the CG in order to accelerate it back towards a more central and stable position. The dynamic range of the CP must be greater than that of the CG to maintain postural stability (Winter, 1992).

In static balance tests, large excursions of an individual's CP are equated with a poorer postural control system (Patla, Frank & Winter, 1990). The control of stance appears to be age related as the excursions of the CP tend to be larger in the very young and the very old (Hytonen, Pyykko, Aalto & Starck, 1993). Children have been found to have decreasing excursions of CP with increasing age in both anteroposterior (a-p) and lateral (lat) directions (Starkes, Riach & Clarke, 1992; Riach & Hayes, 1987; Hasselkus & Shambes, 1975). It has been well documented that excursions of CP increase with age in older adults (Stelmach, et al., 1989; Hayes, Spencer, et al., 1984; Zernicke, Gregor & Cratty, 1982; Holliday, Dornan & Fernie, 1978; Overstall, et al., 1977; Hasselkus & Shambes, 1975; Sheldon, 1963). Excursions of CP when tested during quiet stance were found to significantly increase in people who had fallen because of loss of balance (Lord, McLean & Stathers, 1992; Gehlsen & Whaley, 1990; Brocklehurst, Robertson & James-Groom, 1982; Overstall et al., 1977).

Stability Limits

The test of stability limits is another technique for assessing postural control. Stability limits of an individual encompasses the area with the feet (base of support) that can be utilized to maintain equilibrium by means of torques. It is the boundaries of the area over which the CP may be safely moved that represent the individual's maximum stability limits. Individual stability limits are strongly determined by the forces required to maintain balance as well as the rate at which the nervous system and musculature can deliver corrective forces (McCullum & Leen, 1989; Dettmann, Linder & Sepic, 1987). The ankle strategy is the most commonly used postural movement pattern (Horak, Shupert & Mirka, 1989). The body's CG is shifted by rotating the body about the ankle joints with minimal movement of hip or knee joints. Upright stance is structured by the stability limits that are invariant with respect to the body's base of support. The test of stability limits as a condition is biomechanically more challenging and taxing for the postural control system than quiet standing.

Children below the age of seven years, have been shown by Riach & Starkes (1993) to possess significantly smaller stability limits (normalized for foot size) than children older than seven years of age and adults. It is at seven years of age that children are able to utilize the same percentage of their base of support as adults. Younger children (<7 years) may possess insufficient strength and/or neural control to maintain stability when the vertical line of the individual's centre of gravity approaches the limits of the anatomical base of support (Riach & Starkes, 1993).

Young adults are able to utilize a large percentage of their base of support. Whitney (1962) found that the male subjects' stability limits extended approximately two-thirds of the length (a-P direction) of their base of support. Murray, Seireg & Sepic (1975) found that adult males (40-70 years) on average used 54% (a-p) and 59% (lat) of the anatomical base. Lee and Deming (1987) found the stability limits of adults (<60 years) to have ranges from 35-95% of their anatomical base.

There appears to be a concomitant decrease in stability limits with ageing. Functional base of support in the a-p direction was shown to decrease from 60% to 42% for subjects under the age of 60 and over the age of 60 respectively (King, Judge & Wolfson, 1994). Lee and Deming (1987) found that the stability limits of individuals over 60 years of age dropped to 15-65% of their anatomical base of support. Murray et al. (1975) indicated that the younger adults had the largest area of stability over which weight could be shifted and controlled as compared to the older adults who had the smallest area.

The decrease of stability limits with increasing age may be a result of a number of factors. A limited amount of strength and/or neural control and orthopaedic pathologies may influence an individual's stability limits. Sensory inputs may be processed less sensitively and/or more slowly thus affecting the postural control system. Confidence and/or fear of falling may deter an older person from extending their CG closer to the edges of their anatomical base. By keeping the CP further inside the edges of the anatomical base, the older person allows themselves a wider margin of error to compensate for a diminished postural control system. The smaller stability limits as previous experienced has influenced the controlling mechanisms to avoid risks.

Biomechanics of Quiet Postural Stance and Stability Limits

The maintenance of postural control in the upright stance requires a series of muscular contractions that produce moments about the joints of the musculo-skeletal system in order to counteract the force of gravity acting on the body. In quiet postural stance the CG and CP are closely aligned by the continuous contraction of the postural control muscles (Riach & Starkes, 1993). (Figure 1).

To obtain maximum stability limits, the individual is asked to lean as far as possible in all four directions and hold each maximum position for 2-3 seconds. In the forward position, (Figure 2) the forward torque (M_{CG}) is equal to the weight of the subject (w) multiplied by the perpendicular distance (CG_y) of the line of CG to the axis of rotation (ankle). As the forward lean increases the distance CG_y increases thus increasing the forward torque. In order to maintain the forward lean position the backward torque must equal the forward torque. The backward torque (M_{Fm}) is equal to the force of the muscles (Fm) times the moment arm (d). The moment arm is relatively small and decreases as the forward lean increases. Therefore, the force of the muscles must be greatest when obtaining maximum forward lean. Muscular force is needed to produce maximum stability limits

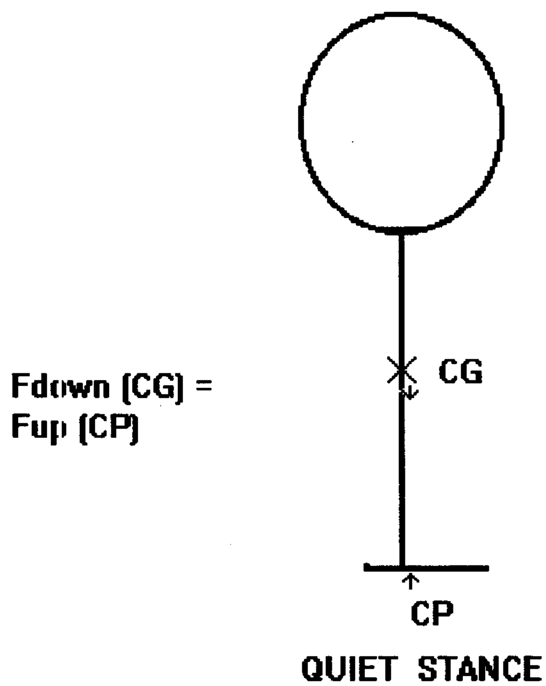

Figure 1: The alignment of the CG and CP in quiet postural stance. To maintain equilibrium the force downward (Fdown) must equal the force upwards (Fup).

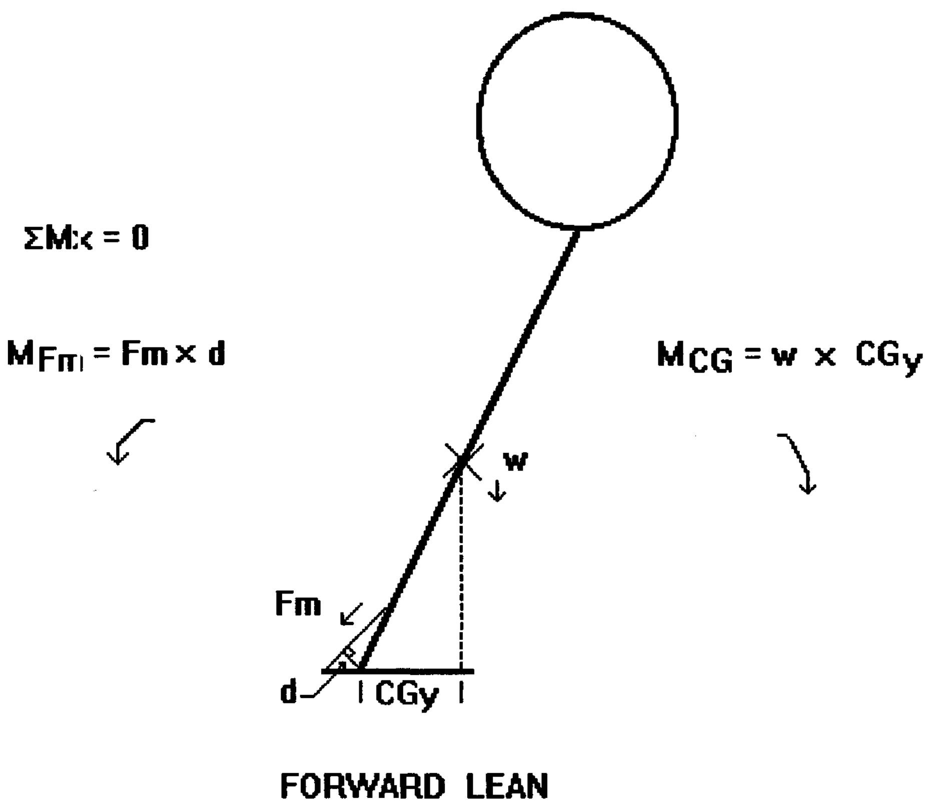

Figure 2: The moments of force (torque) in the maximum forward lean position. The forward torque (M_{CG}) is equal to the weight of the subject (w) times the perpendicular distance to the axis (CGy). The backwards torque (M_{Fm}) is equal to the force of the muscles (Fm) times the moment arm (d).

in all four directions to counteract the torque caused by gravity. For this reason stability limits may be limited by muscle strength.

Vision and Balance

Vision is an integral component of the maintenance of stance and balance (Lord, Clark & Webster, 1991); Dornan, Fernie & Holliday, 1978; Lee & Lishman, 1975). It provides information about 1) the position and movement of the head in relation to the visual field and 2) the body parts in relation to each other and external objects. The eye makes vision possible by transforming light energy into neural impulses to detect self-motion and object-motion. Vision is seen as dominant among the senses in the control of posture in many situations (Paulus, Straube & Brandt, 1984). Vision has been shown to take precedence over sensory information provided by other modalities (Cohn & Lasley, 1985; Straube, et al., 1988).

There is much information suggesting that visual function is affected by age. Visual acuity and contrast sensitivity both decline with age as the eyes undergo many age-associated changes such as decreased curvature of the cornea, reduced pupil size, increased lens thickness, opacity and yellowness (Lord, Clark & Webster, 1991; Sekular, Hutman & Owsley, 1980). The importance of visual information to postural control is greater in the older adults than in any other age group, even with the decline in the visual system with age (Hytonen et al., 1994; Pyykko, et al., 1988; Straube et al., 1988). The visually guided postural reflexes operate slowly and therefore may not react quickly enough to prevent a loss of balance and subsequently a fall in the older adult (Hytonen et al., 1994).

Evidence has shown that both visual function and postural stability are affected by age (Manchester, Woollacott, Zederbauer-Hylton & Marin, 1989; Ring, Nayak & Isaacs, 1989). The relationship between age-related declines in vision and postural stability (quiet postural stance and stability limits) remains unclear.

Strength Training and Balance

The effects of strength training on stability limits and quiet postural stance have not been previously studied. The main focus of this study will be to assess the effect of a strength training program has on the stability limits and balance in the older adult population. It is hypothesized that by increasing leg strength and overall strength, the older adult will be able to obtain greater maximum stability limits. This increase in stability limits may be attributed to the absolute gains in muscular strength. An increase in the individual's confidence also may improve stability limits which may be a secondary resultant of the weight training program.

Changes in the Body with Ageing

With ageing there are numerous changes that occur in the body. An increase in body mass, an increase in adipose tissue, a decrease in lean body mass and loss of bone mass tend to occur after the late 60's or 70's (Kenney, 1985). The most striking feature of old age is the atrophy of skin and muscle together with slowness and impairment of movements. A decline in strength, plus a decrease in fine coordination accompanied by an increase in reaction time are the major causes of the decline in motor performance in old age. Muscular weakness found in the older adult can be attributed to loss of muscle mass and contractility (Overend et al., 1992). The muscle fibre atrophy seen in the older adult results from a decrease in the number of muscle fibres, proliferation of the T-tubules and sarcoplasmic reticulum systems, increase in the number of nuclei, increase in DNA concentration and/or alterations in end-plate structure (Gersten, 1991; Campbell, McComas & Petito, 1973). The decline in muscle fibre area is due to the significant decline in type II muscle fibre with increasing age (Poggi, Marchetti & Scelsi, 1987; Larsson, Grimby & Karlsson, 1979). Aniansson et al. (1978) reported selective type II atrophy as being related to the decrease in muscle strength accompanying the ageing process.

Exercise and Strength Training in the Older Adult

Previous weight training programs have been successful in increasing overall strength in older adults. Mortiani and deVries (1980) found significant increases in strength in response to a progressive weight training program after eight weeks in a group of older adults. The capacity for increasing muscle mass is found to be retained in old age. Furthermore, older adults can obtain marked gains in muscular strength with training (Judge, Whipple & Wolfson, 1994; Agre, et al., 1988; Frontera, et al., 1988).

Physical activity and exercise may lead to increased stability in the older adult population. The extent to which exercise or programs of physical activity and exercise can either prevent a decline in postural control or enhance balance is as yet unclear (Berg, 1989). The type, intensity and duration of the exercise program may have a profound effect on the balance or improvement of balance in the older adult. Petrella, Cunningham & Smith, (1989) suggest that older adults who are institutionalized and show significant losses of muscle mass, may improve their immediate postural control by participating in regular strength exercises and thus aid in the prevention of instability and falls.

A controlled study to assess the feasibility of testing an exercise program as a means of improving balance in aged women was undertaken by Lichtenstein et al. (1989). Twenty-four and Twenty-six older adult women (>65 years of age) served as the exercise and control groups respectively. The exercise sessions were provided in one-hour sessions, three times a week for sixteen weeks. The sessions consisted of stretching, static balance exercises, active balance exercises, response exercises, walking and cool-down. The study was unable to detect a consistent change in balance measure between exercise and control groups but demonstrated the feasibility to test exercise and its effect on balance in older adults. The findings that sway was not significantly less in the exercisers than the nonexercisers is consistent with a study by Crilly et al. (1989). Crilly et al. (1989) found no difference in quiet postural sway between the exercise group and the nonexercise group but their results may be attributed to the relatively undemanding exercise program used. Inadequate duration or type of exercise program may be a cause of the insignificant results obtained. The optimum exercise regiment for improving balance in the older adult has yet to be defined (Lichtenstein, et al., 1989).

Studies to assess postural stability in physically active and physically inactive older adults found a trend of increased postural stability for the active subjects (Speechley & Tinetti, 1991; Gehlsen & Whaley, 1990). Hoy and Marcus (1992) found a significant increase in muscle strength and changes in movement strategy when rising from a chair in the elderly women after a strength training program. It was suggested by Hoy and Marcus (1992) that increased muscular strength favours static and dynamic stability in the older female. A physically active lifestyle appears to be beneficial in maintaining postural stability and balance.

Muscle weakness has been shown to occur with ageing and also contributes to the deterioration of posture and balance. Exercise strategies that can reverse the age-associated decline in muscle force may have the potential to reduce postural instability and increase functional independence. Lord, Caplan & Ward (1993) found that exercise may play a role in contributing to stability and may also help prevent falls in older women. Exercise was found to improve muscle strength and reaction time and it helped the reduction of quiet postural sway when peripheral sensation and ankle support was reduced (Lord, Caplan & Ward, 1993). This study will look at the effects of an overall progressive strength training program on both quiet postural stance and stability limits in the older adult. The study will show if there is a correlation with an increase in strength in the older adult and improved balance.

The effects of weight training on balance in the older adult has both scientific and clinical importance as it looks towards a better understanding of the ability to alter or prevent a decline in postural control and balance. Future research may lead to an optimal strength training or exercise program so that the older adult population will reap the rewards and scientists will have a better comprehension of the effects of training on postural stability and balance.

METHOD

SUBJECTS

Twenty healthy older adults ($\geq$60 years of age, 10 males and 10 females) with no known neurological or physical disorders that would affect postural control comprised the subject group for the study. The age distribution and physical characteristics of the female and male subjects are recorded in table 1 and 2, respectively. The subjects were fully informed about the testing procedures and were required to sign a consent form prior to the participation in the study. The subjects were selected from a group of older adults that were participating in the "Longitudinal Study of Strength Training in the Elderly" (McCartney et al. in press) that was being conducted in the Department of Kinesiology and the Department of Medicine at McMaster University.

TESTING PROCEDURES

The subjects were asked to stand with shoes off and feet together (medial borders touching) on a force platform

TABLE 1: Physical Characteristics of the Female Subjects (n=12)

Variable	Mean	Standard Deviation	Range
age pretest (years)	67.17	4.15	59.5 - 73.9
age posttest (years)	67.97	4.15	60.3 - 74.7
mass pretest (kg)	63.38	9.00	53.0 - 76.4
mass posttest (kg)	64.14	9.54	50.8 - 79.4
height (cm)	161.46	6.46	151.0 - 172.0
foot length (cm)	23.82	1.23	21.8 - 26.1
feet width (cm)	18.46	0.79	17.2 - 19.9

TABLE 2: Physical characteristics of the Male Subjects (n=8)

Variable	Mean	Standard Deviation	Range
age pretest (years)	67.98	4.51	61.6 - 75.9
age posttest (years)	68.78	4.51	62.4 - 76.7
mass pretest (kg)	82.24	6.47	75.9 - 95.0
mass posttest (kg)	82.21	6.33	73.7 - 93.9
height (cm)	173.94	5.03	166.0 - 180.5
foot length (cm)	26.48	0.70	25.2 - 27.5
feet width (cm)	19.65	0.94	17.9 - 20.7

for four trials of thirty seconds. The feet together stance was selected as it normalized the type of stance used by each individual. In the first test the subjects were instructed to stand as still as possible (quiet stance), once with eyes open (EO) and once with eyes closed (EC). The order of testing for EO and EC in the test was randomized across subject and a short rest period (~2 min.) separated the two trials. To assess the effects of vision on quiet postural sway the calculation of Romberg quotients (RQ) have been utilized (Njiokiktjien & deRijke, 1972). Romberg quotients (expressed as a percentage) may be calculated by dividing the standard deviation of the centre of pressure about the mean position (RMS value) of the eyes closed test condition by the standard deviation of the signal about the mean position (RMS value) of the eyes open test condition, multiplied by 100. An RQ value of greater than 100% indicates that vision has a positive effect on the stability of the stance whereas a value of less than 100% indicates that vision has a negative effect on the stability of the stance.

In the second test the subjects were asked to sway as far as possible forward, backward, left and right (stability limits). Again this test was performed once with EO and once with EC and the order of testing for visual condition was randomized across subjects. The subjects were required to maintain the soles of their feet in complete contact with the force platform throughout the thirty second testing periods. If the subject did not maintain complete contact with the force platform or lost their balance the test was aborted and then reperformed after a short rest period. The subjects proceeded first forward through the sequence and then backwards through the sequence, holding each extreme position for approximately two to three seconds.

Anthropometric measures of height, mass and feet size were recorded. A tracing of the subject's feet (feet together) onto a piece of paper enabled the calculation of the individual's foot length and feet width. The measured feet dimensions enabled the normalization of the results (stability limits in both anteroposterior and lateral directions) by dividing each subject's ranges by the appropriate base of support (BOS) dimension. The normalization served to express the measured stability limits as a fraction of the maximum possible displacement and thereby allowing relative stability limits to be compared for subjects of differing body dimensions.

EQUIPMENT

The subjects stood on a strain gauge force platform (AMTI Model CR6-5-1) that measured the subject's ground reaction force in the vertical (Fz) direction and moments of force (Mx and My) about the lateral and anteroposterior axes. The force and moment of force signals were conditioned and amplified (AMTI SGA 6-3 Signal Conditioner/Amplifier) prior to A/D conversion at a sampling frequency of 30 Hz. (910 data samples per trial; one sample every .033 sec.). The centre of pressure of ground reaction forces (CP) can be calculated for both lateral (lat) and anteroposterior (a-p) planes.

$$CPy = \frac{Mx}{Fz} \qquad CPx = \frac{My}{Fz}$$

where CPy=y coordinate of the centre of pressure (a-p)

CPx=x coordinate of the centre of pressure (lat)

The x-y movements of the CP were recorded and the ranges in the a-p and lat directions were measured for each thirty second trial. Data were collected and stored on computer discs to be analyzed.

EXERCISE PROGRAM

The exercise program encompassed the first ten months of the two year program that the subjects were partaking in. Table 3 illustrates the ten month strength training program. During the strength training part of the program the subjects trained twice a week and completed the various strength training exercises: bench press, single arm military press, single arm curls, lateral pull downs, leg press, ankle plantarflexion, ankle dorsiflexion and sit-ups. Strengthening at the ankle joint was of major importance to this study. Ankle plantarflexion was limited by leg press strength as it was completed in the same position as the leg press during full extension. For further detail on the training, refer to McCartney et al. (in press). Table 4 indicates the prime muscles involved in each particular exercise. The subjects were instructed to warm-up and cool-down before and after the strength training program. Increasing percentages of each

Table 3: Weight Training Sessions (10 months, 2 times per week)

Session #	Repetitions	Sets	% of 1 RM
1-4	10 (arms) 10 (legs)	2	40
5-8	10 (arms) 10 (legs)	3	40
9-12	10 (arms) 10 (legs)	3	50
	reevaluate 1 RM in the 12th session		
13-24	10 (arms) 10 (legs)	3	60
	reevaluate 1 RM in the 24th session		
25-36	10 (arms) 10 (legs)	3	60
	reevaluate 1 RM in the 36th session		
37-48	10 (arms) 12 (legs)	1	60
	plus 10 (arms) 12 (legs)	2	70
	reevaluate 1 RM in the 48th session		
49-60	10 (arms) 12 (legs)	3-4	70
	reevaluate 1 RM in the 60th session		
61-72	10 (arms) 15 (legs)	1-2	70
	plus 10 (arms) 15 (legs)	1-2	80
	reevaluate 1 RM in the 72nd session		
73-84	10 (arms) 15 (legs)	1-2	70
	plus 10 (arms) 15 (legs)	1-2	80
	reevaluate 1 RM in the 84th session		

*from "Longitudinal Study of Strength Training in the Elderly" (McCartney et al. in press)

Table 4: Exercises and Prime Muscles Involved in the Strength Training Program

Exercises	Prime Muscles Involved
bench press	-pectoralis major, triceps, deltoid
single arm military press	-triceps, deltoid, pectoralis major
single arm curl	-biceps, brachioradialis, brachialis
lateral pull down	-latissimus dorsi, pectoralis major, biceps
leg press	-quadriceps, gluteal muscles
ankle plantarflexion	-gastrocnemius, soleus
ankle dorsiflexion	-tibialis anterior
sit-ups (curl-up - body weight as resistance)	-abdominal muscle, hip flexors

repetition maximum (1RM) in the various weight training exercises were utilized: bench press, leg press, military press, arm curls, ankle plantar flexion and ankle dorsiflexion. One repetition maximum (1RM) is the greatest amount of weight that an individual can lift in one attempt.

The postural testing procedure was performed prior to the subject's initiation into the training program and immediately following the first ten months of their training.

DESIGN AND ANALYSIS

A comparison between pretest and posttest investigated the effects of the strength training program on postural control (quiet stance and stability limits) in the older adult. Manipulation of visual condition (EO & EC) tested the influence of vision on postural control.

Simple Pearson correlation coefficients were utilized to determine the relationship between the variables in both the quiet stance test and the stability limits test. Variables for inclusion in regression analysis to predict quiet stance and stability limits were: gender, height, weight, foot length, feet width, 1RM (bench press, arm curl, military press, ankle dorsiflexion and plantarflexion).

Separate (2x2x2) (pretest/posttest x gender x visual test condition) repeated measures analysis of variance were performed on each dependent variable to test for significant differences (tables 5,6 & 7). Post hoc analysis were used to determine differences between experimental conditions where statistical significance was found. Statistically significant differences were accepted at a probability level of alpha = 0.05.

REPRODUCIBILITY TEST

In addition, a control group was used to measure test-retest reliability. Ten older adults (5 females and 5 males) (not involved in the strength experiment), mean age similar to the experimental group (69.92 ± 8.91) were tested on both quiet postural sway and stability limits with one week separating the test and the retest. The testing procedure was identical to the balance testing that occurred with the original subjects (see page 21). Intraclass correlation coefficients were utilized to assess the reproducibility of each test.

Table 5: Variables - Quiet Stance

Independent Variable	Level
Testing	a) pretest b) posttest
Gender	a) males b) females
Visual Test Condition	a) EO (eyes open) b) EC (eyes closed)

Dependent Variables	Level
CP (cm)	a) CPx - magnitude of quiet postural sway in the lateral direction b) CPy - magnitude of quiet postural sway in the anteroposterior direction

Table 6: Variables - Stability Limits

Independent Variables	Level
Testing	a) pretest b) posttest
Gender	a) males b) females
Visual Test Condition	a) EO (eyes open) b) EC (eyes closed)

Dependent Variables	Level
Range (cm)	a) Range(x) - range of sway in the lateral direction b) Range(y) - range of sway in the anteroposterior direction
Range/BOS (%)	a) Range(y)/BOSy - lateral range of sway relative to support base width b) Range(x)/BOSx - anteroposterior range of sway relative support base length

Table 7: Variables - Ratio Quiet Postural Sway : Stability Limits

Independent Variables	Level
Testing	a) pretest b) posttest
Gender	a) males b) females
Visual Test Condition	a) EO (eyes open) b) EC (eyes closed)

Dependent Variables	Level
QPS:SL	a) QPS:SL(x) - magnitude of quiet postural sway: range in stability limits in the lateral direction b) QPS:SL(y) - magnitude of quiet postural sway: range in stability limits in the anteroposterior direction

RESULTS

Quiet Postural Stance

Tables 8 and 9 indicate the raw (cm) mean, standard deviation and range of the quiet postural sway measures both before and after the 10 month strength training program. To compare stability across subjects, sway measures (cm) were normalized to foot size (length and width) and expressed as a percentage. Three-way analysis of variance (1 between/ 2 within factors: gender/ training & vision) were conducted. Postural sway normalized for foot size in the lat. and a-p direction (CPx and CPy) were utilized as the dependent variables. Figures 3 and 4 graphically display the quiet postural sway measures (normalized) for each condition.

A main effect for gender was found for quiet postural sway in the a-p direction ($p=0.046$) but not in the lat. direction ($p=0.197$). The male subjects had greater quiet postural sway (normalized to foot size) than their female counterparts in the a-p direction for both visual and training conditions (see figure 4).

A main effect for vision was found for both quiet postural sway (normalized) in both the lat. and a-p directions

TABLE 8: Quiet Postural Sway Measures - Female Subjects (n=12)

Variable	Mean (cm)	Standard Deviation (cm)	Range (cm)
CPx in EO pretest	2.25	0.65	1.30 - 3.60
CPx in EO posttest	2.37	0.78	1.40 - 3.80
CPx in EC pretest	2.94	0.71	2.10 - 4.50
CPx in EC posttest	3.10	0.97	1.40 - 4.50
CPy in EO pretest	2.02	0.63	0.80 - 3.40
CPy in EO posttest	2.24	0.69	1.40 - 3.40
CPy in EC pretest	2.63	0.95	1.65 - 4.70
CPy in EC posttest	2.68	0.71	1.90 - 4.30

TABLE 9: Quiet Postural Sway Measures - Male Subjects

Variable	Mean (cm)	Standard Deviation (cm)	Range (cm)
CPx in EO pretest	2.59	0.57	1.80 - 3.40
CPx in EO posttest	2.58	0.51	2.00 - 3.30
CPx in EC pretest	3.63	0.80	2.60 - 4.90
CPx in EC posttest	3.54	0.63	2.75 - 4.50
CPy in EO pretest	3.23	1.68	1.30 - 6.90
CPy in EO posttest	2.68	0.57	2.00 - 3.70
CPy in EC pretest	3.90	0.66	2.60 - 4.80
CPy in EC posttest	3.33	0.71	2.50 - 4.30

(EO = eyes open, EC = eyes closed)

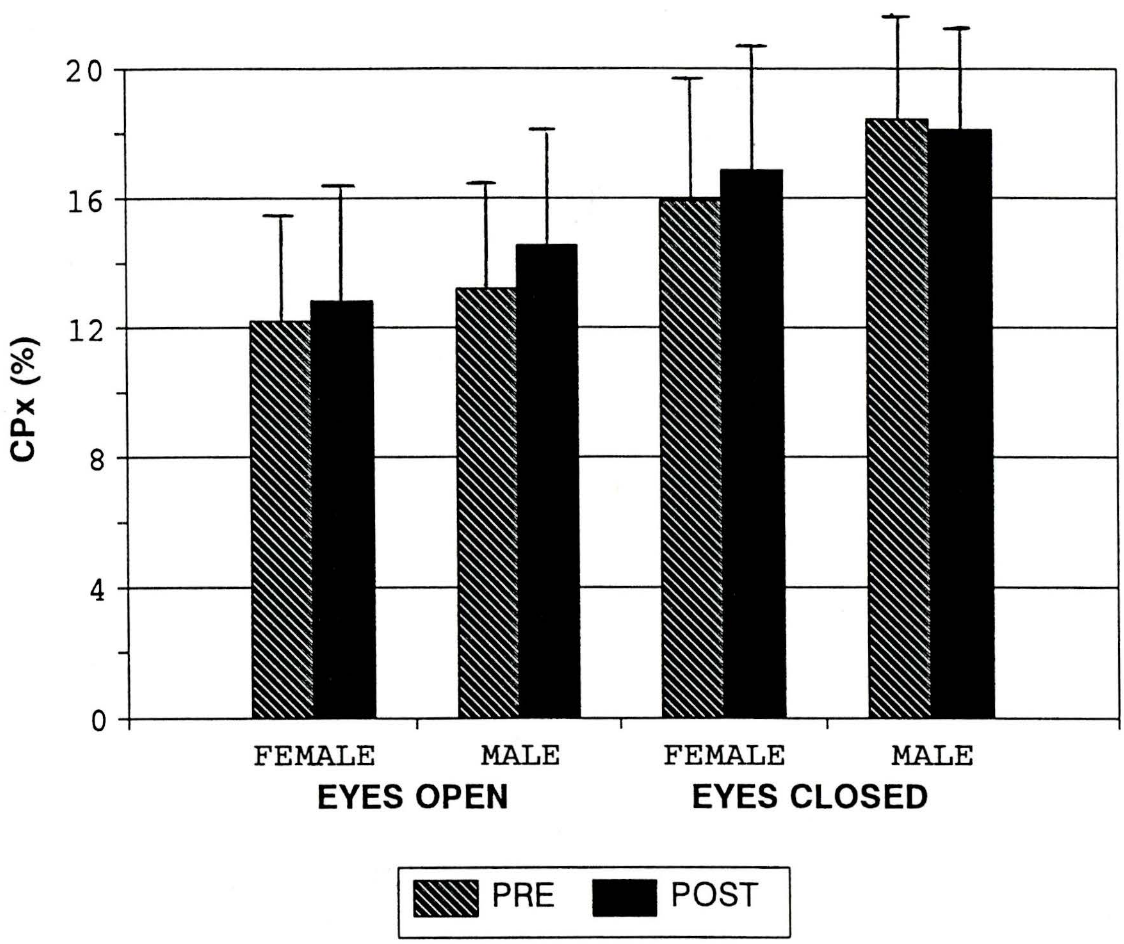

Figure 3: Means and Standard Deviations of Quiet Postural Sway (normalized to foot size) in the Lateral Direction

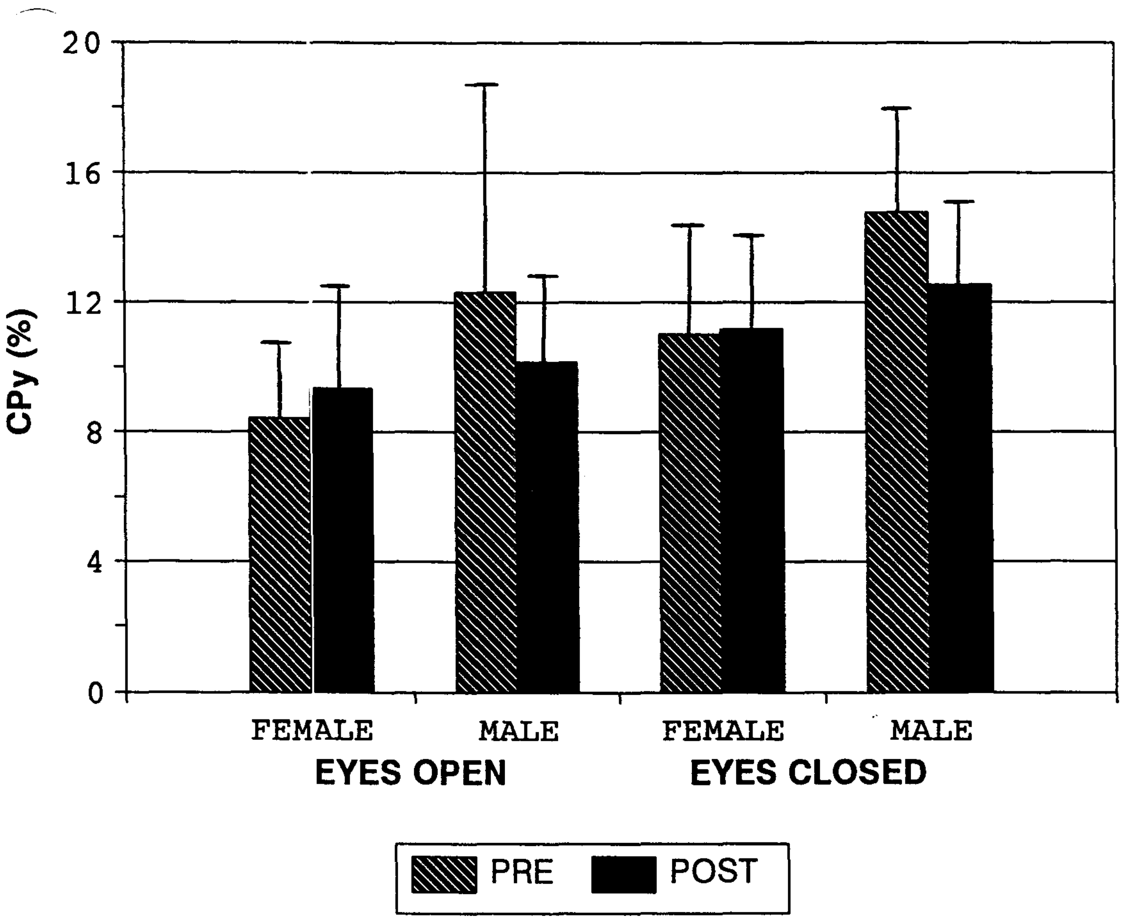

Figure 4: Means and Standard Deviations of Quiet Postural Sway (normalized to foot size) in the A-P Direction

respectively ($p=0.006$ and $p<0.001$). To compare and assess vision the calculation of RQ values were also utilized. The RQ values were calculated by dividing the RMS value in the EC condition by the RMS value in the EO condition, multiplied by 100. Mean, standard deviation and range of RQ are shown in Table 10. Mean RQ values exceeded 100% in both directions both before and after the strength training program. The range of RQ values was very large for this group of older adults. Vision on average stabilized quiet stance for both groups as each group had significantly larger quiet postural sway with their eyes closed as opposed to when their eyes were open resulting in RQ values greater than 100%. Two subjects had RQ values <100% in the lat. direction while six subjects had RQ vales of <100% in the a-p direction (both before and after strength training).

No main effect was found for training for either quiet postural sway in the lat. or a-p directions (figures 3 & 4). A gender by training interaction ($p=0.016$) was found in the a-p direction. The male subjects' sway (a-p) decreased after the 10 month strength training program whereas, the female subjects' sway (a-p) increased slightly after training (figure 4).

Simple Pearson correlations indicated that subjects with larger quiet postural sway (normalized) in one direction

TABLE 10: Romberg Quotient (RQ) Values - Quiet Postural Sway

RQ Value	Mean (%)	Standard Deviation (%)	Range (%)
RQ lat. pretest	141.45	30.53	73.66 - 197.56
RQ a-p pretest	132.51	58.60	50.90 - 278.57
RQ lat. posttest	144.07	41.73	87.50 - 229.03
RQ a-p posttest	119.59	43.01	72.45 - 228.95

$$RQ = \frac{\text{RMS value eyes closed}}{\text{RMS value eyes open}} \times 100\%$$

(RMS = standard deviation of the centre of pressure about the mean position) and one condition had large quiet postural sway (normalized) in the other direction and the other visual and training conditions ($p<0.05$). Age showed only a weak and inconsistent relationship to sway in the lat. and a-p directions, simple Pearson correlations ranged from -0.07 ±0.38. Height did not correlate significantly with any of the quiet postural sway measures. Mass did correlate significantly with quiet postural sway (normalized) in the a-p direction (EC) both before ($r=0.497$) and after ($r=0.583$) the training program. Mass did not correlate significantly with any of the other quiet postural sway measures. The leg strength of the subjects (1RM - leg press, plantarflexion and dorsiflexion) did not correlate significantly with any of the quiet postural sway measures either before or after the strength training program. Figures 5-10 illustrate the relationship between the three leg measures (leg press, plantarflexion and dorsiflexion; normalized to body mass) and quiet postural sway in both the lat. and a-p directions. An inverse relationship was not found as greater strength to body mass ratios did not have the smallest values for quiet postural sway. This was consistent both before and after the strength training program.

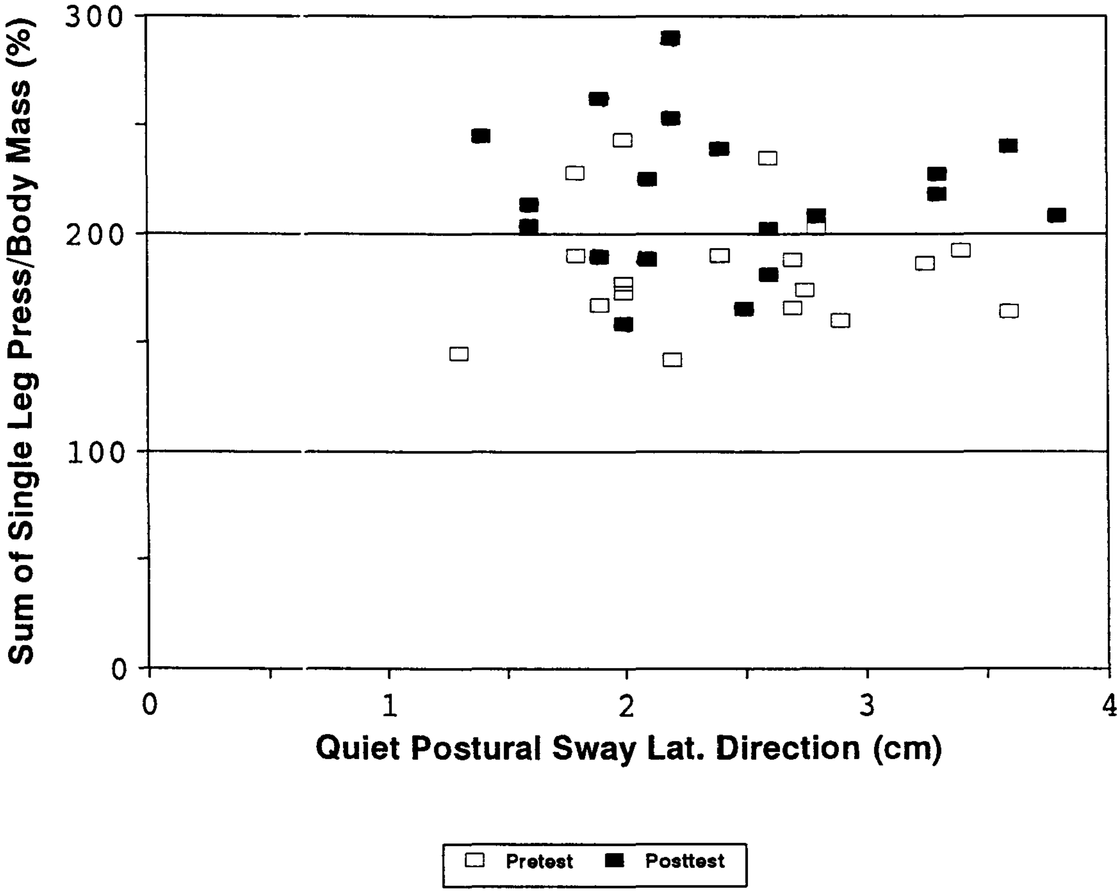

Figure 5: Scatterplot of Sum of 1RM, Single Leg Press (normalized to body mass) and Quiet Postural Sway in the Lat. Direction

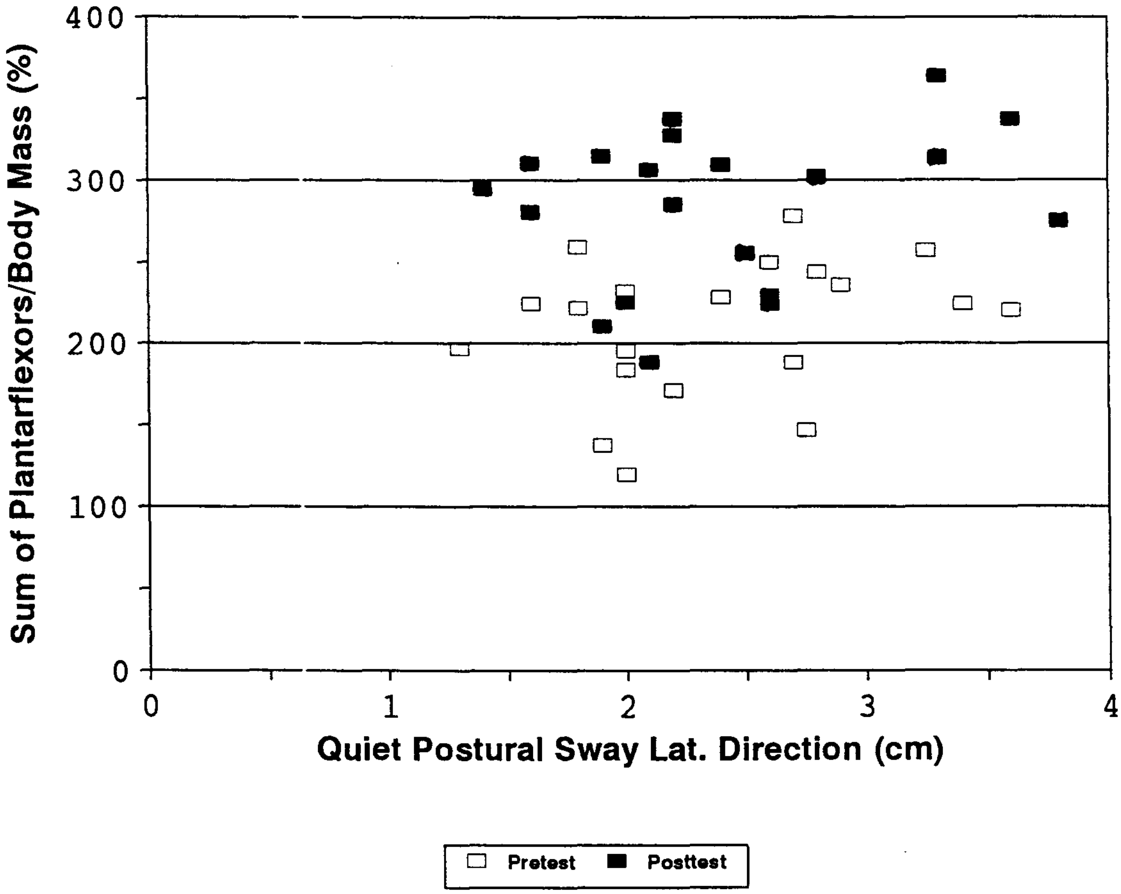

Figure 6: Scatterplot of Sum of 1RM, Plantarflexors (normalized to body mass) and Quiet Postural Sway in the Lat. Direction

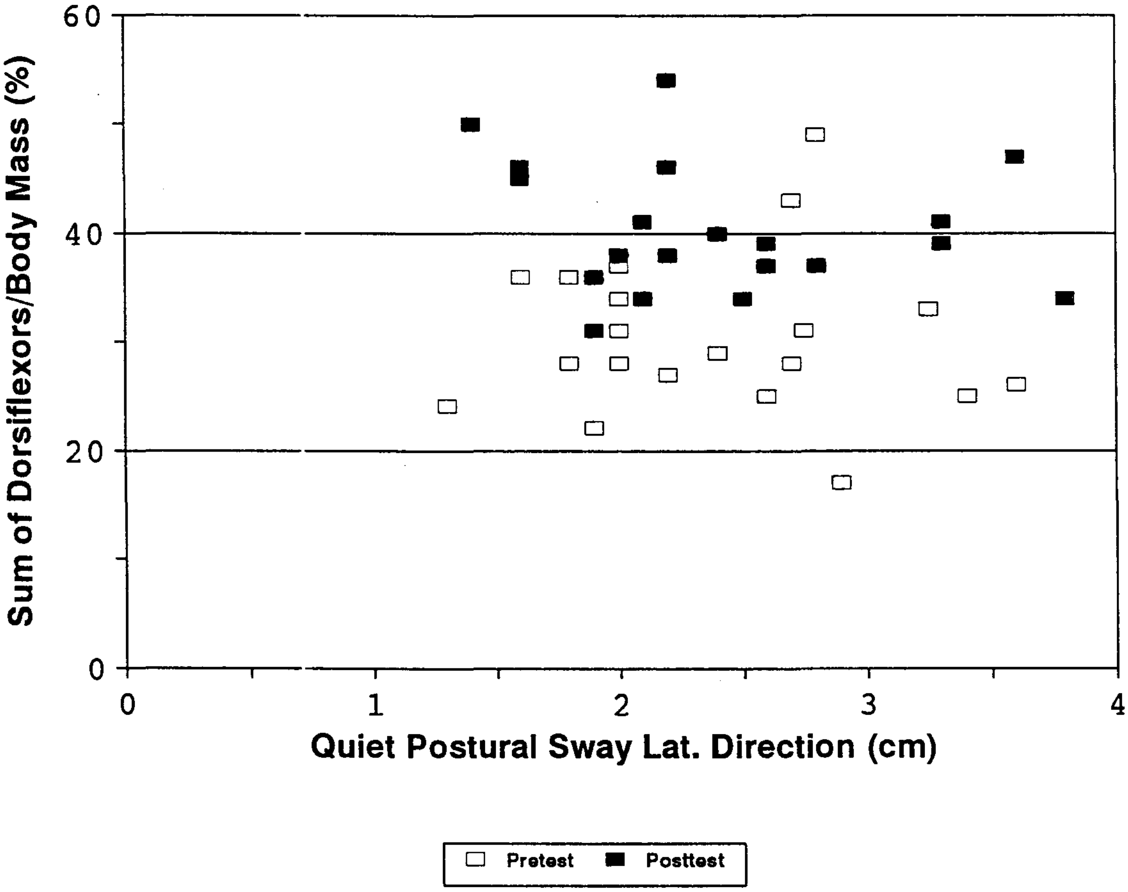

Figure 7: Scatterplot of Sum of 1RM, Dorsiflexors (normalized to body mass) and Quiet Postural Sway in the Lat. Direction

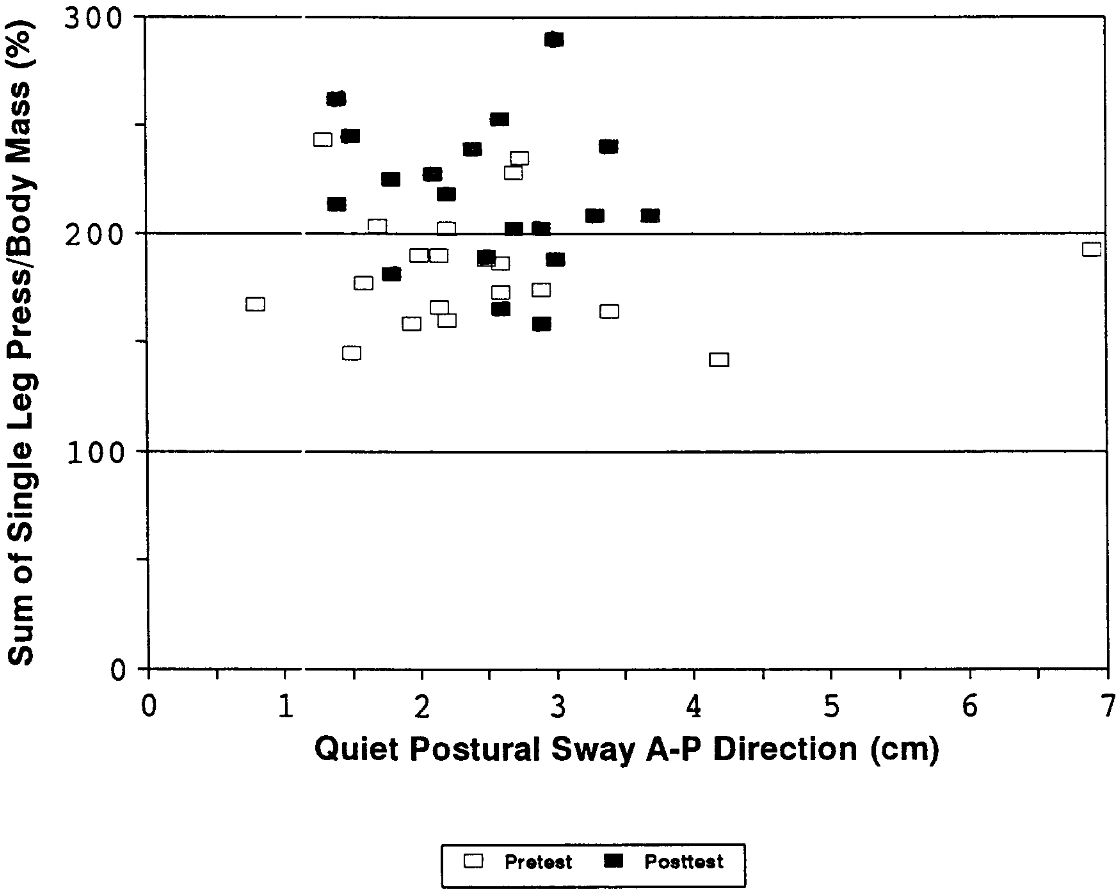

Figure 8: Scatterplot of Sum of 1RM, Single Leg Press (normalized to body mass) and Quiet Postural Sway in the A-P Direction

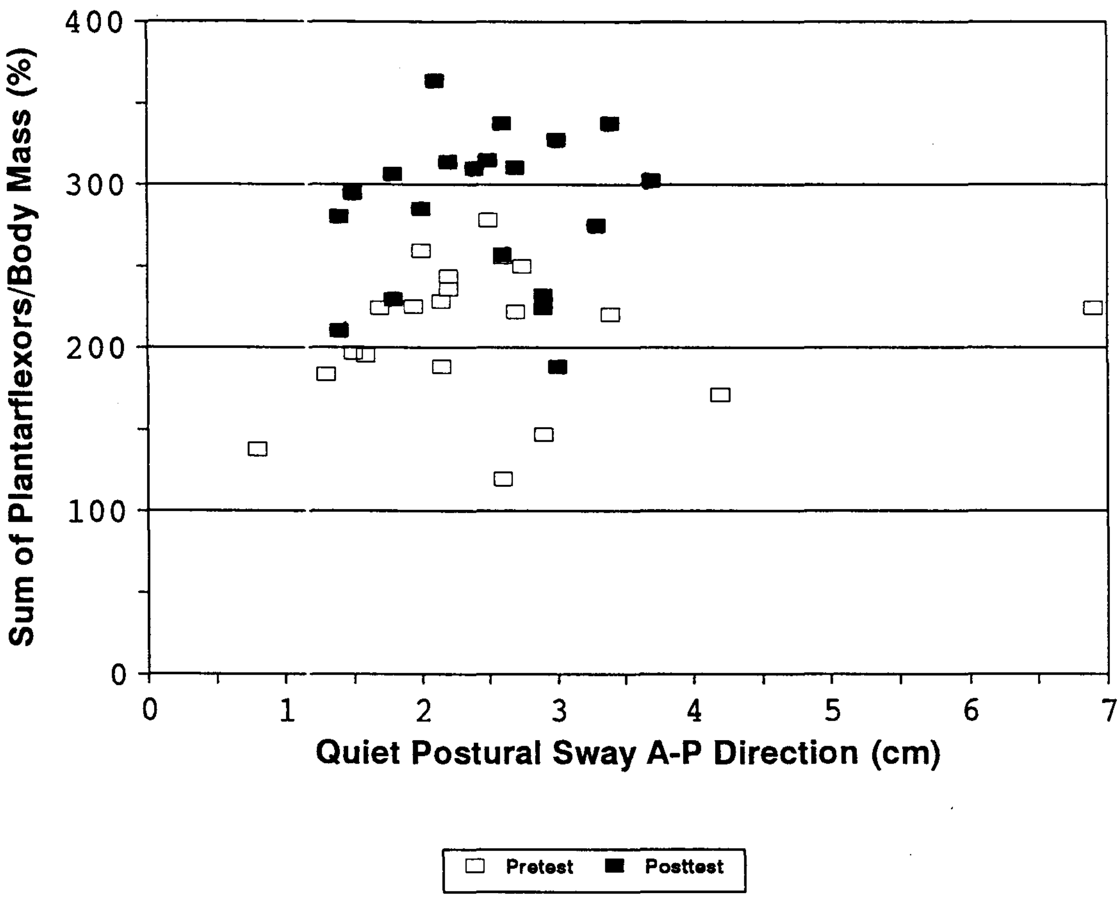

Figure 9: Scatterplot of Sum of 1RM, Plantarflexors (normalized to body mass) and Quiet Postural Sway in the A-P Direction

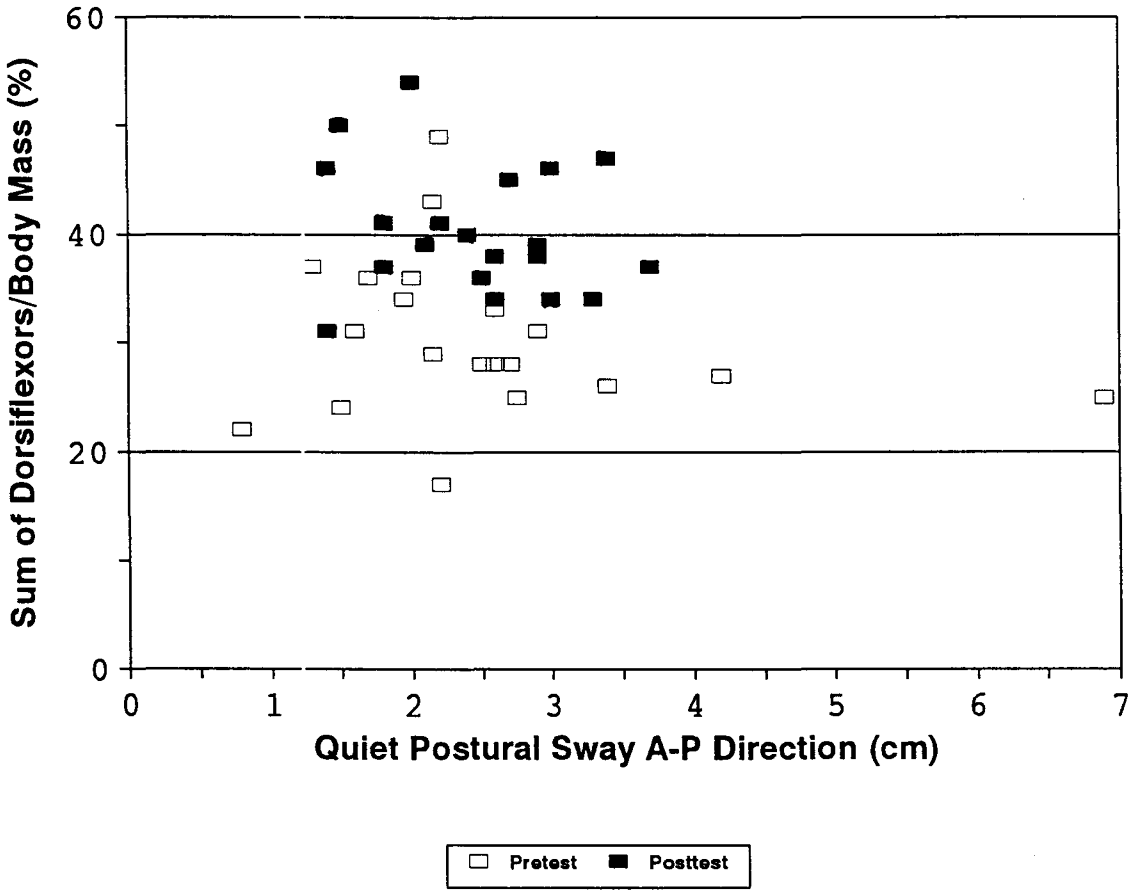

Figure 10: Scatterplot of Sum of 1RM, Dorsiflexors (normalized to body mass) and Quiet Postural Sway in the A-P Direction

Stability Limits

Tables 11 and 12 indicate the mean, standard deviation and range of the stability limits for both visual and training conditions. To assess the effects of gender, training and vision on stability limits, three-way analysis of variance (1 between/ 2 within factors: gender/ training and vision) were conducted. Stability limits normalized to foot size in both the lat. and a-p directions were utilized as the dependent variables.

Figures 11 and 12 illustrate the stability limits (normalized) in the lat. and a-p directions, respectively, for both training (pre and post) conditions and visual (EO and EC) conditions. There was no main effect for gender found for stability limits (normalized) in the lat. or a-p directions.

A main effect for vision was found for stability limits (normalized) in the a-p direction (p=0.020) but not in the lat. direction (p=0.277). Subjects were able to obtain significantly greater stability limits in the a-p direction when their eyes were open as opposed to when their eyes were closed (figure 12). A gender by vision interaction (p=0.049) was found for stability limits (normalized) in the lat. direction. The male subjects were able to utilize vision (EO) to increase their stability limits in the lat. direction

TABLE 11: Stability Limits - Female Subjects (n=12)

Variable	Mean (cm)	Standard Deviation (cm)	Range (cm)
SLx in EO pretest	9.38	3.07	5.00 - 14.20
SLx in EO posttest	10.67	2.97	5.80 - 14.10
SLx in EC pretest	10.03	2.39	5.60 - 13.40
SLx in EC posttest	10.63	2.13	7.40 - 13.40
SLy in EO pretest	12.72	3.60	5.90 - 18.90
SLy in EO posttest	14.03	3.29	7.10 - 17.40
SLy in EC pretest	12.80	3.52	7.00 - 19.80
SLy in EC posttest	13.08	3.54	5.90 - 18.90

TABLE 12: Stability Limits - Male Subjects (n=8)

Variable	Mean (cm)	Standard Deviation (cm)	Range (cm)
SLx in EO pretest	10.99	3.31	4.40 - 16.20
SLx in EO posttest	11.38	2.96	4.60 - 13.80
SLx in EC pretest	9.76	3.63	3.60 - 15.40
SLx in EC posttest	10.30	1.94	6.40 - 13.00
SLy in EO pretest	14.06	3.24	7.00 - 16.50
SLy in EO posttest	14.40	3.37	6.40 - 13.00
SLy in EC pretest	13.33	3.84	5.30 - 18.00
SLy in EC posttest	13.31	3.63	5.90 - 18.80

(EO = eyes open, EC = eyes closed)

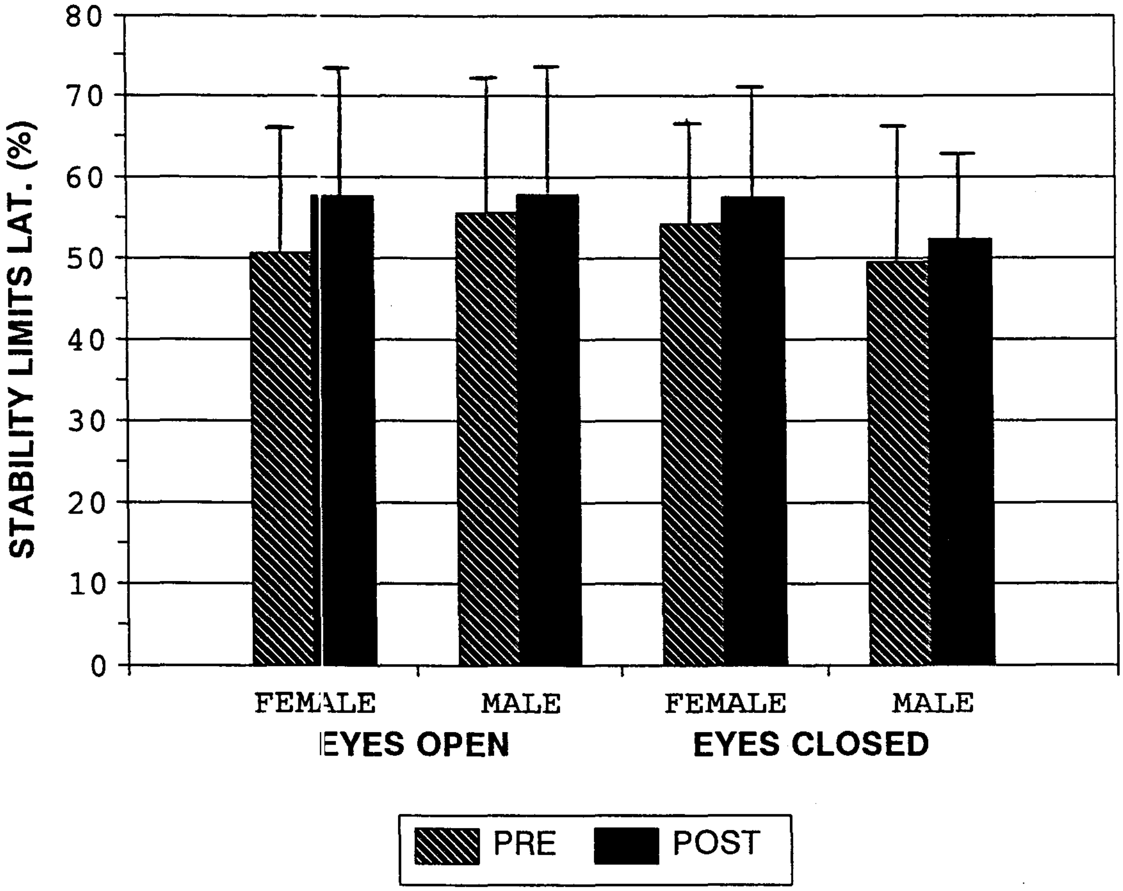

Figure 11: Means and Standard Deviations of Stability Limits (normalized to foot size) in the Lat. Direction

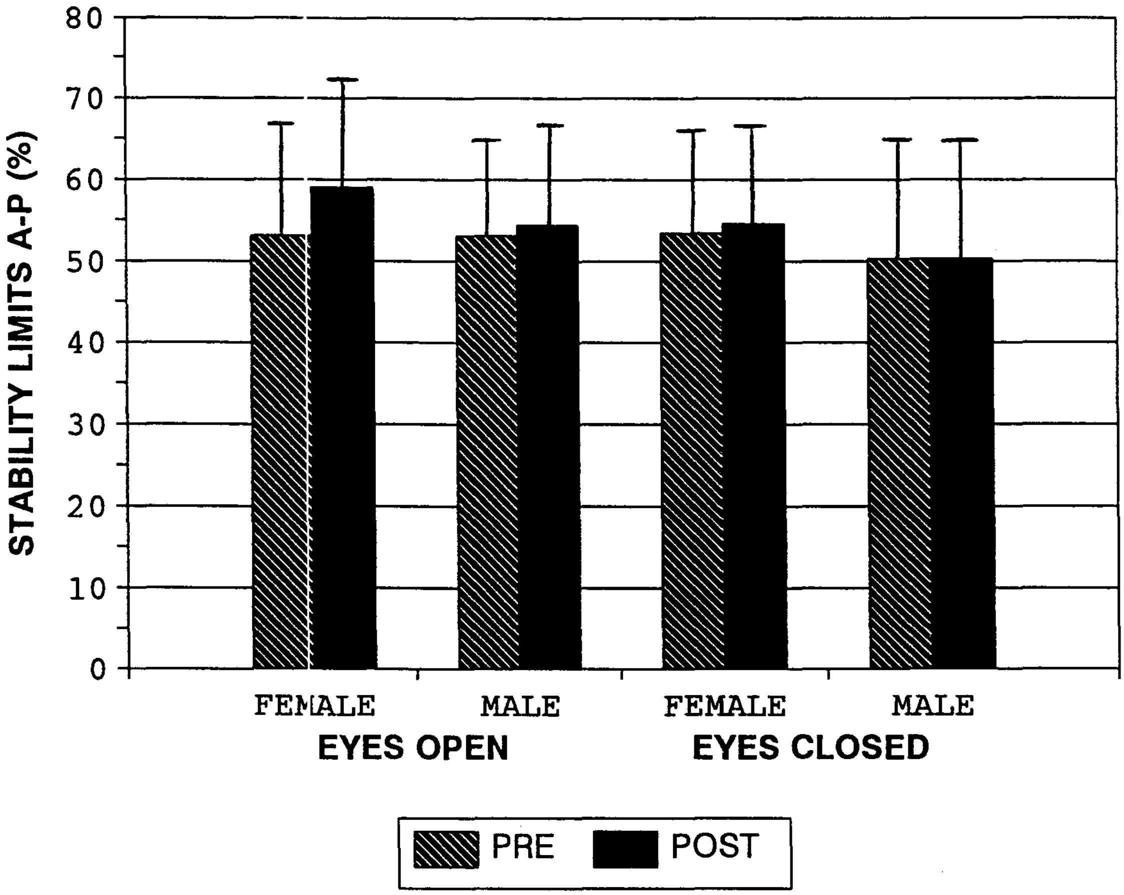

Figure 12: Means and Standard Deviation of Stability Limits (normalized to foot size) in the A-P Direction

whereas, the female subjects' stability limits (lat) did not increase with the presence of vision (figure 11). Seven of the eight male subjects had greater stability limits (normalized) in the lat. direction with EO than with EC for both the pretest and posttest results. Three of the twelve female subjects had greater stability limits (normalized) in the lat. direction with EO than EC in the pretest condition and the number increased to seven of the twelve female subjects who had greater stability limits with visual input in the posttest condition.

There was no main effect for training. Although not statistically significant, there was a trend for stability limits to increase in both directions after the 10 month strength training program (tables 11 & 12). A greater increase in stability limits (normalized) was found in the EO condition with smaller increases seen in the EC condition. A training by vision interaction also approached significance with $p=0.059$. Fourteen subjects (7 females, 7 males) had increased stability limits (lat) and 14 subjects (9 females, 5 males) had increased stability limits (a-p) after the 10 month strength training program in the eyes open condition. In the EC condition 13 subjects (7 females, 6 males) had increased stability limits (lat) and 11 subjects (6 females, 5 males) had increased stability limits (a-p) after the training program.

Simple Pearson correlations indicated that subjects with larger stability limits (normalized) in one direction and one condition had larger stability limits in the other direction and conditions (training and vision) ($p<0.05$). No significant correlations were found between stability limits (normalized) and each of the variables of age, height and mass. The leg strength (1RM - leg press, plantarflexion and dorsiflexion) did not correlate significantly with any of the stability limits measures (lat. and a-p).

Figures 13-18 illustrate the relationship of leg press, plantarflexion and dorsiflexion strength (normalized to body mass) and stability limits in both the lat. and a-p directions.

Quiet Postural Stance - Normalized to Stability Limits

Figures 19 and 20 illustrate the ratio of quiet postural sway when normalized to stability limits in the lat. and a-p directions, respectively. Both graphs demonstrate a significant increase in the ratio of quiet postural sway to stability limits when eyes are closed compared to when eyes are open ($p<0.001$). In the lat. direction a gender by vision

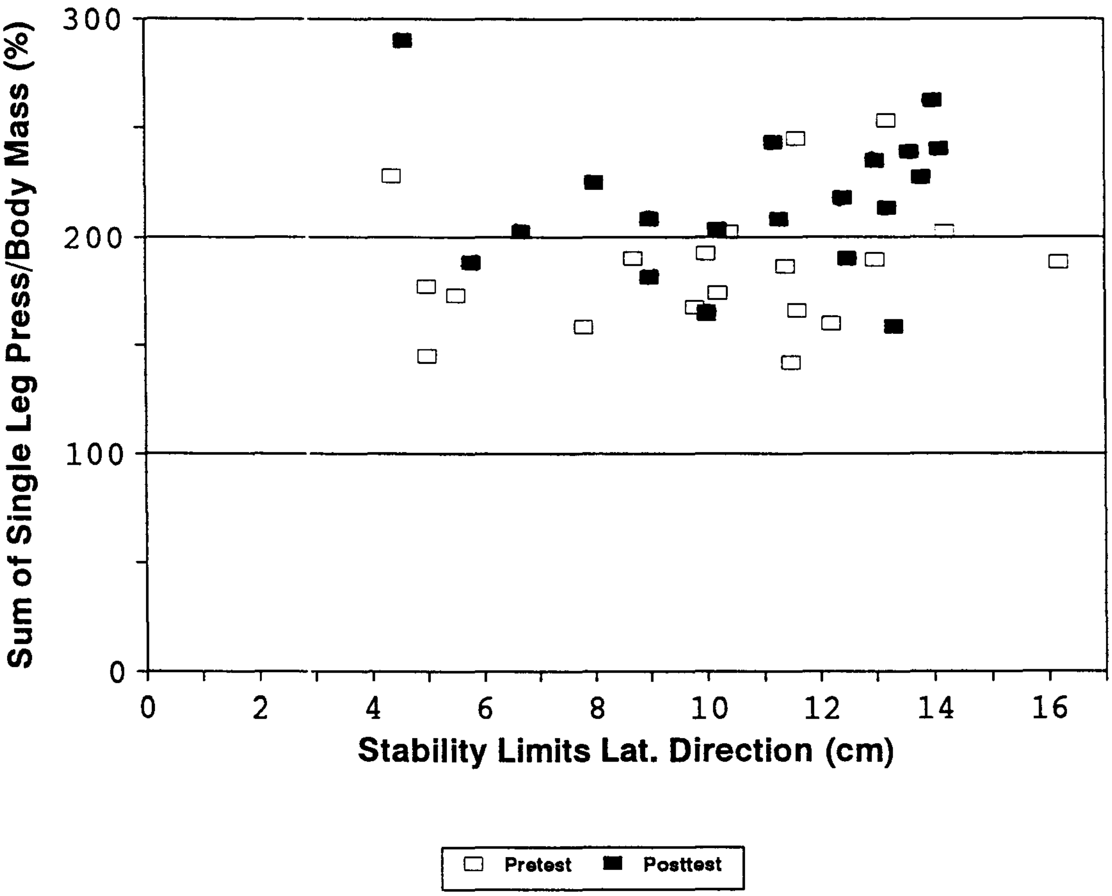

Figure 13: Scatterplot of Sum of 1RM, Single Leg Press (normalized to body mass) and Stability Limits in the Lat. Direction

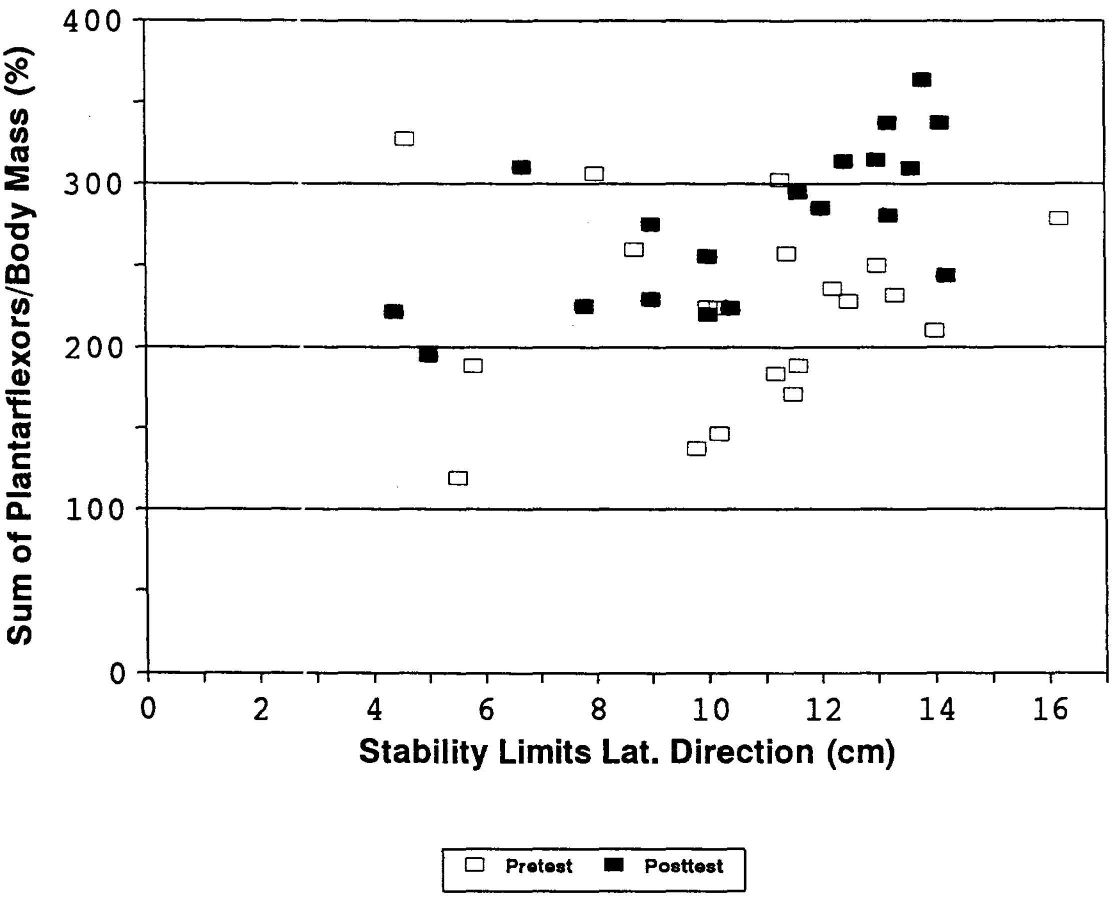

Figure 14: Scatterplot of Sum of 1RM, Plantarflexors (normalized to body mass) and Stability Limits in the Lat. Direction

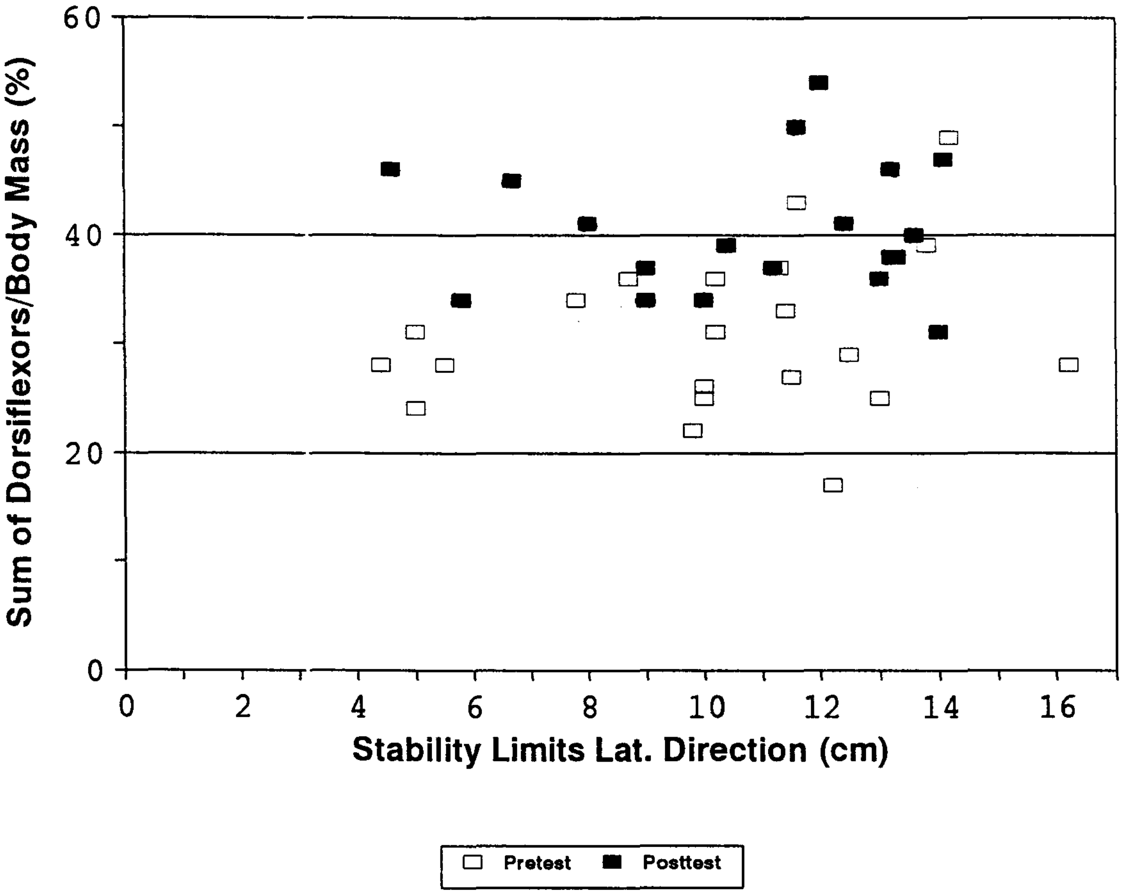

Figure 15: Scat:terplot of Sum of 1RM, Dorsiflexors (no:malized to body mass) and Stability Limits in the Lat. Direction

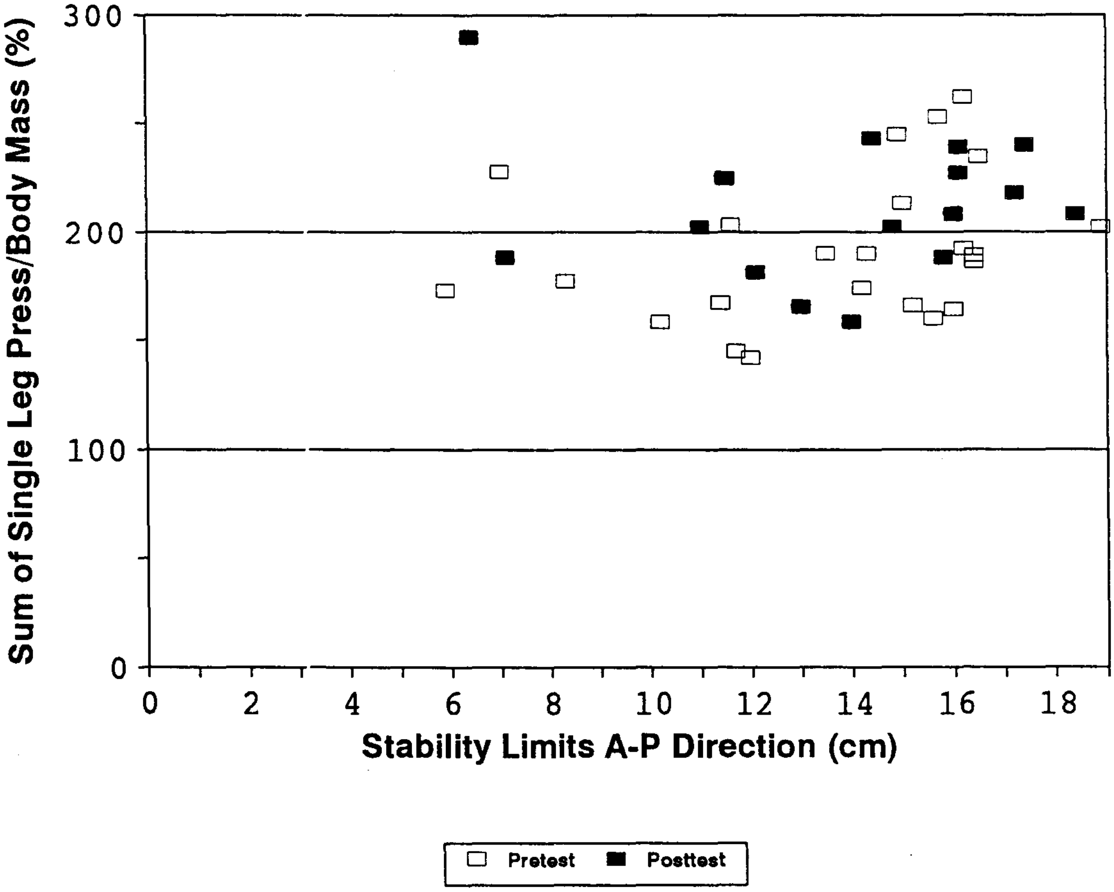

Figure 16: Scatterplot of Sum of 1RM, Single Leg Press (normalized to body mass) and Stability Limits in the A-P Direction

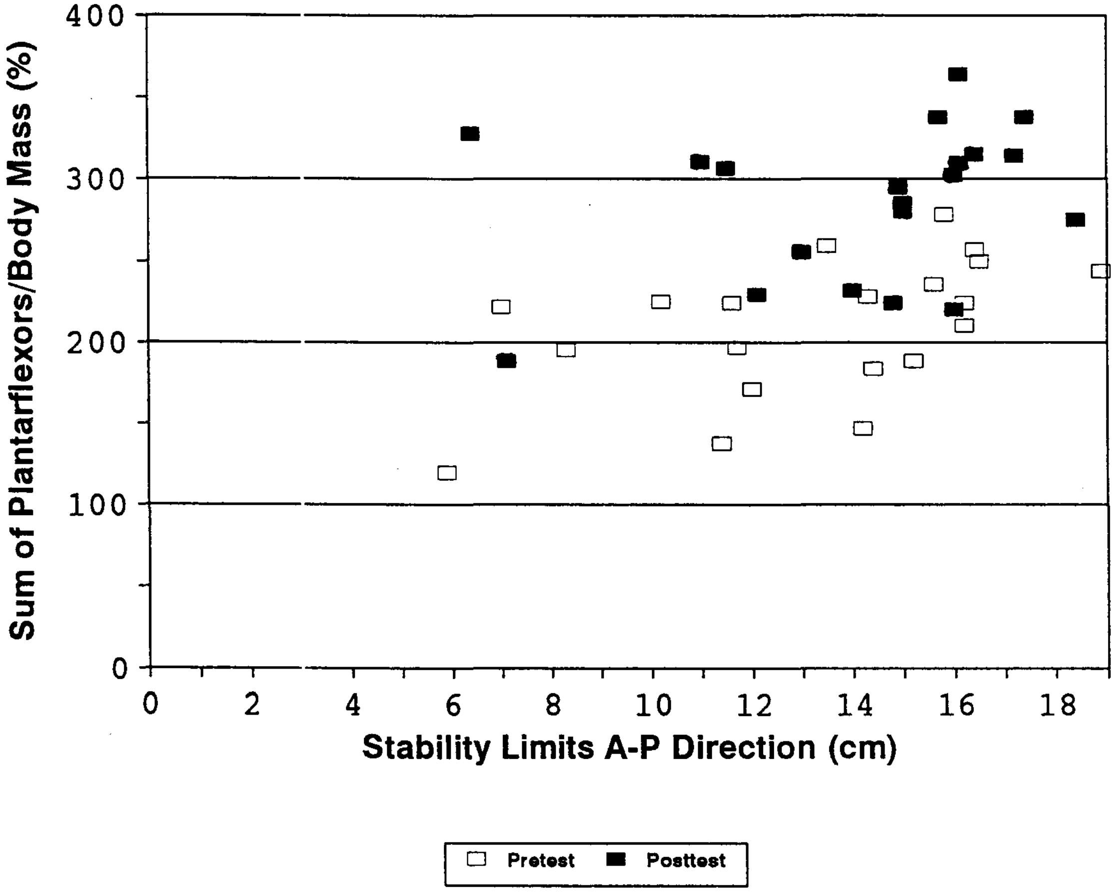

Figure 17: Scatterplot of Sum of 1RM, Plantarflexors (normalized to body mass) and Stability Limits in the A-P Direction

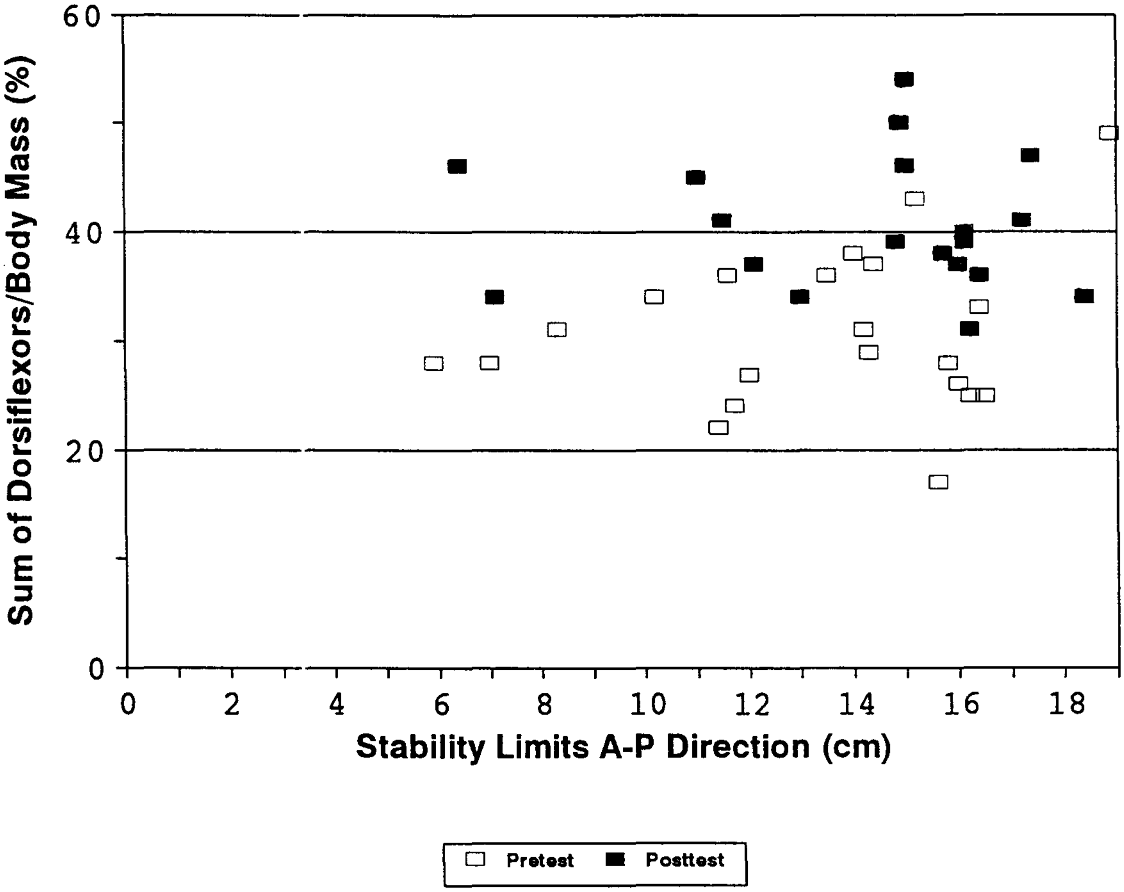

Figure 18: Scatterplot of Sum of 1RM, Dorsiflexors (normalized to body mass) and Stability Limits in the A-P Direction

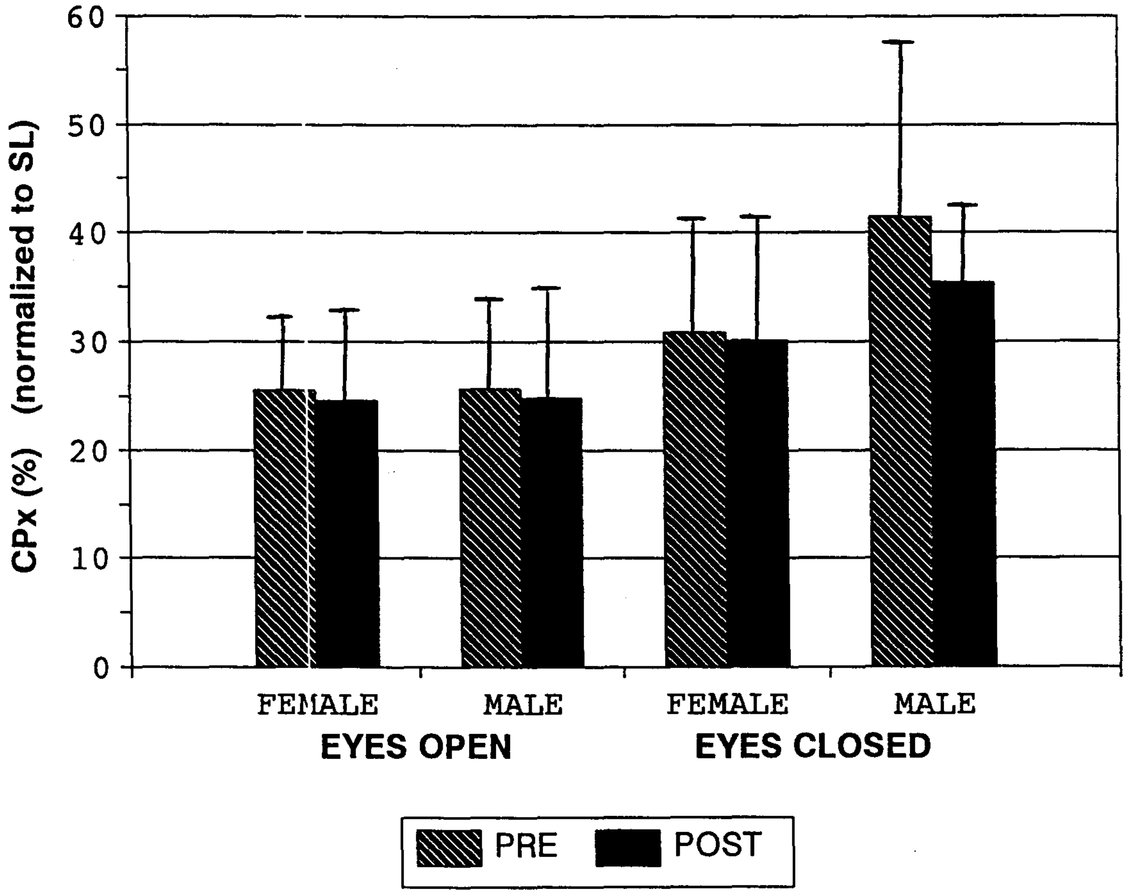

Figure 19: Means and Standard Deviations of Quiet Postural Sway (normalized to stability limits) in the Lat. Direction

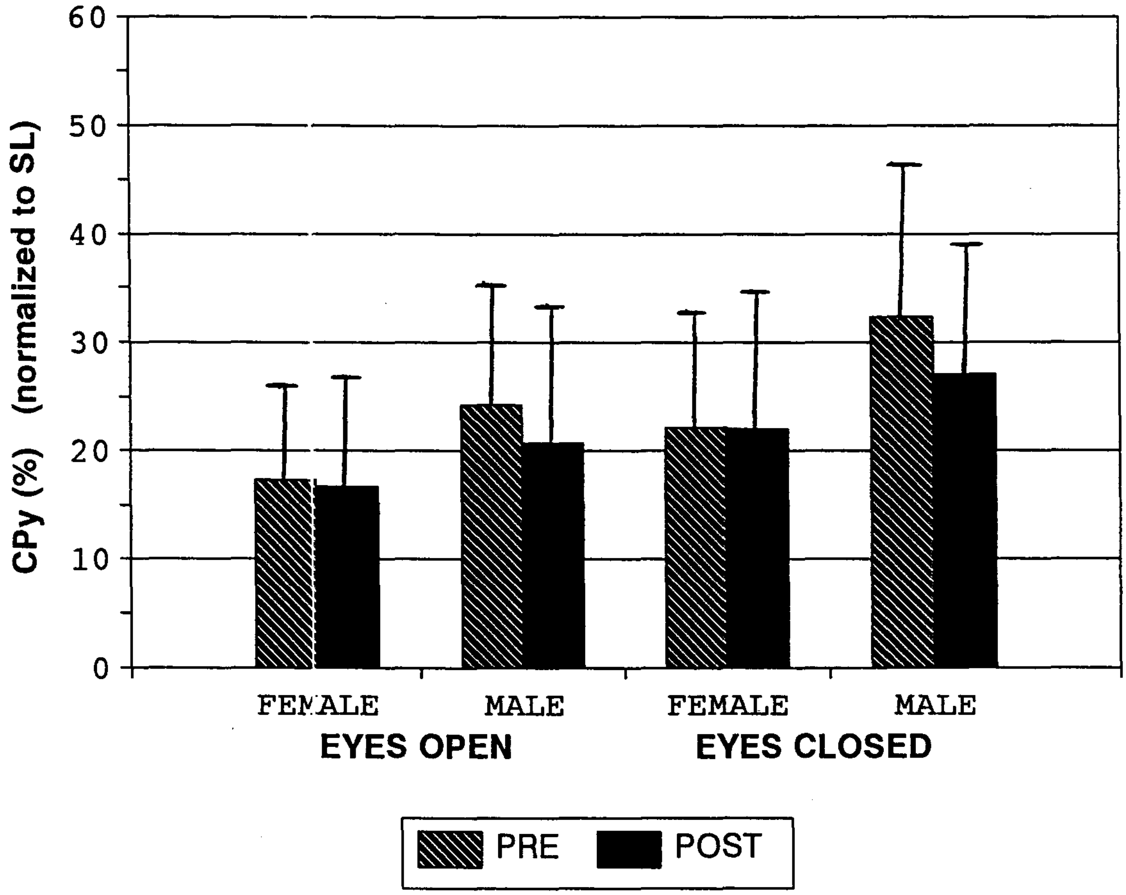

Figure 20: Means and Standard Deviations of Quiet Postural Sway (normalized to stability limits) in the A-P Direction

interaction is present (p=0.046). The absence of visual input was found to have a greater impact on the male subjects than on the female subjects in the lat. direction (figure 19). In the a-p direction (figure 20) the male subjects had decreased the ratio of CPy:SLy x 100% after the 10 month training program whereas, the females had very little change after the training program. The gender by training interaction in the a-p direction reached significance at p=0.045.

Leg Strength

Table 13 indicates the mean and standard deviation of the 1RM measures in each of the weight lifting exercises both before and after the 10 month training program. Pearson correlations were utilized to look at the change in quiet postural sway and stability limits to the change in leg strength (leg press, plantarflexion and dorsiflexion). Change in leg strength did not correlate with the change in quiet postural sway, as well, change in leg strength did not correlate with changes in stability limits.

TABLE 13: Results from 1 Repetition Maximum (1RM), Before and After the Training Program

Exercise		Pretest (kg)	Posttest (kg)
Single Arm Military Press	(f)	15.77±3.29	24.33±4.94
(sum of both arms)	(m)	30.84±7.82	41.75±9.95
Single Arm Curl	(f)	13.67±4.72	19.42±4.23
(sum of both arms)	(m)	30.38±5.42	42.31±9.62
Bench Press	(f)	23.69±4.93	33.25±6.69
	(m)	46.69±6.78	58.06±14.38
Single Leg Press	(f)	110.29±16.09	136.31±25.42
(sum of both legs)	(m)	162.72±27.31	192.19±37.50
Single Leg Plantarflexion	(f)	129.72±28.78	175.17±31.28
(sum of both legs)	(m)	178.13±40.44	245.00±44.72
Single Leg Dorsiflexion	(f)	19.45±4.86	25.02±3.31
(sum of both legs)	(m)	24.10±3.97	33.88±3.56

(f=female, m=male)

Control Group

Test-retest reliability of quiet postural sway and stability limits was assessed in a control group with a one week interval between the tests. Intraclass correlation coefficients were high for all test-retest values under both visual conditions (EO and EC) (see table 14).

TABLE 14: Intraclass Reliability Coefficients for Test-Retest Conditions

Quiet Postural Sway Measures	Intraclass Correlations (r_{intra})
CPx (EO)	0.854
CPy (EO)	0.808
CPx (EC)	0.830
CPy (EC)	0.918
Stability Limits Measures	
SLx (EO)	0.845
SLy (EO)	0.958
SLx (EC)	0.850
SLy (EC)	0.854

DISCUSSION

Quiet Postural Stance

The reliability of testing quiet postural sway was assessed to find out how variable the older adults results were in a test-retest situation. The 10 older adults were tested twice, with a one week interval between tests. The tests were found to be very reliable with intraclass correlation coefficients ranging from 0.8 - 0.9 for all the quiet postural sway measures. This is in agreement with Hattori, Starkes & Takahashi (1992) and LeClair & Riach (in press) who both found the assessment of quiet postural sway to be a reliable sensitive test. Both studies utilized Pearson product moment correlations to assess test-retest reliability. Hattori et al. (1994) recorded Pearson correlation values of 0.64-0.89 while LeClair & Riach (in press) analysis resulted in reliability coefficients exceeding 0.8. Hattori et al. (1992) also indicated that one test of quiet postural sway is probably sufficient and that the time of day of testing need not be controlled. This is positive from an experimental design perspective as it denotes stability of the test results.

One purpose of the study was to assess quiet postural standing in the older adult. Sway in the lateral direction was found to be greater than sway in the a-p direction for the values normalized for feet size. The subjects utilized a greater percentage of their anatomical base of support in the lat than a-p direction. This may have been due to the stance utilized (feet together, medial borders touching). The subjects generally found the stance uncomfortable and unnatural as most individuals would generally stand with their feet slightly apart (increased base of support in the lat direction).

The assessment of gender and quiet postural sway measures found that the male subjects generally had greater quiet postural sway than the female subjects. After normalizing quiet postural sway for feet size a significant gender difference was found in the a-p direction but not the lat direction. Previous research on quiet postural sway and gender differences in the older adult have been conflicting. Overstall, et al., (1977) found that at all ages women swayed to a greater extent than their male counterparts. It was suggested that the body weight: muscle mass ratio may explain the gender differences found. The difference found may also have been due to a failure to normalize for feet dimensions and differences in footwear that may have increased the sway in the female subjects. A number of studies did not find any gender differences when assessing quiet postural sway in the older adult (Baloh, et al., 1994; Brown, 1992; Maki, Holliday & Fernie, 1990; Brocklehurst, Robertson & James-Groom, 1982). Other research on quiet postural stance and the older adult have either tested only one gender (Lord & Ward, 1994; Hasselkus & Shambes, 1975) or have collapsed the data across gender (Hytonen, Pykko, Aalto & Starck, 1993; Walt, Patla, Winter & Frank, 1990; Stelmach, et al., 1989; Ring, Nayak & Isaacs, 1989; Hayes, et al., 1984; Holliday, Dornan & Fernie, 1978; Sheldon, 1963).

Studies using quiet postural sway have reported an age dependency in sway, with young children and aged individuals having the greatest amount of sway (Hayes et al. 1984; Zernicke, Gregor & Cratty, 1982; Sheldon, 1963). After the age of 60, postural stability in quiet postural stance has been shown to decrease significantly when compared to younger adult groups (Baloh et al. 1994; Walt et al., 1990; Pyykko et al., 1990; Maki et al., 1990; Hasselkus & Shambes, 1975). Sheldon (1963) found that improvement in control developed rapidly and reached a plateau which extended from the late teens until the forties, after which an increasing deterioration set in. Hytonen et al., (1993) found stability to be optimal around the ages 30 to 60 years and to deteriorate after that point.

The effect of age within the older adult group in this study showed only a weak and inconsistent relationship to sway in the older adult group (60 - 80 years of age). Pearson correlations were very weak with ranges from -0.07 to 0.38 when looking at the relationship between age in the older adult group (60-80 years) and quiet postural sway measures. Duncan, et al., (1992) and Brocklehurst, Robertson & James-Groom, (1982) also found that there was no consistent relationship between age in the older adult (66-89 years of age) and sway. It may be that the association of increased sway and age demonstrated in some studies may result from an increased prevalence of disease processes rather than ageing itself (Overstall, et al., 1977; Sheldon 1963). The very active and healthy older adults utilized in the study may explain why there was not a relationship between quiet postural sway and age within the older adult group. Difference in function across the age span may not be as pronounced in the older adult (60-80 years) due to changes in lifestyle and increased quality of life resulting from better health care, nutrition and education. Testing may have to include individuals who are over 80 years of age. Health status and lifestyle are two factors that can introduce large variability in the balance control system when dealing with the older adult population (Patla, Frank & Winter, 1990).

Quiet Postural Stance and Vision

The human body when standing quietly experiences small changes in position that are continuously monitored by the visual, vestibular and somatosensory systems. The Romberg Quotient (RQ) is commonly used to assess the effect of visual information on posture. The RQ value is a ratio between body sway values recorded in the nonvisual and visual condition. Vision for the older adult in this study was stabilizing in quiet postural stance as RQ values surpassed 100%. A RQ value of greater than 100% indicates that vision has a positive effect on the stability of stance, whereas a value less than 100% would have indicated that vision was destabilizing. The older adults were able to decrease sway in the a-p and lat directions with EO as opposed to the EC condition. This is similar to young adults who have also been shown to have RQ values greater than 100% (Riach & Hayes, 1987). Straube et al. (1988) also found that both the older adults and the younger adults had RQ values >100% but that the values for the older adults exceeded those of the younger adults. Vision has been found to be stabilizing for both young and older adults but to be more important to the older adult group (Straube et al. 1988; Pyykko et al. 1988; Tobis et al. 1985).

The main effect found for vision indicates that vision has a positive effect on the stability of stance in the older adult. Even though the visual system has been noted to deteriorate with age (Cohn & Lasley, 1985) the older adult is still able to utilize visual information to improve quiet standing balance. The sensory systems in healthy young adults may be redundant, so that by taking one system away there is no noticeable loss in stability. With age each sensory system may experience some deterioration so that there is less overlap or redundancy among the three systems. In the elderly, taking away one system, ie. eyes closed, may have a greater influence as the two systems left are not functioning at the capacity they are in the young adult. Confidence may also come into play as the older adult may be less comfortable and confident in the EC condition thus increasing sway with EC.

Training and Quiet Postural Sway

The extent to which a progressive strength training program can alter balance as seen in quiet postural sway was studied. A main effect for training was not present but a gender by training interaction was found in the a-p direction. The male subjects' mean quiet postural sway decreased after the training program whereas the female subjects' mean sway increased slightly, though not statistically significant, after training. Even with the decrease in the quiet postural sway in the male subjects after the strength training program, the female subjects still sway to a lesser extent than the male subjects. The finding that sway improved significantly in the male subjects after the strength training program is contradictory to the findings by Lord et al. (1993) and Crilly et al. (1989). Both studies found that sway on a firm surface was not significantly less in the exercisers when compared to the nonexercisers.

Larger excursions of an individual's CP in static balance tests have been equated to a poorer postural control system (Patla, Frank & Winter, 1990). The decrease in the sway measures in the male subjects after the strength training program indicates the benefits of improving strength to improve balance. The lack of improvement in quiet postural sway in the female subjects may have been minimal because their postural sway was very low to begin with. Lord, Clark & Webster (1991) suggested that reduced sensation, muscle weakness in the legs, and increased reaction time are all associated with lack of stability in the older adult. They found that peripheral sensation was the most important sensory system in maintaining quiet postural stance and this may have been a limiting factor in the female subjects in this study. In subjects who have good postural control (small sway measures) the strength training program would help to maintain balance control of the individual. The lifestyle and health of the female subjects may explain the low base line levels of sway displayed.

It was shown that participation in a progressive strength training program can help decrease quiet postural sway in the healthy older adult, who have initially high sway measures. The implementation of a strength training program to improve quiet postural sway may have a more profound effect on a group of weak, less active older adults.

STABILITY LIMITS

An important factor in assessing balance in the older adult population is the reliability of the test. In this study, repeated stability limit testing (1 week apart) on 10 older adults with eyes open and eyes closed indicated test-retest reliability with intraclass correlation coefficients ranging from 0.84-0.96. King, Judge & Wolfson (1994) also demonstrated that the test of stability limits is a reliable test (intraclass correlation coefficient of 0.80) of voluntary postural control.

Balance in the older adult was also assessed by measuring the stability limits of each individual. The stability limits of an individual is the maximum range that the CP can be voluntarily moved without changing the base of support. The limits of CP are an important measure of balance as it indicates the point between static and dynamic balance. If the stability limits are exceeded, a change of base of support (dynamic balance) must occur or a fall will result. A decrease in the usable base of support with age may result in a decrease in the ability to perform daily activities. The test of stability limits is more taxing to the postural control system and requires greater muscular force than the test of quiet postural sway.

In this study, the distance the CP moved in the lat. and a-p directions were divided by feet width and foot length respectively to compensate for differences in body size between subjects and to provide comparable measures. The older adult subjects obtained stability limits that were 50% - 60% of their base of support in both the lat. and a-p directions. These values were significantly less than those obtained by younger adults who went through the same testing procedure (Vamos & Riach, 1992). In the younger study, twenty-eight adults (18-30 years of age) were tested and found to have ranges of 66-73% of their base of support. These results are similar to those found by King et al. (1994) and Lee & Deming (1987). King et al. (1994) reported that the older adults (>60 years of age) had mean normalized stability limits (a-p) of 42%±12 and that the younger adults had mean stability limits (a-p) of 60%±7 of their base of support. Changes in stability limits with age were also found by Lee & Deming (1987) who reported ranges of 35-90% and 15-65% of the anatomical base of support for individuals under the age of 60 and those over the age of 60 respectively.

In addition, the results showed large variations in stability limits in the older adults (ranging from 23%-78% of feet width and 18%-78% of foot length). While the decrease in stability limits appears to reflect the age-associated decline in balance, some of the older adults were able to demonstrate ranges that were the same as those obtained by the younger adults. Pearson correlations also indicated that age in the older adult group did not correlate with maximum stability limits. This may suggest that voluntary stability limits does not significantly decline between the ages of 60 to 80 years.

Stability Limits and Vision

Abundant research has investigated the effects of vision on quiet postural stance while there is very little information on how visual input effects the acquisition of maximum stability limits. In testing children and young adults, Riach & Starkes (1993) found that vision (EO & EC) did not increase postural stability limits (lat. or a-p) in the children but vision had a positive effect on stability limits in the young adults. The results of this study indicated that the older adults tested were able to utilize visual information, as did the younger adults, to improve stability limits (a-p). This is in contrast to what was found by Blaszczyk, Lowe & Hansen (1994), who indicated that the older adults (72.8 ± 2.7 years) in their study were not able to increase stability limits (lat. or a-p) with EO as compared to EC.

Individual differences were found between the older adult subjects in this study and their ability to utilize visual information to obtain maximum stability limits. The ability to use vision to assist stability limits may be due to the type of visual information utilized. In the EO trials, the subjects may have fixated upon an object, fixated intermittently, fixated on a variety of objects or failed to fixate on any specific object. Thus, the variability in the visual information utilized, may account for some of the differences between subjects to have larger stability limits with their EO. To date research has been minimal on the optimal type and distance of visual fixation in testing maximal stability. Institutionalized older adults have been shown to have more dramatic losses in muscle mass (Petrella et al. 1989) therefore, strength training exercises may show greater improvements in stability limits in this population.

Strength Training and Stability Limits

Standing is constrained by stability limits which are determined by the muscular forces required to maintain balance and the speed with which the forces can be applied (McCollum & Leen, 1989). In obtaining maximum forward lean the chief muscular activity comes from the plantarflexors of the ankles (soleus and gastrocnemius). In the backwards lean position the dorsiflexors of the ankles (tibialis anterior) and the toe extensor muscles are the main muscles activated (Whitney, 1962).

For a person with reduced stability limits (functional base of support), even relatively small disturbances may elicit a loss of balance or a fall. The extent to which strength training can improve stability limits is of clinical importance and may be utilized with those at risk of falling. The subjects in this study successfully completed the 10 month progressive strength training program and were found to have significantly increased strength measures (both upper and lower body exercises) (McCartney, et al., in press). The trend for increased stability limits after the strength training program indicates the benefits of implementing a strength program.

After strength training a greater increase in stability limits was found with EO as compared to EC. This may suggest a reluctance for the older adult to reach their maximum stability limits, especially in the absence of visual feedback. It has been suggested by Lee & Deming (1987) that the failure to obtain greater ranges in the older adult may be due to the subjects allowing themselves a wider "margin of safety". The "margin of safety" is the distance between the maximum stability limits the subject is willing to lean and the mechanical limits of stability (Blaszczk et al. 1994).

Keeping a large "margin of safety" allows for more time to recover from postural instability. In an effort to reduce the chance of a fall and subsequent injury the older adult may not extend themselves to their actual maximum stability limits. With the absence of visual information the older adult may also be more reluctant to expose themselves to their maximum ranges.

The lack of correlation between muscular strength and stability limits suggests that leg strength in the healthy, active older adult may not be the primary limiting factor. Many systems are working at less than optimal levels in the older adult, thus improvement in muscular strength can improve balance but it can not compensate for deficiencies in the postural control system or lack of confidence to obtain maximum stability limits. Greater improvements in stability limits and higher correlations between leg strength and stability limits may have been found in older subjects with lower baseline strength levels. Institutionalized older adults have been shown to have more dramatic losses in muscle mass (Petrella et al. 1989) therefore, strength training exercises may show greater improvements in stability limits in this population.

Quiet Postural Stance - Normalized to Stability Limits

Postural stability in the older adult diminishes as the following two changes occur: increased quiet postural sway and a reduction in stability limits. With these two changes, postural sway will account for a greater percentage of the area of stability in the older adult in comparison to the younger adult group. The ratio of quiet postural stance to stability limits may provide a better basis to evaluate static balance as it expresses the full range of static balance control. Quiet postural stance represents the corrective body movement resulting from the control of upright standing whereas stability limits tests the end point of static balance before dynamic balance control occurs.

The gender by training interaction for this measure reached significance ($p=0.045$) in the a-p direction when the dependent measure was CPy:SLy. The ratio decreased significantly after the strength training program for the male subjects whereas, the female subjects had very little change. The male subjects' balance was seen to improve as both quiet postural sway (a-p) decreased and stability limits (a-p) increased.

Both balance measures (quiet postural sway and stability limits) have been shown to be reliable tests of postural control. Increases in quiet postural sway have been associated with individuals with a history of falls (Lord et al., 1992; Gehlsen & Whaley, 1990; Brocklehurst et al., 1982; Overstall et al., 1977). Falls resulting in injury commonly occur during activities such as leaning and reaching which indicate the importance of testing both stability limits and quiet postural sway when assessing the risk of falls. To represent quiet postural sway as a ratio of stability limits may be a better predictor of those at risk of falls than the test of quiet postural stance or stability limits alone. Research is needed to establish the applicability of a strength training program and its benefits for physically impaired older adults.

CONCLUSIONS

Quiet Postural Stance

* Vision was a significant stabilizing factor as it improved quiet postural sway in both the a-p and lat directions for the older adults.

* Strength training was found to improve quiet postural sway (a-p) for the male subjects, who had substantially high base-line levels of postural sway to begin with.

Stability Limits

* A trend for increased stability limits after the strength training program was found.

* The older adults were able to utilize the visual condition of eyes open, to increase their stability limits in the a-p direction. The male subjects, (not the female subjects) were able to increase stability limits in the lat direction with eyes open.

Quiet Postural Stance - Normalized to Stability Limits

* Improvements in the ratio was seen with training as quiet postural sway decreased and stability limits increased and the greatest improvements were seen in those individuals with poorer balance initially.

* Representing quiet postural sway to an individual's mechanical limits as opposed to an individual's anatomical limits, may be a better predictor of those individuals at risk of falling.

Strength Training to Improve Balance

* Research is needed to establish the benefits of a strength training program for physically impaired older adults and adults who are less active initially.

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APPENDIX 1.

ANOVA Tables

Table 15: Source table for split-plot analysis of variance: quiet postural sway %width (lat)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	59.890	1	59.890	1.768	.197
ERROR	609.597	18	33.866		
WITHIN BLOCKS/SUBJECTS					
TRAINING	4.754	1	4.754	.961	
GENDER TRAINING	.000	1	.001	.0002	
ERROR	89.065	18	4.948		
VISION	337.429	1	337.429	25.164	<.001
GENDER VISION	.756	1	.756	.056	
ERROR	241.367	18	13.409		
TRAINING VISION	1.493	1	1.493	.128	
GENDER TRAINING VISION	5.481	1	5.481	.471	
ERROR	209.355	18	11.631		
(RESIDUAL)	539.787	54			

Table 16: Source table for split-plot analysis of variance: quiet postural sway %length (a-p)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	104.823	1	104.823	4.450	.046
ERROR	424.020	18	23.557		
WITHIN BLOCKS/SUBJECTS					
TRAINING	9.659	1	9.659	1.551	.227
GENDER TRAINING	42.775	1	42.775	6.869	.016
ERROR	112.083	18	6.227		
VISION	99.764	1	99.764	9.427	.006
GENDER VISION	.439	1	.439	.041	
ERROR	190.489	18	10.583		
TRAINING VISION	.995	1	.995	.208	
GENDER TRAINING VISION	.813	1	.813	.170	
ERROR	86.049	18	4.781		
(RESIDUAL)	388.622	54			

Table 17: Source table for split-plot analysis of variance: stability limits %width (lat)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	27.701	1	27.701	.047	
ERROR	10587.098	18	588.172		
WITHIN BLOCKS/SUBJECTS					
TRAINING	284.330	1	284.330	2.334	.140
GENDER TRAINING	34.353	1	34.353	.282	
ERROR	2192.673	18	121.815		
VISION	79.585	1	79.585	1.255	.277
GENDER VISION	275.927	1	275.927	4.352	.049
ERROR	1141.263	18	63.404		
TRAINING VISION	11.172	1	11.172	.437	
GENDER TRAINING VISION	25.048	1	25.048	.979	
ERROR	460.573	18	25.587		
(RESIDUAL)	3794.509	54			

Table 18: Source table for split-plot analysis of variance: stability limits %length (a-p)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	177.548	1	177.548	.280	
ERROR	11427.483	18	634.860		
WITHIN BLOCKS/SUBJECTS					
TRAINING	81.255	1	81.255	2.000	.171
GENDER TRAINING	38.189	1	38.189	.940	
ERROR	731.401	18	40.633		
VISION	147.796	1	147.796	6.302	.020
GENDER VISION	8.520	1	8.520	.363	
ERROR	422.116	18	23.451		
TRAINING VISION	47.963	1	47.963	3.963	.059
GENDER TRAINING VISION	16.203	1	16.203	1.339	.261
ERROR	217.877	18	12.104		
(RESIDUAL)	1371.394	54			

Table 19: Source table for split-plot analysis of variance: quiet postural stance/stability limits (%) (lat)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	362.182	1	362.182	1.425	.246
ERROR	4575.199	18	254.178		
WITHIN BLOCKS/SUBJECTS					
TRAINING	120.130	1	120.130	2.344	.140
GENDER TRAINING	16.358	1	16.358	.319	
ERROR	922.463	18	51.248		
VISION	1808.896	1	1808.896	33.774	<.001
GENDER VISION	238.981	1	238.981	4.462	.046
ERROR	964.068	18	53.559		
TRAINING VISION	18.404	1	18.404	.307	
GENDER TRAINING VISION	56.245	1	56.245	.938	
ERROR	1078.804	18	59.934		
(RESIDUAL)	2965.335	54			

Table 20: Source table for split-plot analysis of variance: quiet postural stance/stability limits (%) (a-p)

SOURCE	SS	DF	MS	F	P
BETWEEN BLOCKS/SUBJECTS					
GENDER	714.017	1	714.017	1.699	.206
ERROR	7566.225	18	420.346		
WITHIN BLOCKS/SUBJECTS					
TRAINING	69.502	1	69.502	2.623	.119
GENDER TRAINING	119.570	1	119.570	4.513	.045
ERROR	476.874	18	26.493		
VISION	711.775	1	711.775	21.759	<.001
GENDER VISION	24.875	1	24.875	.760	
ERROR	588.814	18	32.712		
TRAINING VISION	2.600	1	2.600	.131	
GENDER TRAINING VISION	5.601	1	5.601	.283	
ERROR	356.502	18	19.806		
(RESIDUAL)	1422.190	54			