EFFECTS OF TRAINING SCHEDULE AND AGE ON BALANCE TRAINING UTILIZING VISUAL FEEDBACK

by

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B.Sc. (Kinesiology)
Simon Fraser University, 1990

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF
MASTER OF SCIENCE
in the School
of
Kinesiology

Simon Fraser University
December 1991

APPROVAL

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DEGREE: Master of Science

TITLE: EFFECTS OF TRAINING SCHEDULE AND AGE ON BALANCE TRAINING UTILIZING VISUAL FEEDBACK

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Date Approved: Dec. 12, 1992

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Title of Thesis/Dissertation:

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18 March 92

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ABSTRACT

There has been a growing popularity and success rate of balance rehabilitation programs, and this success is paralleled with the growth of technology, making available instruments providing objective, quantitative, and immediate results regarding postural variables. The Balance Master® is such a commercially available instrument which consists of a dual force platform connected to a microcomputer which provides visual feedback of the center of gravity (COG) in relation to the theoretical limits of stability. Spontaneous body sway can be measured in a static central position, or in peripheral positions around the limits of stability (peripheral sway area). The trajectory between targets can also be analyzed in terms of time (transition time) and accuracy (path error) of transition, which gives a quantitative measure of dynamic movement of the COG. This study examined the practice effect that occurs while using this instrument over repeated sessions for two schedules of training (daily and weekly), and over two age groups (20-35 yrs and 60-75 yrs). Each group completed a series of postural exercises, with an assessment of static and dynamic postural variables before and after training, and at approximately 3 and 6 weeks post-training. Spontaneous body sway was measured with eyes open, eyes closed, and with visual feedback of the COG. No significant changes were observed in these variables as measured over the four standard assessment occasions. Peripheral sway area and path error both decreased significantly for both the daily and weekly training groups from pre- to post-training, and these skills were retained over both retention tests, whereas the tendency towards decreasing transition time was not significant. There were no significant differences between the daily and the weekly training groups. For the elderly group, transition time was the variable with the largest improvement, while path error and peripheral sway area exhibited no significant change. These results identify task specific training effects with repeated practice for a normal population. Also, variables introduced by the Balance Master® system are novel, and these results help to determine the criterion of each one to indicate changes in performance, which appears to vary with age.

DEDICATION

To my mother, Phyllis Cooper.

ACKNOWLEDGEMENTS

My sincere gratitude goes out to the following people:

Igor Mekjavic, my senior supervisor, for providing me with a project in an environment that has given me immeasurable experience and direction with regards to my future, and for putting many things in perspective for me.

John Dickinson and Neil Longridge, my committee members, who always made themselves available in their hectic schedules for their help and support.

The Neuro-Otology and Otolaryngology staff at Vancouver General Hospital, notably Art Mallinson, Shannon Roseborough, and especially Catherine Nault for organizing peculiar schedules of "subjects" and "patients."

Richard Carson and Winston Byblow for their statistical advice.

Victoria Panzer and Leslie Allison for their advice and hospitality, and the entire staff at NeuroCom who were promptly available for technical advice.

All of my subjects, for their perseverance and patience in completing several sessions without a complaint. This would not be possible if it weren't for them, and I have established many new friendships as a result of their participation.

My husband Brian for his patience.

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Introduction

The retraining of balance skills in the patient suffering from disequilibrium and postural instability has, in the past, been random in its approach. Rehabilitation in this area has become a therapeutic measure of increasing importance. The complexity of the sensorimotor arrangement of the "balance system" makes it difficult to diagnose causal factors, and consequently, the rehabilitation imprecise.

A system of exercises for treating patients with vertigo was first described by Cawthorne and Cooksey (as referenced by Dix, 1984). Approximately 50 years later, a systems approach to treating balance disorders, initiated by Shumway-Cook and Horak (1989, 1990), has taken into account the intricacy of maintaining stable equilibrium. This program includes assessment of postural control in sitting, standing and walking (musculoskeletal components, motor coordination, sensory organization, detecting centre of mass movements, and perception of stability), eye-head coordination and gaze stabilization, motion perception, and overall physical conditioning (Shumway-Cook and Horak, 1990). Thus, the Cawthorne-Cooksey exercises compose only a small part in the overall assessment and rehabilitation of a patient with an equilibrium disorder.

Assessment of progress during the rehabilitation process has normally relied on the therapist's subjective opinion (amount of body sway, scales indicating intensity of vertigo, etc.). This is useful in clinical environments, however these methods are subject to low inter-rater reliability and sensitivity. Technological advances are making available instruments providing objective and quantitative measurements and assessment during rehabilitation. The Balance Master® is a commercially available instrument which provides some diagnostic information and offers rehabilitative procedures for the unstable patient. It consists of a dual force platform connected to a microcomputer, and theoretically works to estimate a subject's centre of gravity (COG) and projects it as a reference point onto a computer screen. By this means, subjects may use this reference as a source of feedback while moving their body in space. It is an instrument to be used as a component within the scope of a rehabilitation program. In this thesis, the practice effect that occurs while using this instrument over repeated sessions is compared for two schedules of training, and two age groups.

Postural Rehabilitation

Maintenance of posture is a dynamic activity requiring constant input and integration of visual, somatosensory, and vestibular information, and the appropriate motor output to keep the body's COG over its base of support (Nashner and McCollum, 1985). Balance and equilibrium disorders can therefore result from compromise of any of these peripheral senses, distorted perception or integration of the incoming messages, or inappropriate motor output. Rehabilitation is broadly based on the principles of vestibular compensation and central nervous system adaptive plasticity, and several approaches can be taken. The success of its use depends on the nature of the disorder, and appropriate assessment (Brandt and Daroff, 1980; Shumway-Cook and Horak, 1989; Herdman, 1990; Horak et al., 1990b; Telian et al., 1990; Shepard et al., 1990; Shumway-Cook and Horak, 1990; Whitney and Blatchly, 1991).

Vestibular compensation can be defined as the "process of recovery following a vestibular lesion by which an ideal functional state is reinstated" (Telian et al., 1990). Peripheral vestibular disorders often result in symptoms such as postural instability and/or ataxia, vertigo or dizziness, and vegetative symptoms. Fortunately, these cases are quite responsive to vestibular rehabilitation, based on the ability of the CNS to adapt to, or compensate for, any modifications in the sensory information that it is required to process. It accomplishes this by means of two mechanisms: i) in a unilateral loss of function, the balance between the left and right vestibular centres is re-established; and ii) visual and kinaesthetic information is substituted for lost vestibular signals (Bles et al., 1984; Igarashi, 1984). By this compensation process, most people with equilibrium disorders of a vestibular nature will eventually undergo spontaneous recovery, however the process may be accelerated or may proceed more efficiently with the appropriate rehabilitative exercise program (Maioli and Precht, 1985; Takemori et al., 1985). Successful compensation depends also on age, and the integrity of several CNS structures such as the vestibular nuclei, the visual system, the cerebellum, the inferior olive, the commissural system, and the spinal cord (Igarashi, 1984). It is also limited by central nervous efferent dysfunction, as well as physical difficulties such as arthritis.

Cawthorne and Cooksey (as referenced by Dix, 1985) focussed on the idea of specific exercises to attenuate symptoms caused by peripheral labyrinthine insult. They laid out a series of exercises ranging from simple eye tracking movements to whole body actions coordinated with eye and head maneuvers. Following this, several habituation exercise protocols have been developed (Brandt and Daroff, 1980; Norre, 1987). The theory proposed that this activity would accentuate the compensation process by habituating a response to a repeated stimulus, and is quite successful for peripheral vestibular disorders such as benign positional paroxysmal vertigo (BPPV) (Herdman, 1990; Horak et al., 1990b). Shumway-Cooke and Horak, (1989; 1990) have established a comprehensive program of physical therapy for equilibrium disorders involving habituation exercises along with general exercise conditioning, with treatment being specific to each patient, and for a diversity of patient populations. The effectiveness of physical activity on the vestibular compensation process has been known for some time. Because "compensation is dependent on accumulation of direction-specific information delivered through various gravity and linear force sensors" (Igarashi, 1984), passive or active movement in itself is advantageous in the compensation process (Dichgans et al., 1973). Lacour and Xerri (1981) have demonstrated that the restriction of motor activity in cats or baboons following unilateral vestibular lesions prevents full compensation. Exercise, along with exposure to visual and/or somatosensory stimuli is the basis of a comprehensive vestibular rehabilitation program. All of these protocols combined, aid in exposing the patient to stimulus situations to assist in: i) rebalancing the tonic labyrinthine activity between the two sides, and; ii) activating sensorimotor rearrangement by multisensory substitution requiring activity of the subject.

Equilibrium may also be affected by inappropriate motor control of postural responses. Effective balance requires the COG to be positioned over some portion of the support base. A concept which is integral to the Balance Master® is the theoretical limits of stability (LOS). The LOS is pictured as a cone with its apex projecting from the centre of the base of support (the feet in a neutral standing position) (Fig. 1). If movement about the ankle joints occured like an inverted pendulum, the LOS would extend approximately 12^{o} in the antero-posterior (AP) direction (8^{o} anteriorly and 4^{o} posteriorly; Fig. 1a), and 16^{o} in the lateral direction (8^{o} to either side; Fig. 1b) (Nashner, 1989). The area within this cone represents the range in which the COG can be moved safely without changing the base of support or relying on an external object for stability. The area of the theoretical LOS cone should differ between individuals based on total height and foot length, however it was found that these 2 variables co-vary, and therefore the area of the cone is approximately the same for everyone (Nashner, 1989).

Target positions on the Balance Master® screen are expressed as coordinates of the theoretical LOS cone. The distance of the target from the apex of the cone is expressed as a percentage of the LOS cone, and the position of the target is expressed in degrees with the anterior position at 0^{o} or 360^{o}, the right lateral position at 90^{o}, the posterior position at 180^{o}, the left lateral position at 270^{o}, etc. The amount of body sway can be calculated in a central position, or anywhere within the area of the theoretical LOS , and is expressed as a percentage of the LOS. For example, if body sway in a central position were measured for 20 seconds, the total area of COG excursions would be calculated, and this area would be expressed as a percentage of total LOS. Likewise, the accuracy of the transition from target to target is defined as path error, and is the area of the deviation taken from a straight line path between targets, expressed as a percentage of the total LOS cone.

Theoretically, a variety of strategies could be taken by the various body segments, which would result in many postures. However, the moving platform studies of Nashner and colleagues (Nashner, 1976; 1977; 1982; 1983; Nashner and McCollum, 1985; Horak and Nashner, 1986) suggest that movements of the COG are controlled through central processes that organize the postural muscles into distinct movement strategies. They observed three discrete strategies which control postural sway in the AP-plane, these are: i) ankle strategy; ii) hip strategy and; iii) stepping strategy. These strategies, or combinations of them, are shown to be "automatic" postural reactions in normal subjects when their equilibrium is unexpectedly displaced under various circumstances (Horak and Nashner, 1986). Ankle strategy is used to compensate for small displacements of the COG relative to foot length within the LOS, on firm support surfaces supporting the entire base of the feet. This strategy exerts torques about the ankle joints to restore an equilbrium position by activating muscles in a distal to proximal sequence (ankle-thigh-trunk). Hip strategy is used to exert horizontal shear forces against the support surface in response to larger, faster perturbations within the LOS, or if the support surface is short in relation to foot length. This strategy recruits muscles in a proximal to distal sequence and produces relatively little, if any, ankle torque. A stepping strategy is needed to establish equilibrium when the postural perturbation is of sufficient magnitude to displace the centre of body mass outside the base of support of the feet.

These automatic postural reactions have an onset latency between that of a simple stretch reflex and the earliest volitional movements (Nashner, 1982). However, they are also adaptable based on prior experience of postural stimulus velocities and amplitudes (Horak et al., 1989b). Prior knowledge of stimulus conditions is termed "central set" or "postural set", and can decrease the time it takes for the CNS to respond to an eliciting stimulus. If the stimulus conditions unexpectedly change, the central set can lead to errors in the response. Sensory feedback may also be used to modify the response to correct for unexpected conditions (Diener et al., 1983). The use of these automatic postural responses may be affected by disease (Black and Nashner, 1984; Horak, 1990a; Black et al., 1992), sensory deprivation (Horak et al., 1990c), or age (Woollacott et al., 1988). For example, when somatosensory information was removed from normal subjects by placing pneumatic cuffs above the ankle joints and inducing ischemic hypoxia of nerve fibers, they were unable to select or control an ankle strategy (Horak et al., 1990c). Bilateral vestibular deficit patients display a lack of hip strategy when the environmental constraints call for one (Horak et al., 1990c). Patients with cerebellar lesions display an inability to use previous experience effectively to scale the amplitude of postural responses to the amplitude of the stimulus (Horak, 1990a). Aging populations have increased latencies of responses to postural perturbations (Woollacott et al., 1988), and have an altered perception of their LOS cone (Horak et al., 1989a).

Thus, there is an intricate connection between sensory detection and motor control of postural responses. In terms of postural rehabilitation, it is speculated that lost postural strategies can be "retrained" (Balance Master® Clinical Integration Seminar, 1991). Within conventional physical therapy, the repetition of an action is necessary for gaining skilled movement in retraining neurologically impaired patients (Lee et al., 1991), and that repeated practice of voluntary movements can "reprogram" automatic responses. This theory is utilized in physical therapy by repetition of motor skill formations. Bach-y-Rita and Bailliet (1987), as a therapy for post-stroke patients, suggest that:

> "volitional motor control sequences will ultimately have to be practiced thousands of times in order to store a new motor program that is relatively fast i.e. automatic, co-ordinated, effortless, functional and generalizable." (p298)

Theoretically, providing visual feedback while repeatedly practicing these strategies should substantially augment the retraining process of the patient lacking sources of intrinsic feedback. Retraining of postural strategies by volitional repetition during therapy, however, has not been directly studied.

Assessment of Posture

The measurement of postural sway in a central position with eyes open and eyes closed is well documented as an index of stability known as the Romberg quotient (Allum, 1990). Since it's inception in 1853, it has been used as a standard neurological test of standing stability, however it is a subjective measure, and suffers in reliabilty, especially between individual measurers. After years of use, it has been found that the standard Romberg test is not sufficiently capable of differentiating patients with vestibular defiencies from normal (Allum, 1990). There was therefore a need for quantitative, objective measures of static posture which would be sensitive to classify specific patient groups, and document changes over time (Stribley et al., 1974). The force platform, which provides a measure of center of foot pressure (COP) has therefore been largely used as a quantitative measure of postural stability (Murray and Peterson, 1973; Stribley et al., 1974; Dickstein et al., 1984). The reliability of COP measures to indicate postural instability has also been questioned because the COP does not adequately reflect movement of the COG, and it is the deviations of the COG from a static central position which more adequately reflect postural instability (Patla et al., 1990; Panzer et al., 1992).

The Balance Master® system introduces variables which are new to the field of balance rehabilitation and the study of posture in general. For example, although the static postural tests (eyes open and eyes closed) have been utilized for years, expressing these measures as a percentage of one's theoretical LOS cone is very novel. Just as the Romberg quotient, and several other standard tests of stability (one-legged stance test, COP measures) have been found to lack sensitivity to differentiate patient populations (at a gross level), the static variables produced by the Balance Master® need adequate evaluation.

The Balance Master® incorporates a novel approach to record movements of the COG. Excursions of the center of foot pressure are filtered of high frequency components (Panzer et al., 1992). COG sway angle is found via a simple right angle relationship between the filtered COP readings and the height of the COG. Although it was not an objective of this thesis to evaluate the validity and reliability of this method, the sensitivity of the variables, produced by this method, to document changes over training were examined. The evaluation of a normal population is an obvious starting point, before examining different patient populations.

The dynamic variables produced by the Balance Master® are also unique. Accuracy and speed of transitions while visually tracking targets, and stability at non-central targets have been defined, in this thesis, as measures of balance in a dynamic environment, in that the subject is required to control the "COG" while moving within the theoretical LOS cone. Several tests of balance in a "non-central' position have been developed (Era and Heikkinen, 1985; Chandler et al., 1990; Hill et al., 1990) where the subject is unexpectedly/expectedly perturbed from static upright posture. None of these tests monitor volitional movements of the subject, thus the Balance Master® provides novel information regarding movement strategies. When the dynamic assessment is being performed, the goal of the subject is to place the COG cursor into the desired target, and although an "ankle strategy" may be the correct and most effective way of doing this, there are other postural strategies that may be "voluntarily" executed by the subject. Although it is ultimately the decision of the therapist/clinician to monitor the strategy utilized, too much intervention renders an "assessment" invalid. From a theoretical standpoint, any person who repeatedly practices on this instrument will change by some means. It was the purpose of this thesis to examine and report the changes that occur by repeated practice.

Visual Feedback for Postural Rehabilitation

Sensory feedback therapy is a technique that utilizes visual, auditory, or somatosensory feedback to relay information about internal physiological events in order to help one control these events (Mulder and Hulstyn, 1984). Patient populations in need of neuromuscular re-education are generally lacking or have distorted feedback loops, as in the vestibular deficient patient. Often, these patients recieve no, or inadequate intrinsic information regarding their performance. All contemporary motor learning models incorporate sensory feedback as a mandatory part of the acquisition of motor skills (Mulder and Hulstyn, 1984), therefore inadequate feedback during the retraining process may hinder this process. Feedback from extrinsic sources regarding one's performance has been extensively studied (Schmidt and Young, 1991). In rehabilitation, often the external source of information is a clinician or a therapist, however the information is often qualitative, subjective, superficial and slow (Mulder and Hulstyn, 1984). On the other hand, augmented sensory feedback can be characterized by quantitativity, objectivity, accuracy and immediateness.

With reference to postural rehabilitation, artificial feedback in the form of visual, somatosensory or auditory information customarily provides feedback about measured body sway (Seeger and Caudrey, 1983; Brandt and Paulus, 1989; Clarke et al., 1990; Hamann and Krausen, 1990; Jobst, 1990; Ohashi, 1990) or symmetry of stance (Wannstedt and Herman, 1978; Shumway-Cook et al., 1988; Winstein et al., 1989). Providing feedback by these means has been used with varying degrees of success. For example, Wannstedt and Herman (1978) used a Limb Load Monitor which provided auditory feedback regarding symmetry of weight bearing in patients with unilateral hemiparesis. They found this to be successful in teaching symmetrical weight bearing in stance.

Force platform arrangements have been found advantageous in quantifying postural characteristics for normals (Sheldon, 1963; Shipley and Harley, 1971; Murray and Peterson, 1973; Stribley et al., 1974) and for patients with peripheral and central vestibular disorders (Diener et al., 1984; Dickstein et al., 1984). Shumway-Cook (1988) and Winstein (1989) used a force platform connected to a microcomputer to help hemiplegic patients (secondary to cerebral vascular accident) visualize their center of pressure, and used this information as feedback to reduce load assymetries in stance. This biofeedback therapy integrated with conventional physical therapy showed better results for the task than physical therapy alone. Jobst (1990) used the same type of arrangement for ataxic patients with brainstem or cerebellar lesions by displaying both desired and actual movements of body leaning in the antero-posterior (AP) plane on a microcomputer screen. He used one static feedback exercise aimed at reducing overall body sway, and four dynamic exercises with increasing levels of difficulty, requiring subjects to lean forward out of the upright standing position. He found that a percentage of the patient group displayed a dramatic improvement within the first 2-3 sessions, which he defined as a short term adaptation to training, and not as a real improvement in the task ability. In another portion of the group, he observed a continuous positive trend, which he defined as a training success. He did not however, differentiate learning from "performance" in that there was no long term assessment executed. In following with this training effect, Clarke et al. (1990) had 10 "normal" subjects pursue a visual target driven by a sinusoidal function at 0.05 Hz. The basic training session consisted of four-one minute exercises (of varying difficulty) repeated 5 times at intervals of 5 minutes. He found a deterioration of performance after 3 of the 5 exercises which he attributed to fatigue. He also had the subjects repeat the exercises every 24-hours for four sessions. He reported that after the first session, a constant level of performance was maintained following an initial learning effect. Hamann and colleagues (1990) showed that normal subjects and patients with peripheral vestibular disorders reduced their body sway over a 10 day training session by visualization of the COG with computerized feedback of AP sway. They did not, however, differentiate between the learning curves of the vestibular patients and normals, and again gave no information of long term retention of body sway reduction. An interesting point to this study was the claim that a transfer effect of training carried over to other vestibular symptoms such as a reduction of vertiginous complaints, and an improvement in rotatory asymmetries and spontaneous nystagmus. These results were not quantified, however, nor were they explained.

The growing popularity and documented success of vestibular rehabilitation programs has been accompanied by the parallel growth of technology, with the development of instruments capable of providing objective, quantitative, and immediate information regarding postural variables as a source of biofeedback. With any type of patient population, this treatment strategy requires training over repeated sessions, therefore a practice effect is introduced based on the difficulty and the specificity of the task involved. This practice effect must be taken into account when evaluating rehabilitative results of a therapy. It has been previously demonstrated in "normal" populations that task-specific training occurs after performing dynamic postural exercises using visual feedback of position (Hasselkus and

Shambes, 1975; Brandt et al., 1989; Hamann et al., 1990). Hamman et al. (1992, see also Appendix A) monitored young adults (ages 20-35) tracking targets on a computer screen by moving a cursor representing their estimated COG over a 5 session training protocol. They reported a 24% reduction of path error in the trajectory between targets, as well as a 50% reduction of body sway upon reaching the target. This decrease occurred within the first 2-3 sessions of training, after which a plateau in performance occurred.

What needs to be determined is whether this practice effect is based on the specificity of the task, or if an effect on balance has ensued for any given patient population. What appears to be improvement as documented by the quantitative output by the instrument, may not represent an improvement in balance performance in a functional sense.

Training Schedules and Postural Training

The first objective of this thesis was to determine the effects of practice on both the performance and learning of dynamic postural exercises using visual feedback of COG position. A comparison is made between a short-term (daily) and a long-term (weekly) practice schedule. There is a clear distinction between "performance" and "learning". In the context of motor skill acquisition, performance is the observable behavior, and can often be measured quantitatively, whereas learning is inferred from the performance (Magill, 1980). Whether learning has occurred is normally inferred from the relative long-term improvement in performance as a result of practice. An assessment of learning can be made via a retention test, which is a quantitative performance score after a time period of not performing the task to be learned. A retention test allows for a measurement of performance after the temporary effects of practicing a skill have dissipated (Lee and Genovese, 1988).

Schedules of practice, and their effects on performance and learning have long been debated (Lee and Genovese, 1988). Massed practice is normally defined as a schedule of practice with little or no rest in between practice trials, or in more general terms, where the amount of practice in a trial is greater than the amount of rest between trials (Schmidt, 1982). In contrast, distributed practice is defined in terms of rest intervals that are relatively longer than under massing conditions (Magill, 1985). The lengths of the inter-trial intervals vary quite remarkably for these two defined schedules in different experiments. In a review by Lee and Genovese (1988), several experiments were re-analyzed to determine the effects of practice schedules on performance and learning by use of absolute retention scores. They concluded that distributed practice is better than massed practice in terms of performance, and to a lesser extent, for learning.

In postural training studies, different training schedules have been employed, but the question has never been researched directly. Brandt and coworkers (1981) studied the effects of training on postural instability by having healthy subjects balance with their necks extended posteriorly (thereby putting the utricular otoliths out of their optimal working range). This was done with eyes open and eyes closed, and also while standing on foam to remove somatosensory information. Training sessions were held for 1 hour/day for 5 days, and then weekly measurements were taken up to 40 days after termination of training. It was found that sway area decreased by 50% after 5 days of training and returned to pre-training scores within weeks. Seeger (1983) used acoustical feedback therapy to help hemiplegic children achieve symmetrical gait patterns. Retention tests were performed 18-24 months after termination of a 1-6 month feedback program and scores had returned to pre-training levels. Both Jobst (1990) and Clarke (1990) documented performance effects using visual feedback of postural variables in both ataxic patients (brainstem and cerebellar lesions) and normals respectively, however, no long-term retention assessments were conducted to establish how well these tasks were learned.

To apply the results of traditional motor skill acquisition experiments regarding distribution of practice schedules to postural retraining in therapy, the distributed practice is the only one that may be applied. In practical terms, due to the limitations of both the therapist and the patient, the lower end of the scheduling continuum would be limited to once or twice daily. A more distributed practice schedule would be suitable for out-patients, and occur one or twice weekly at most. Efficiency of scheduling and its implications for learning have never been considered for any discipline of therapy. Hamman et al., (1992, see also Appendix A) revealed no observable difference in performance scores of several postural variables between a daily and a weekly training protocol using visual feedback of the COG. However, there was no assessment of learning in terms of a long-term retention.

Age and Postural Retraining

Balance in the older generation is of particular interest because of the high incidence of falls leading to disability and mortality in this age group (Overstall et al., 1977; Woollacott et al., 1982; Hill et al., 1990; Horak et al, 1989a; Patla et al., 1990). Thus, much research has been devoted to examining factors which predispose this group to falls, and methods of preventing them (Brocklehurst et al., 1982; Fernie et al., 1982; Chandler et al., 1990; Gehlsen and Whaley, 1990a, 1990b). The second objective of this thesis was to compare practice effects of postural training using visual feedback between a young and an elderly population, and it was hypothesized that the performance curves would differ significantly.

Learning in older individuals is believed to occur at a slower rate (Welford, 1982). Again, the slower acquisition of motor skill, notably postural skills, could be caused by disease or deterioration of sensorimotor mechanisms, or a complex combination of both (Isaacs, 1982; Welford, 1984). Welford (1982; 1984) has offered several explanations for the slower rate of learning motor skills in the elderly such as slower central processing, an example would be the increase in reaction time with age as the number of choices are expanded. Welford ((1982) also suggested a decrease in the short term memory capacity in older individuals, in that they need more trials to reach any given criterion of learning. Another observation is that older individuals place a greater emphasis on accuracy compared to a younger population (Salthouse, 1979).

It is a well known fact that the amount of standing body sway is increased in the older population (Hellebrandt and Braun, 1939; Sheldon, 1963; Hasselkus and Shambes, 1975;

Overstall et al., 1977; Era and Heikkinen, 1985), and is greater in those predisposed to falls (Overstall et al., 1977; Fernie et al., 1982; Chandler et al., 1990; Gehlsen and Whaley, 1990b). A lack of standardization in testing balance function makes it difficult to confirm any conclusions as to the factors predisposing elderly persons to lose their balance. Patla et al. (1990) reviewed several methods of assessing balance function in an elderly population and judged that static unperturbed balance tests, such as the Romberg tests and one legged stance test (eyes open and eyes closed), were not predictive for predisposition to falls, because very few falls occur when people are standing quietly. Several dynamic tests have been introduced which assess balance under expected and unexpected (Era and Heikkinen, 1985; Chandler et al., 1990; Hill et al., 1990) perturbations to equilibrium. Again, to identify fall-prone individuals these studies had to accept high false positive rates.

Studying an aging population introduces several factors apart from the experimental variables, which may greatly confound any results. Inter-individual variability increases as a function of increasing age, which means that a sample population may contain a "substantial number of old people performing at a level at least equal to that of the average group of younger subjects" (Welford, 1958 as quoted by Ingram, 1988). The process of aging is a highly individual process influenced by both genetic and environmental factors (Ingram, 1988; Light, 1990), and therefore not difficult to obtain a biased experimental sample. Another issue involved with the aging population is that of "aging" as an exclusive phenomenon as opposed to pathology. With reference to the field of motor control, specifically postural control, it is difficult to classify aging vs. pathological effects (Woollacott et al., 1982; Welford, 1984; Horak et al., 1989a). In this respect, it becomes difficult to compare individual studies due to the criterion of each one to define a "normal " aging population. An example of this difficulty is evident in a study designed to observe variability of gait between young and old populations conducted by Gabell and Nayak (1984). They screened 1187 elderly subjects for pathological disorders of the musculoskeletal, neurological, or cardiovascular systems, and in the final sample of 32, observed that gait patterning mechanisms did not differ significantly from the younger population. Several age-related changes occur to the nervous and musculoskeletal tissues which could contribute to the reduction of postural control, commonly observed in an elderly population (Frolkis et al., 1976; Brody, 1982; Isaacs, 1982), and it is beyond the realm of this thesis to discuss these in any detail.

The Balance Master® is only one tool in a large number of available instruments aimed at postural retraining. It was designed to be utilized within the context of a well-designed rehabilitation program. It has the advantage of providing quantitative variables intended to reflect different components of static and dynamic balance measures. These quantitative variables are, however, novel in their use based on the design of the instrument. This thesis was designed to evaluate shifts in the variables produced by the Balance Master® over two separate training schedules, and between two age groups. This was intended to identify task-specific training effects with repeated practice on the instrument, and also to identify which variables may indicate changes in performance for a normal population.

Methods

Subjects

Two groups of subjects were selected to fit specific age categories. The subjects were not randomly chosen, as many of them were hospital employees, or relatives of hospital employees. This made it more convenient for the subjects to return repeatedly. Group 1 were between the ages of 25 and 35 years. This group was pseudo-randomly subdivided further into two groups. Group 1a (n=10) consisted of 5 females, 5 males, with a mean age of 26 $\pm$ 2.2 yrs. Group 1b (n=9) consisted of 5 females, 4 males, with a mean age of 26.8 $\pm$ 1.9 yrs. Group 2 (n=10) consisted of 5 females, 5 males, and were between the ages of 60 and 75 with a mean age of 66.8 $\pm$ 2.9 yrs.

A questionnaire was administered to each subject to identify any known neurologic or musculoskeletal complications (see Appendix B). For an elderly population, it is difficult to rule out such complications completely. If symptoms were reported that may have been of vestibular origin such as dizziness, instability in the form of unexplained falls, the subject would have been excluded from the study. None of the subjects had any gross aberrations affecting the balance system as determined by questionnaire, however none of the subjects underwent any visual, vestibular or physical tests. No one was excluded from the study.

Apparatus

The Balance Master® system (NeuroCom™ International Inc., Clackamas, Oregon) was used for both the assessment and the training protocol. A schematic diagram depicting the layout of the Balance Master® system is shown in Fig. 2. The platform consists of two adjacent forceplates, each with two strain guages in the anterior and posterior corners. Total vertical force is determined by adding the anterior and posterior right and left forces exerted by the subject standing on the force plates. The height of the subject's COG (H_{COG}) is calculated based on their standing height (Webb, 1964). In normal quiet standing, it has been determined that the body is vertically erect when the COG is approximately 14% of foot length, or 2.3^{o} in front of the medial malleolus of the ankle (Balance Master® Operator's Manual, 1989).

COG sway angle (θ), defined as the angle between a vertical line projecting upward from the centre of foot support and a second line projecting from the same point to the subject's COG (Balance Master ® Operator's Manual, 1989), can be estimated from the vertical force data and the H_{COG}. This is based on a model depicting the body as a rigid mass with rotation occuring at the ankle joints like an inverted pendulum. As an example, COG sway angle in the AP-plane at time i is computed from sampling the instantaneous positions of the total vertical force (PY). PY at time i, therefore, is an average position of the center of total vertical force sampled over 14 data points at a sampling rate of 20 Hz. This value can be defined by the equation:

$$PY(i) = \frac{\sum_{j=0}^{13} PY(i-j)}{14} \quad (1)$$

where $PY(i\text{-}j)$ is the instantaneous position of the total vertical force at the i-jth sample, and 14 is the number of data points on which the running average is computed (Balance Master® Operator's Manual). The value of $PY(i)$ is low-pass filtered to eliminate the high frequency components of the center of pressure (Panzer et al., 1992).

The position of the COG at time i is then be estimated by the geometric relationship between $\theta(i)$ and $PY(i)$ (Fig. 3). From the estimates of H_{COG}, and the position of the COG over the force plate ($PY(i)$), the COG sway angle (θ) can be calculated from the following equation:

$$PY(i) = H_{COG} \times \sin [\, \theta(i) + 2.3] \quad (2)$$

The value of 2.3 represents the angle of the COG from the medial malleoli of the ankles. This procedure for calculating sway angle is accurate for sway rates up to 0.3 Hz, at which point the sway angle lags behind the actual sway angle (Balance Master® Operator's Manual, 1989). The COG appears as a cross on the screen facing opposite the subject at eye level.

Procedure

During the first session, the subjects' feet were placed according to a recommended foot position on the force plate (Balance Master® Operator's Manual, 1989). A sheet of paper was fixed and referenced to a point on the force plate. Subjects were asked to have bare or lightly stockinged feet. The feet were placed symmetrically on both sides of the plate, keeping them equidistant from the vertical axis. The ankle joints were positioned immediately above the horizontal axis position as referenced by a grid etched on the platform. The medial malleoli were used as landmarks for positioning on the horizontal axis. The subjects were then allowed to splay the feet to a comfortable position while keeping the heels in place. The subjects' feet were then traced onto the sheet of paper which was used in subsequent sessions to keep foot position constant.

After proper foot positioning, the concept of COG movement was explained to the subjects. A screen was displayed with a central target and the COG cursor. Subjects were instructed to move in all directions by swaying about their ankle joints and note the corresponding trajectory of the COG cursor on the screen. It was demonstrated that movement about the ankle joints moved the COG cursor more effectively than movement about the hips. The subjects were asked to assume that their bodies were rigid rods and that they could only move about the ankle joints. Motion about the ankles and/or hips was not directly measured. This procedure was described only once and not demonstrated again throughout the course of training. The only time that any mention was made of the subjects' postural actions was when they arched the back, increasing lower lumbar curvature, as this was not permissible. They were then asked to situate themselves in the central target, and adjustments in foot position were made, if needed, to have normal upright stance as a central reference position on the screen.

Standard Assessment Protocol

The standard assessment consisted of a group of tests administed to each group before the initial training session (pre), after the final training session (post) and for two retention assessments (retI and retII) at approximately three and six weeks respectively after the post-training assessment. The Balance Master® was used for all of these tests, which included the following:

1) A measure of standing body sway, without feedback of COG position, with eyes open (Sway-EO). Subjects were instructed to relax with the arms down at their sides, look straight ahead, breathe normally, and stand as still as possible.

2) A measure of standing body sway with eyes closed (Sway-EC).

3) A measure of standing body sway with feedback of the COG position (Sway-VF). For this test, a central target and the COG cursor were depicted on the screen. The subject's were instructed to hold the cursor "as steady as possible" in the central target.

The above three tests comprised the static postural variables. Body sway, under each of the above three conditions, was measured for 20 seconds, at a sampling rate of 20 Hz. Body sway was expressed as a percentage of the subject's theoretical LOS.

4) This test displayed 8 targets on the computer screen arranged in a circle, placed at 45° increments, at 75% of the theoretical LOS limit. Another target was placed in the central position (Fig. 4). This target tracking exercise required the subjects to begin with the COG cursor placed in the central target. A peripheral target was then highlighted and the subjects were instructed to move the COG cursor to the highlighted target "as quickly and accurately as possible," and then to hold the cursor in the peripheral target until the central target was again highlighted. Peripheral targets were then highlighted in a clockwise manner, with the COG

cursor being returned to centre before proceeding to the subsequent highlighted peripheral target. A pacing speed of 9-seconds was set, meaning the peripheral target was highlighted for 9 seconds before returning to the central target. The variables from this test comprised the dynamic postural variables:

a) transition time, TT (s): time taken to move the COG cursor from the central target to the highlighted peripheral target (failure to reach the peripheral target at all was recorded as a time of 9.0s).

b) path error, PE (%LOS): the deviation from a straight line path taken from the central target to the highlighted peripheral target. The area of the deviation from a straight line was calculated and expressed as a percentage of the subject's theoretical LOS cone.

c) peripheral sway area, PSA (%LOS): the amount of body sway calculated after the subject reached a highlighted peripheral target, a measure of stability or control when the body was placed in a non-central position. The amount of peripheral body sway was dependent on the time that was actually spent at the peripheral target. Therefore, peripheral sway area was recalculated manually and expressed as the amount of body sway at the peripheral target divided by the time spent at that target (%LOS/s).

Training Protocol

Each group completed the same protocol over 5 training sessions. Group 1a completed one training session per day at approximately the same time each day. Group 1b and 2 completed one training session per week. The training protocol consisted of target tracking exercises on the Balance Master®. The practice regime consisted of a random presentation of eight different target trajectories. Each target trajectory comprised a target representing vertical center and one peripheral target at 75% of the theoretical LOS limit. Each target was highlighted so that there was a total of two round trips to the peripheral target and back to the central target. The pacing speed was also set at 9 seconds for these exercises. Transition time and path error were recorded for each trajectory between targets, and central and peripheral sway area was recorded once the target was hit. These scores were recorded to evaluate the actual performance curves over the course of training.

Data Analysis

Significance was determined at a 0.05 α-level using the Huynh-Feldt correction factor for degrees of freedom adjustment. *Post-hoc* multiple comparisons were performed using Tukey's honestly significant difference (HSD) tests.

1. Gender Effect

Because each group consisted of approximately the same number of males and females, analysis was done to rule out any effect of gender. Both static and dynamic postural variables for the standard assessment protocol on all 4 assessment occasions (pre, post, retI, and retII) were analyzed . Two-way analyses of variance (ANOVA) for repeated measures were used collapsed over groups (daily and weekly) allowing comparison of males (n=9) and females (n=10) over the 4 assessment occasions.

2. Practice Schedule Effect

For the static variables (Sway-EO, Sway-EC, and Sway-VF), two-way ANOVAs for repeated measures were used for comparison of groups over the 4 assessment occasions.

Scores for each of the dynamic variables (TT, PE, and PSA) were averaged over the 8 target transitions. Two-way ANOVAs for repeated measures were then used to compare groups over the 4 assessment occasions. In addition, each target for the dynamic assessment was standardized, because the theoretical LOS cone extends 8^{o} anteriorly and laterally, but only 4^{o}

posteriorly. To standardize the targets for equal weighting in an analysis, the scores for the 3 posterior targets (right-posterior, posterior, and left-posterior) were multiplied by a factor of 2. These scores were used to investigate any directional preferences. Three-way ANOVAs for repeated measures were performed to observe directional differences in performance over the course of the 4 assessment occasions.

Two-way ANOVAs for repeated measures with a mixed design were used.

3. Age Effect

The elderly group were trained once per week and therefore compared to the weekly training group. Two-way ANOVAs for repeated measures were used to compare group differences over the 4 assessment occasions, and over the 5 training sessions.

Results

The analysis for groups 1a and 1b was completed to investigate the effect of practice schedules on the individual variables before the elderly group was recruited. Group 1a (daily) completed the first retention assessment at an average time of 21 days after the post-training evaluation, and the second retention assessment averaged 45 days post-training. Group 1b (weekly) completed the first and second retention tests at an average of 25.8 days and 44 days post-training, respectively.

1. Gender Effects

There was no difference between males (n=9) and females (n=10) for the static postural variables (Sway-EO, Sway-EC, Sway-VF) over the 4 assessment occasions.

For the dynamic variables, a gender difference was found for transition time only (Fig. 5a), where females were consistently slower than males. Path error and peripheral sway area displayed no group effects (Figs. 5b and c). Gender was not considered as a factor in the remaining analysis.

2. Practice Schedule Effects

Static Variables

The overall trend for the static variables (EO, EC, and VF) was a decrease in postural sway from the pre- to the post-training assessment. Postural sway then increased to a level between that of pre- and post-training for the two retention tests. Departures to this trend did, however occur.

There was no significant difference between groups or assessment occasions over repeated measures for static sway as measured with eyes open. There was, however, a group by assessment interaction for this variable (Fig. 6a).

Postural body sway measured with eyes closed showed a significant difference between groups. Figure 6b shows that this difference occurs between the pre- and post-scores of the weekly group compared to the same scores of the daily group. There was no significant effect for assessment over repeated measures.

There was no effect for group or assessment over repeated measures for static sway measured with visual feedback provided (Fig. 6c).

Table 1 shows the mean difference between the pre- and post-training scores for static sway measured under each condition. A negative mean difference would indicate that an increase in postural sway occurred from the pre-training to the post-training measurement. For conditions with eyes open and with visual feedback provided, and for the daily training group with eyes closed, there was a decrease in the overall amount of body sway from the pre- to the post-training assessments. The weekly training group under the eyes closed condition showed a slight increase in postural body sway between these two assessments.

Dynamic Variables

The first part of this analysis was executed to compare groups over the 4 assessment occasions. For each subject, the values for transition time, path error, and peripheral sway area were obtained by averaging the scores for all 8 targets on the standard assessment. These means were then used in the subsequent analysis. There was no significant effect for group for any of the three variables. For both the weekly and the daily training groups, the scores for transition time, path error, and peripheral sway area all decreased significantly from the pre-training to the post-training assessment, with no significant change occurring between the post-training scores and the retention scores for any of the variables (Fig. 7). Fig. 8 depicts the percentage of improvement for each score for both groups between the pre- and post-training assessments. Averaging the scores of both groups, transition time displayed an overall 13.5% decrease, path error a 26% decrease, and peripheral sway area a 51% decrease.

The dynamic standard assessment was further analyzed to evaluate scores for individual targets, notably, the magnitude of change that occurred in each direction of movement over the course of training. After standardizing all of the targets, three-way ANOVAs for each variable revealed an effect for assessment over repeated measures (which was demonstrated in the previous analysis to occur between the pre- and post-training scores), and an effect for target, with no significant difference between groups. *Post-hoc* analysis was performed for target means collapsed over session and group. The general trend indicated difficulty in the posterior direction. Specifically, Fig. 9 depicts the target means for transition time, displaying a significant increase in the time taken to move to the three posterior targets. The path error (Fig. 10) was significantly increased for the right and left posterior targets, but not for the posterior target itself. Peripheral sway area (Fig. 11) also, was significantly higher for the three posterior targets.

Training Results

For each training session, there were four scores per variable for each individual target. Two scores marked the transition to the peripheral target, and two scores marked the transition from the peripheral target back to the central target. The mean for each excursion was taken for each target/session for transition time and path error. Sway area was separated into peripheral sway area and central sway area for analysis. There was no significant difference between groups for any of these four variables. The overall trend depicts a decrease in scores until session 3, followed by a plateau in performance for the remaining 2 sessions. Transition time, however, departs substantially from this trend (Fig. 12a). Analysis of this variable revealed a significant effect for session, and *post-hoc* analysis showed that the scores for session 4 were significantly higher than the scores for the remaining sessions. Path error, peripheral, and central sway area decreased, and plateaued at session 3, with the differences between the first two sessions being significant.

Sway area was divided into central and peripheral measures to evaluate postural sway at the non-central peripheral targets vs. sway in a central position. Figs. 12c and d show the results for peripheral and central sway area respectively, over the course of training, and the trends are very similiar for both variables. However, the values for central sway area are much higher during the earlier sessions than those values for peripheral sway area, and they both plateau at approximately 0.06 %LOS/s.

3. Age Effects

The elderly group was recruited subsequent to the analysis of groups 1a and b. Based on the findings that showed no significant differences between the weekly and the daily training groups, it was determined that the elderly group would train for one session per week and comparisons would be made with group 1b. The elderly group completed the first and second retention assessments at an average time of 21 and 43 days after the post-training assessment, respectively.

Static Variables

The overall trend in comparing the elderly and younger groups indicated no real change in static sway with fluctuations going in both the positive and negative directions with eyes open and closed. Postural sway as measured with eyes open and eyes closed displayed no significant effect for group or assessment over repeated measures, however there was a group by assessment interaction for both of these variables (Figs. 13a and b). An improvement in score was seen when visual feedback was provided over the course of the four assessments. This variable (Fig.

13c) showed a significant difference between the young and the elderly groups, and over the four assessment occasions, as well as a group by assessment interaction.

Dynamic Variables

Again, the mean for all 8 targets was used to evaluate trends from pre- to post-training and across the two retention assessments. Unlike both of the younger groups, which showed relatively little change between the pre- to post-training assessments for transition time, the elderly group showed a significant decrease in speed between these two assessments. Both groups were then able to maintain the speed of transition at this level across the two retention tests (Fig. 14a). Analysis of this variable revealed a significant effect for assessment occasion and a group by assessment interaction. *Post-hoc* analyses showed that the pre-training scores differed significantly from the post-training scores.

Path error and peripheral sway area were similiar in their results. The trend for the younger group was a significant improvement between the pre- and post-training assessments, and no significant fluctuations from the post-training scores over the retention tests. The elderly group, however, showed an insignificant decrease from the pre- to post-training scores, and then an increase to pre-training levels for both retention tests (Fig. 14b and c). The ANOVA results for these two variables both revealed significant effects for group, assessment over repeated measures, and group by assessment interactions. Essentially, there were significant differences between groups for post-training, retention I, and retention II scores for both of these variables.

Fig. 15 shows the post-training scores for the dynamic variables expressed as a percentage of the pre-training scores for the elderly and the weekly training groups. For the younger groups (daily and weekly), the percentage of improvement from pre-training scores showed similiar ratios with peripheral sway area exhibiting the greatest improvement, followed by path error, and transition time with the least improvement (Fig. 8). Contrary to these results, the elderly group displayed the most improvement for transition time, followed by peripheral sway area, and then path error, although these latter two variables decreased proportionately.

Training Results

While transition time showed insignificant increases in speed over the five training sessions for the younger group, the elderly group decreased the time taken to move between targets significantly over the five sessions (Fig. 16a). The scores for the first three sessions for the elderly group were significantly larger than those of the last two, where evidence of a plateau occurs. There was also a significant group by session interaction for this variable.

Path error (Fig. 16b) displayed opposite results from transition time, in that the performance curve was more distinct for the younger group. The elderly group started to improve only after the second session, and the improvement was minimal. Analysis revealed a significant effect for group, where the elderly group had consistently higher scores, and a significant effect for session. *Post-hoc* analyses showed sessions 1 and 2 to be significantly higher than the remaining 3 sessions for the elderly group.

Peripheral and central sway area (Fig. 16c and d) both revealed significant differences between groups. For both of these measures, the elderly group had considerably higher values for sway than the younger group. Peripheral sway area had a significant group by session interaction. The values for peripheral sway area increased over the course of training for the elderly group, whereas they decreased for the younger group. For central sway area, the values for the elderly group fluctuate over the five training sessions.

Discussion

The primary purpose of this study was to document the training effect over repeated practice sessions using the Balance Master® system. The importance of this information becomes evident when considering the results of this study and a previous study by Hamman et al. (1992, see also Appendix A). There are distinct similiarities between these studies, but also clear differences based on difficulty of the training task, and age. This information is not only important when providing therapy using the Balance Master® specifically, but some concepts may provide recommendations to the field of balance retraining in general.

There was a distinct training effect apparent in the the dynamic scores over repeated practice sessions. There was no difference in performance or long-term retention between the daily and the weekly training groups. Those scores reflecting accuracy of transition were most improved in the younger groups, whereas scores reflecting speed of transition exhibited greater overall improvement in the elderly group. The static postural scores remained generally unaffected by training for all groups in the present study.

Effects of Training Schedule

Previously, Hamman et al., (1992, Appendix A) reported no difference in performance between groups practicing on a daily and a weekly practice schedule, over the course of training, and no difference between groups on a pre- and post-training assessment. The results of the present study agree with these previous results, however, long-term retention of the skills learned were assessed. By not performing the task learned for specified time periods, the amount of learning can be inferred by how well the task is performed after this time lapse (Magill, 1980). The practice schedules studied, and the length of time before a retention analysis was completed, had to be redefined in clinically practical terms. Thus, daily and weekly sessions seemed plausible to provide endpoints for a possible range of appointments for balance retraining.

Postural training of normal subjects over repeated practice trials has been demonstrated previously, although the paradigm normally utilized alters or removes sensory input (Brandt et al., 1981; Roos et al., 1988; Brandt and Paulus 1989). In these studies, the training was interpreted as recalibration of neural pathways programming the response, without the sensory modality in question. The results of the present study demonstrate that performance does improve with practice of a task involving movements of the COG, with all pertinent sensory faculties intact, as demonstrated by the significant improvement which occurred between the pre- to post-training assessments (Figs. 7 and 8). This improvement over training indicates that the task is novel and unfamiliar, therefore a training effect is introduced specific to the exercises using the Balance Master® system, in this case moving the COG cursor effectively to the desired target on the computer screen.

The overall decrease in transition time, path error, and peripheral body sway of 13.5%, 26%, and 51% respectively (Fig. 8), closely resembles the results of Hamman et al. (1992, Appendix A), which showed an average decrease of these variables to be 24.9%, 23%, and 62.6% respectively. The training task of Hamman et al., (1992, Appendix A) differed from the present study in that the subjects were required to move the COG cursor in clockwise and counterclockwise circles, without restabilizing in the central position. This could be suggested as a more difficult task than the one presented in this study. Thus, it is interesting to note that the percentage of improvement from the pre- to the post-therapy retention assessment for these dynamic variables is similiar, regardless of the task. The largest discrepancy for these pre- to post-training ratios is for transition time. The explanation for this, is that all exercises on the Balance Master® are controlled by a pacing speed. The pacing speed defines the time interval in that sequential targets are highlighted, and is set as a default of 9-seconds for the standard assessment dynamic protocol. In the pilot study, the pacing speed for the training exercise was 5-seconds, and in the present study it was 9-seconds. Thus, the greater decrease in transition time for the pilot study between the pre- to post-therapy assessments, was due to the fact that the subjects had become conditioned to the 5-second pacing speed, which ultimately improved their speed on the post-training assessment.

Hamman et al. (1992, Appendix A), reported an observation regarding a directional preference, in that there were significantly higher scores (decrease in performance) for the left lateral, and posterior targets. It was hypothesized that there may be a correlation with hand and/or foot dominance. Figs. 9, 10, and 11 display distinct differences in the posterior direction exclusively. There are several logical explanations for these observations. First is simply that the biomechanics of the foot limit backward movement. There is a much larger area in the anterior portion of the foot, in that the intrinsic foot muscles may support a forward lean (clutching the toes to the support surface). However, there is very little area of support beyond the heel, and therefore utilizing an ankle strategy without bending at the hips is limited in the posterior direction. From observation only, as the subject's first attempted to move to the posterior targets, they displayed a tendency to arch their back and move their torso backwards. This movement, in essence, pushed the hips forward and the COG cursor did not move on the screen. This method was discouraged for this reason, and because of the stress it placed on the lower back. Ankle strategy in the posterior direction was encouraged by having the subjects balance on their heels while keeping the rest of the body rigid. Overall, the subjects had considerable difficulty moving to these targets, and a lateral directional preference was not observed in the present study.

Because the previous study (Hamman et al, Appendix A) required subjects to track targets in a circle without restabilizing in the centre, this type of exercise may have precipitated a directional preference, demonstrating more stability on the dominant side. This was not demonstrated in the present study possibly because the subjects were allowed to restabilize in the centre before moving to a peripheral point within the LOS cone. The question of a directional preference while performing postural exercises is therefore left unanswered and requires further investigation. One of the purposes of the dynamic assessment on the Balance Master® is to determine directional difficulties while moving within the LOS cone (i.e. hemiplegia secondary to strokes, balance retraining using orthotic devices). If a directional preference is evident in a normal population, whether it be lateral dominance, or posterior movement, then the clinician should be aware of this over the course of therapy, so as not to confuse the observation with a pathological finding.

During the course of training, performance improves and plateaus approximately after the third session (Fig. 12). Transition time for both of the younger groups, however, did not follow this trend at all. There are three possible explanations for the obvious lack of improvement in speed of transition. First, because the Balance Master® works with a pre-set pacing speed, actual transition time is not a pure measure of the time taken to move the COG cursor between targets. The subjects appear to learn by trial how much time they have to get to a target, and then condition themselves to move within this time limit. The second explanation is that, although the subjects were instructed to move to the targets as "quickly and accurately" as possible, this of course is a reciprocal relationship, and therefore different interpretations can be made as to where emphasis should be placed. In this case, it appears that more emphasis was placed on accuracy than time. Thus, time was altered only to improve accuracy (as measured by path error), and this result is clearly seen (Figs. 12a and b). Thirdly, there is evidence to suggest an individual preference may have a preferred velocity of movement. Therefore, transition time may be independently regulated by the individual, and moving at faster or slower rates may make it difficult to control their stability.

Sway area was separated into peripheral and central measures to observe the relationship between peripheral and central stability while performing dynamic exercises. Central sway area should, theoretically, display better scores than peripheral sway area. Figs. 12c and d, however, show that there is no difference in the nature of the performance curves for peripheral and central sway area. However, when comparing the scales of both graphs, the values for central sway area are much higher during the earlier sessions than the peripheral sway area scores, thus the scores decreased more overall for central sway area. This phenomenon is contrary to what would be hypothesized, as one would be less stable at the periphery of the LOS cone than standing in a central position. However, the time taken to reach the peripheral targets would theoretically be higher than the time taken to move back to the central position. If this were the case, then the values for central sway area would be higher due to the fact that the ratio (%LOS/s) would be affected by the lower value for transition time.

From these results, including those from the previous study (Hamman et al., 1992, Appendix A), it can be argued that the frequency of therapy sessions utilizing this technique has no effect on performance or learning of these skills. This was surprising considering the literature comparing massed vs. distributed practice schedules for motor skill acquisition. On the other hand, the training schedules introduced in the present study do not fall into the domain of the schedules previously studied. Distribution of practice trials normally fall into the range of several seconds up to 24 hours (Lee and Genovese, 1988). Although short term learning effects could have been measured in this study, of interest was the inter-session interval, in this case being one or seven days. These schedules more effectively mimic a schedule for rehabilitation. For the younger age group, it can be concluded that the inter-session interval had no effect on the magnitude of training that occurred. This skill level was retained over three and six weeks. These results do not agree with the results of Brandt et al., (1981), in assessing postural sway after training normal subjects while altering vestibular, visual, and/or somatosensory information. There was a significant training effect, but sway levels returned to pre-training levels after 40 days. It could be suggested, that the training effect for the normal subjects in the present study, with no sensory deprivation, involved no recalibration of neural loops, and was a simple training effect of the task involved.

It may be postulated that the three static variables (Sway-EO, Sway-EC, and Sway-VF) would show no change, or improve (decrease) from a pre- to post-training measure, as normal populations typically display small amounts of body sway. The results of the present study indicate a small, but insignificant change in body sway from pre- to post-training (Fig. 6). These results concur with those of Brandt and Paulus (1989), who had subjects perform similiar training with visual feedback of the COG, and found insignificant effects on static sway for normals. Also, the training protocol involved dynamic and not static exercises, therefore specificity of training could explain the minimal change in static measures.

At approximately three and six weeks (Ret I and II), the static scores appear to be approaching pre-training levels. The relevance of this is probably very small, because the magnitude of change is only $\pm$ 0.02 %LOS, which can easily fall into the variability for this measure. This may also explain the group by assessment interaction for sway-EO. The amount of sway can be easily affected by other factors such as respiration and attention.

A negative difference score between the pre- and post-training assessment would indicate that there was an overall increase in the amount of body sway. The only negative difference was observed for the weekly training group, displaying an increase in the amount of postural sway with the eyes closed. Similiar results were reported by Hamman et al. (1992, Appendix A), although the differences between the pre- and post training scores were not significant at the 0.05-α level. In this study, there was a significant difference between the post-training score and that achieved at the first retention test for the weekly group. It is postulated that the reason for the negative mean difference often seen for body sway in the absence of visual input (EC) is that balance training with constant visual feedback of the COG position could lead to a dependence on visual cues. A removal of any visual input after a series of practice sessions using visual feedback could account for the mean increase in body sway with eyes closed. This information is important for the clinician using visual feedback for retraining, as it is possible for the patient to become dependent on this feedback, and in turn on visual cues for maintaining posture. This could also be antagonistic to the goals of the therapy, if a dependence on visual cues is seen as a problem to maintaining equilibrium (Black and Nashner, 1983; 1984).

A final note to the static sway measures is that the values for each variable (EO, EC and VF) relative to each other always remain in the same ratio for this population. Scores for sway measured with eyes closed are higher than those with eyes open, which in turn are higher than those with visual feedback provided. This is in agreement with past results (Shipley and Harley, 1971; Stribley et al., 1974).

The purpose of analyzing for effects of gender on static and dynamic variables was to preclude this effect as a major factor during the subsequent analysis. Previous studies that have examined the effect of gender on postural stability have been, for the most part, inconclusive. Sheldon (1963), studying an elderly population, concluded that females are less stable than males because statistics indicated that females had a higher incidence of falls than males. Stribley et al., (1977) studied one and two foot stance characteristics and found no difference for gender in a younger population (ages 18-21). In 1977, Overstall et al., reported that postural sway, as measured by COP fluctuations, was higher for females across all ages. However, there was no control for footwear or foot position. Panzer et al., (1992) did extensive biomechanical analysis of postural sway over a large age range (21-78 yrs.) using kinematic measures of body segment and whole body coordinates, and EMG analysis. They found that only medial-lateral sway, and vertical hip and knee displacements were increased in women. There was no gender difference for sway in the AP direction.

It was not a primary purpose of this study to analyze gender effects on variables produced by the Balance Master®. There was no effect for gender on the static variables, or for path error (Fig. 5b) or peripheral sway area (Fig. 5c). The significance of the gender difference for transition time (Fig. 5a) may indicate that females place more emphasis on accuracy of transition as opposed to speed, however this is not apparent in the results for path error.

Effects of Age

The acquisition of motor skills in the elderly individual normally occurs at a slower rate when compared to younger populations (Welford, 1982). This conclusion is borne out of chronometric reaction time studies, where the the time taken for certain stages of information processing can be studied while manipulating environmental factors (Welford, 1988; Light, 1990). Reaction time studies can be likened to the volitional responses of postural movements required by the dynamic assessment in the present study, where initially, the time taken to move between targets was significantly longer than the younger group (Fig. 14a). This age difference was diminished, however, on the post-training assessment and over the two retention trials. This has been observed previously by Murrell and colleagues (1970), who demonstrated that reaction time differences were eliminated in age groups if the older subjects were extremely well practiced. Light (1990) demonstrated that an elderly group improved significantly more than a younger practice group for both simple and complex reaction time tasks. In fact, over the course of training in the present study, the elderly group finished with faster scores than the younger group by the fifth training session (Fig. 16a).

Although there was a substantial improvement in transition time for the elderly group, there was a much smaller improvement in path error and peripheral sway area (Figs. 14b and c) in comparison to the younger group. It is interesting to note that the elderly group seemed to improve the transition time between targets by altering the accuracy to meet this goal, while the younger group altered the time to show a substantial improvement in accuracy. In tasks where it is possible to evaluate both the speed and accuracy of performance, it has been found that the instructions to move as "quickly and accurately as possible" are interpreted differently by different people (Salthouse, 1988). In the relationship between speed and accuracy, it has generally been accepted that elderly adults place more emphasis on accuracy, thus offering an explanation towards age differences with speed of performance (Salthouse, 1979). The present results can be interpreted in different ways. One possible explanation, which would agree with the relationship between the speed-accuracy trade-off with age, is that the elderly group had reached a plateau in accuracy by the post-training assessment. Perhaps this group was not capable of improving their accuracy beyond this level. In this case, this level of accuracy was maintained throughout the course of training, while time was steadily improved (Figs. 14 and 16). However, it could also be speculated that the elderly group did not reach their peak level of accuracy. Perhaps, then, more sessions were needed to observe further changes in accuracy.

From this view, it could be postulated that the two groups used different strategies to learn the given task. The older group improved their time, while keeping accuracy at a constant level, while the younger group did the opposite. If given more sessions, it could be hypothesized that time may have decreased for the younger group, while accuracy might improve for the older group, once a criterion level was attained for the opposite variable. In this case, not enough time was given in the present study for the elderly group to reach a plateau for path error and peripheral sway area (Figs. 16b and c), as elderly adults normally require more trials to reach a given criterion of learning (Welford, 1982).

Although the elderly group represented a small sample of the aging population, the results for the dynamic variables show clearly that this group applied a different learning strategy than the younger group. This observation warrants further study, as it could offer important training strategies for postural rehabilitation, which has become a central focus of research due to the general diminishment of postural stability in this group, which ultimately leads to falls.

There is substantial literature supporting the fact that body sway is increased in elderly individuals as opposed to a younger population (age > 14 yrs.) (Sheldon, 1963; Overstall et al., 1977). This, however, was not observed in the present study, as body sway with eyes open and eyes closed did not differ significantly from the younger group (Fig. 13). It is speculated that the variability within these two samples was sufficient to cause a notable overlap of results for these variables. It can be seen from Fig. 6 that postural sway measured under all three conditions was consistently higher for the weekly training group than the daily training group, indicating a larger variability within this sample. Therefore, when comparing the weekly training group to the elderly group, there was no significant division between the two populations.

A positive training effect is seen when visual feedback of the COG was provided to the elderly group (Fig. 13c), and this effect was more dramatic than that for the younger group. It has been suggested previously that addition of visual feedback requires conscious interpretation before the subject can generate appropriate motor commands (Hawken et al., 1990). Thus, when first presented with this information, the elderly group had to first process the information, which became more automatic with repeated exposure. This too could explain the training effect for the younger group, however this group began at a lower baseline for sway in this condition. These results agree with previous studies using a visual feedback signal (Sheldon, 1963; Hawken et al., 1990).

It appears that visual feedback does have a positive influence in controlling levels of body sway, as these scores were consistently lower than sway with eyes open and closed for all three groups (daily, weekly, elderly). This suggests that even normal subjects can reduce their standing postural sway levels, and a training effect also occurs by providing this feedback even within a central, stable position. Visual feedback not only provides an additional source of information to process regarding postural sway, it provides a focal point as a source of attention. It is possible that this variable removes some of the variability in normal standing sway, which is highly influenced by factors such as attention, motivation, and state of mind.

Practical Considerations

There are several recommendations which stem from the results of the present study. Because of the objective, quantitative measures provided by the Balance Master®, an opportunity is given to institutions to examine postural rehabilitation in a controlled, reliable manner. This may, hypothetically, provide a way to standardize tests of static and dynamic postural stability. Some of the variables produced by the Balance Master® could be refined make them more meaningful. Transition time is not a pure measure of the time taken to move between targets, as one becomes conditioned to the pre-set pacing speed. Although the pacing speed is needed to provide a reference for measuring path error and sway area, a feature that would allow assessment of pure transtion time would make this variable more meaningful. As it stands, transition time as a variable must be evaluated within a context that takes the pacing speed into account.

Transition time and peripheral sway area are inversely related in the fact that the measure of peripheral sway area is dependent upon how much time the COG cursor is at the peripheral target. Peripheral sway area must therefore be corrected for the time spent at the highlighted target. The importance of this becomes relevant when comparing the young and elderly groups. The elderly group was initially slower in reaching the peripheral targets, therefore an uncorrected peripheral sway area would have theoretically been very low due to the fact that the elderly group took a longer time to reach the target. On the other hand, the younger group travelled to the peripheral targets relatively quicker, therefore, peripheral sway area was measured for a longer time, and would theoretically be higher. Thus, time should be taken into account for the measure of peripheral sway area.

Finally, the Balance Master® produces a substantial amount of output with graphics and quantitative information for each exercise performed. From a clinical point of view, this is an informative way to present information to both clinician and patient. However, if future research is to be done using this instrument, a method of downloading the information into a database program would be very helpful. Presently, there is a lot of room for human error entering large quantity of numbers into a spreadsheet manually for further statistical analysis.

Theoretical Considerations

Introduction of this instrument to the field of rehabilitation provides a means to answer several questions regarding the unstable patient. However, several basic issues must be addressed before these questions can be answered effectively. First, the reliability of this instrument is still unknown, and test-retest reliability scores for a normal population still need to be produced.

Secondly, the model by which the COG position is calculated is based on several approximations, and the sensitivity of the instrument to adequately track COG movements needs to be studied. The height of the COG is estimated based on the standing height of the person, and the COG position is estimated based on a geometric relationship that assumes no rotation about the knee and hip joints. This model is also accurate up to sway rates of 0.3 Hz, in which it faster movements are possible, and likely to occur while moving between targets. Although the cursor movement on the computer screen appears to adequately track movements of the patient, for research purposes, the combined effect of these approximations leaves questions regarding the sensitivity.

Finally, the reliability of the dynamic measures needs extensive investigation. What information transition time, path error, and/or peripheral sway area will provide in terms of balance function is still unanswered. Performance as measured by each one of these variables can improve or worsen over the course of training, and the meaning of this with regards to balance requires further study. A cross comparison of several more standard tests of balance function with the assessment provided by the Balance Master® would be an obvious starting point to this.

Concluding Remarks

Biofeedback has been documented as a successful tool to facilitate equilibrium and postural rehabilitation (Shumway-Cook et al., 1989, Winstein, 1989). This fact along with the need for objective, quantitative information regarding postural variables has provided a market for instruments such as the Balance Master®. There is, however, a training effect that occurs with repeated use of this tool. This observation is promising with reference to its rehabilitative capabilities. However it must be cautioned that this training effect may be task specific to the Balance Master®. Although it is possible to assess performance over the course of therapy, if the

Balance Master® is being used as a tool for therapy, independent assessment of balance function should be made in conjunction with Balance Master® assessment.

The training effect is more evident in the dynamic conditions than static ones, although there is evidence to support a dependence on visual feedback which is reflected in the static measures. This should be taken into consideration for therapy design using augmented sensory feedback, as a dependency on the feedback could theoretically impede recovery.

The greatest magnitude of difficulty in the dynamic conditions occurs in the posterior direction, and there may be a lateral directional preference, especially when moving within the LOS without restabilizing in the centre, although this needs to be further studied. This difficulty with posterior movements should be recognized as "normal" when performing evaluations using the Balance Master®.

The clinician should be aware of therapy goals in terms of speed and accuracy when evaluating dynamic variables. These are reciprocally related and individual preferences influence the ratio of the magnitude of change between these variables. This relationship also appears to vary with age.

It must be stressed that the Balance Master® is to be used only as a component part of a rehabilitation program, and the results should be integrated with other more functional measures of balance. However, caution should be used when the quantitative variables produced by the Balance Master® are rigorously evaluated.

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Table 1: Mean difference scores between the pre- and post-therapy postural sway scores for daily and weekly training groups under conditions of eyes open, eyes closed, and visual feedback provided.

	Postural Sway		
	Eyes Open	Eyes Closed	Visual Feedback
Daily Training Group	0.01	0.02	0.02
Weekly Training Group	0.08	-0.02	0.03

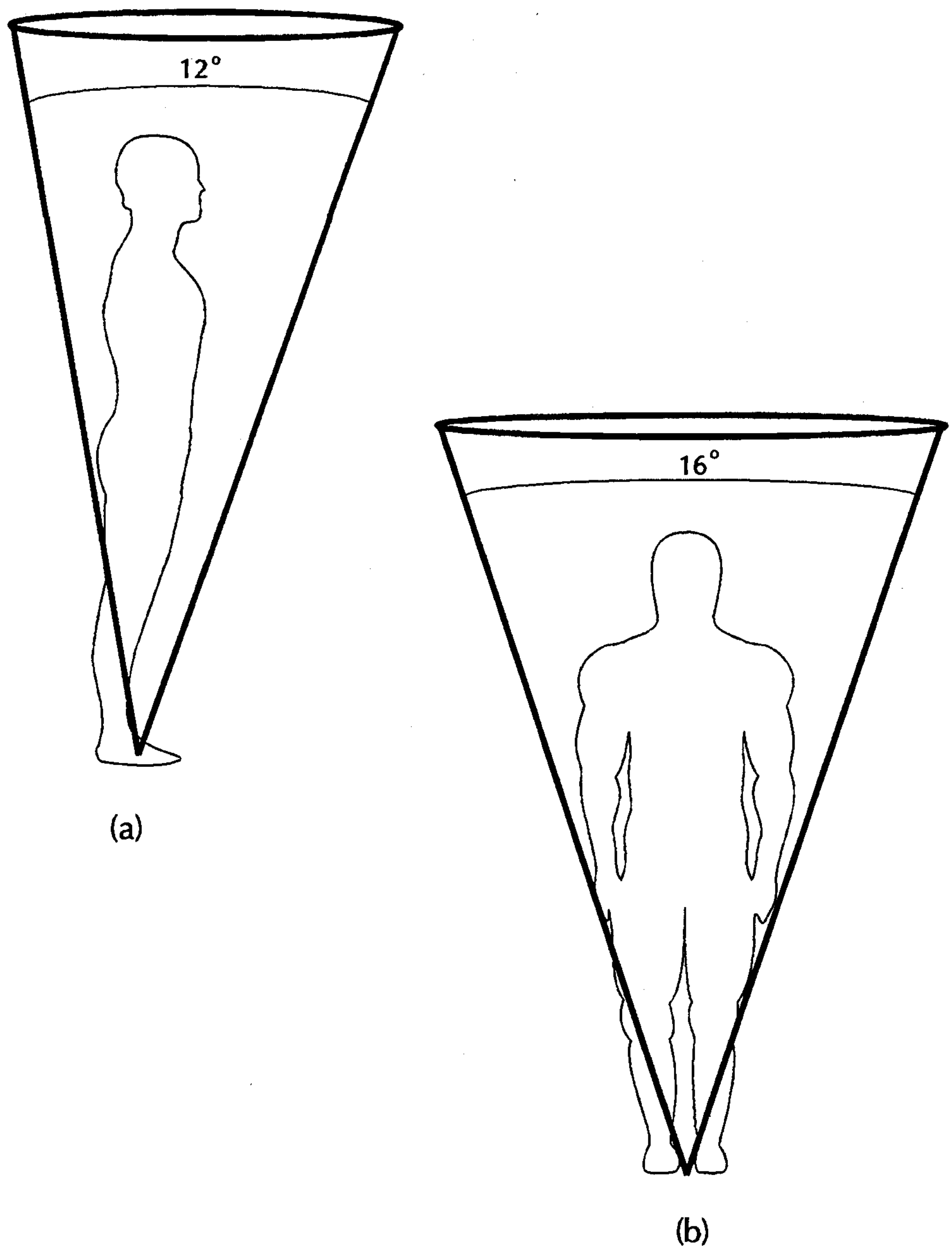

Figure 1: Theoretical limit of stability (LOS) cone depicted in the (a) antero-posterior direction and (b) lateral direction. The range of the LOS cone extends approximately 8° anteriorly and laterally, and 4° posteriorly.

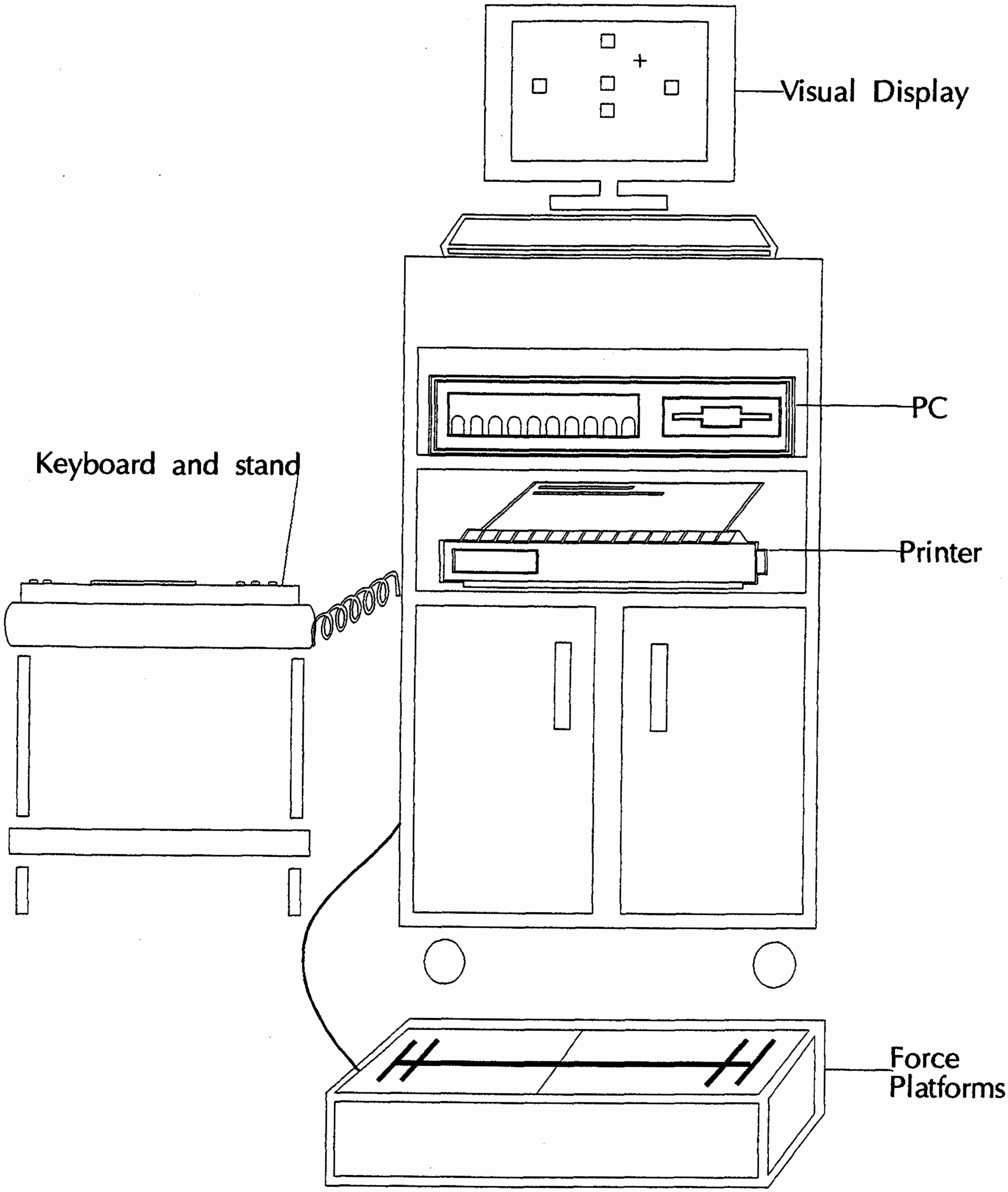

Figure 2: Schematic diagram of the Balance Master® system.

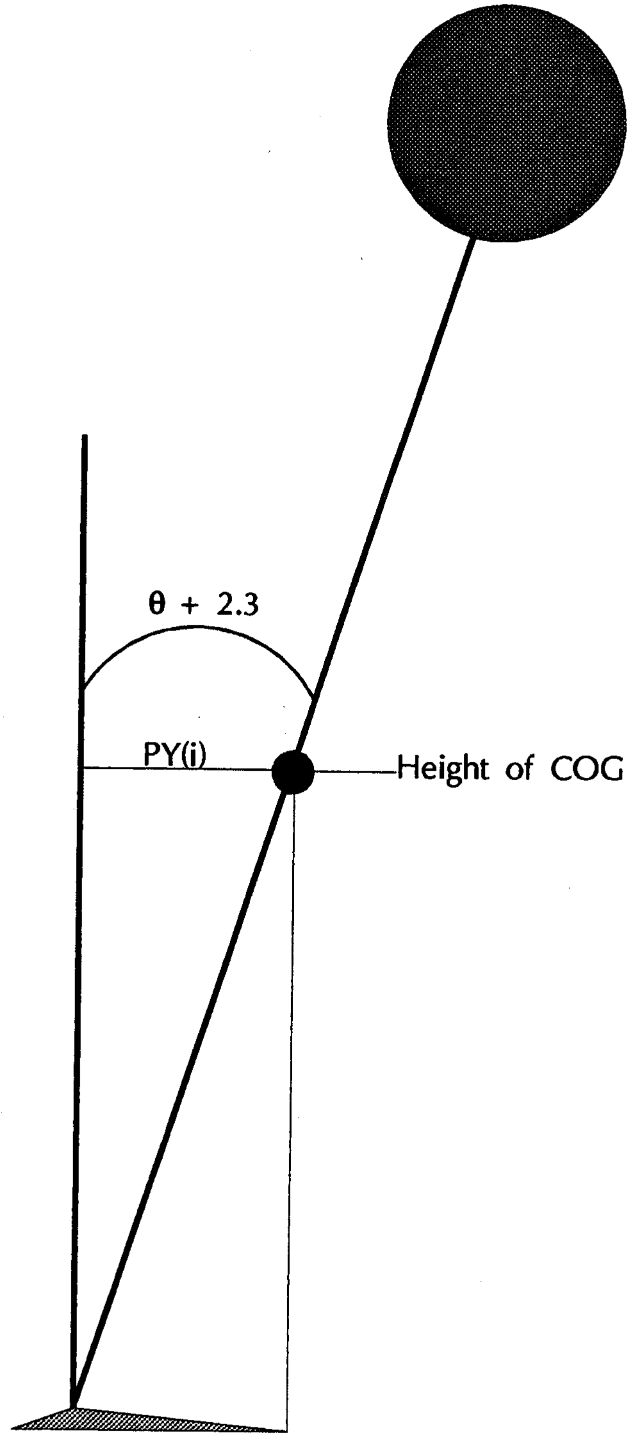

Figure 3: The geometric relationship depicting how COG sway angle is calculated in the antero-posterior plane. COG sway angle (θ) is found by the equation: $\sin \theta + 2.3 = PY(i)/H_{COG}$. The value of 2.3 represents the forward lean of the COG from vertical as referenced by the medial malleoli of the ankle.

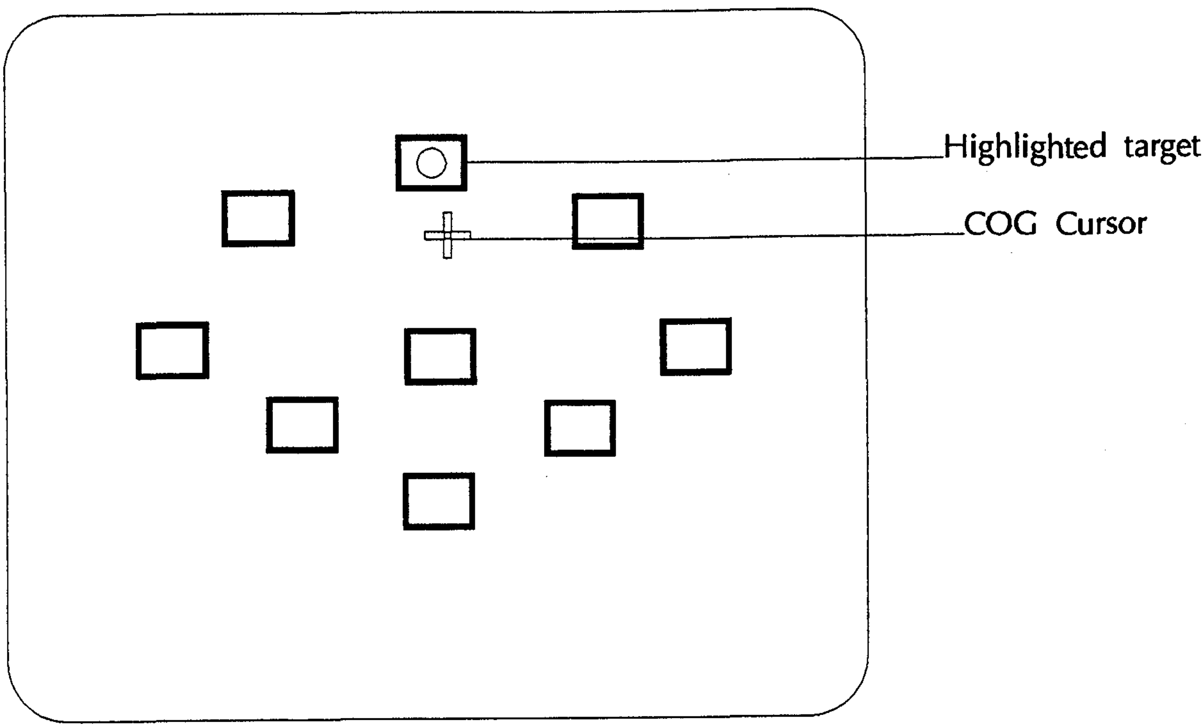

Figure 4: Visual display of the standard assessment protocol. The peripheral targets are arranged at 75% of the theoretical limits of stability. Targets are highlighted in a clockwise manner returning to the central target each time.

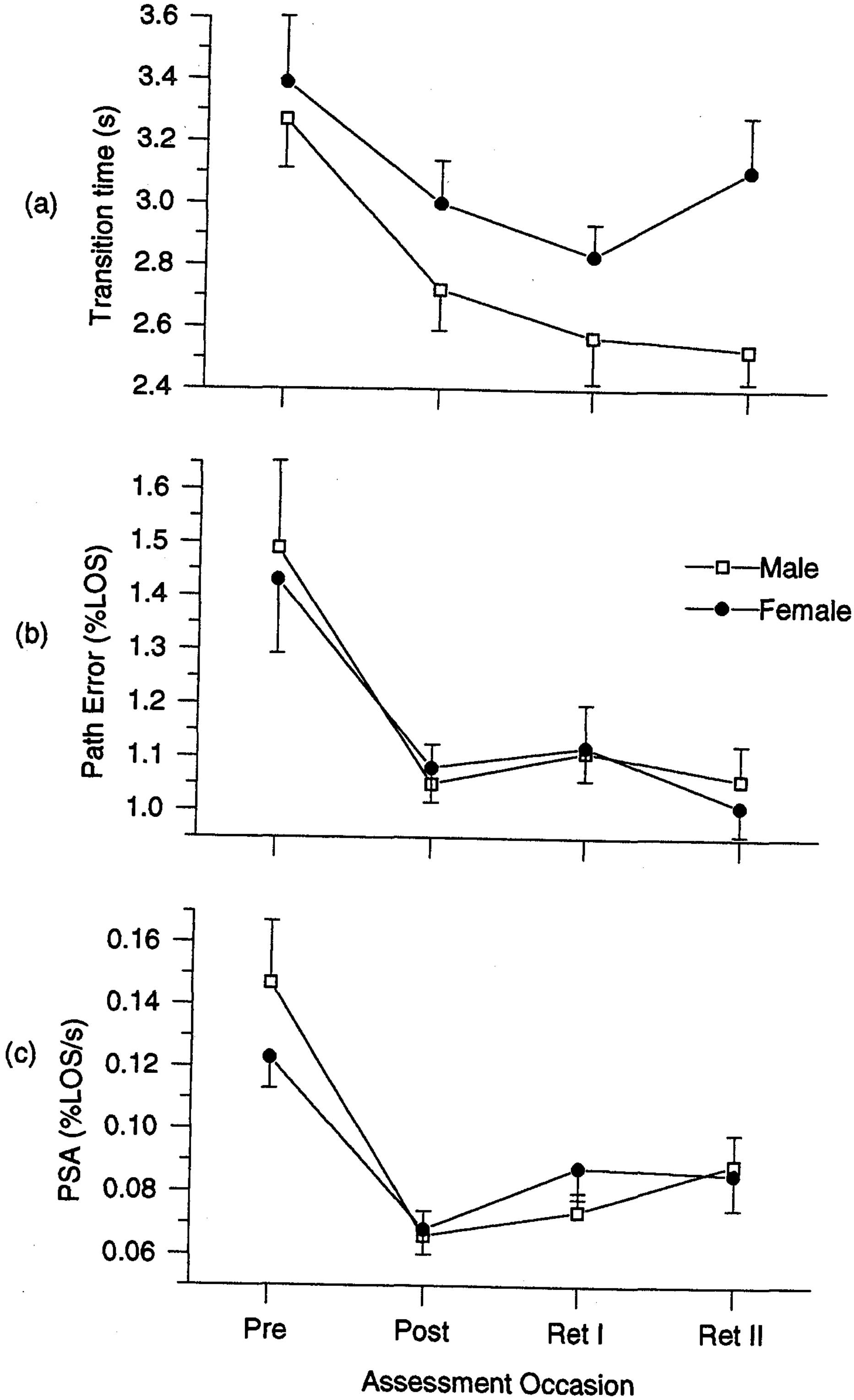

Figure 5: Effects of gender on the three dynamic variables: (a) transition time; (b) path error and; (c) peripheral sway area (PSA) over the four standard assessment occasions. Results are shown for both the daily and the weekly training groups. A group effect of gender is seen for transition time only.

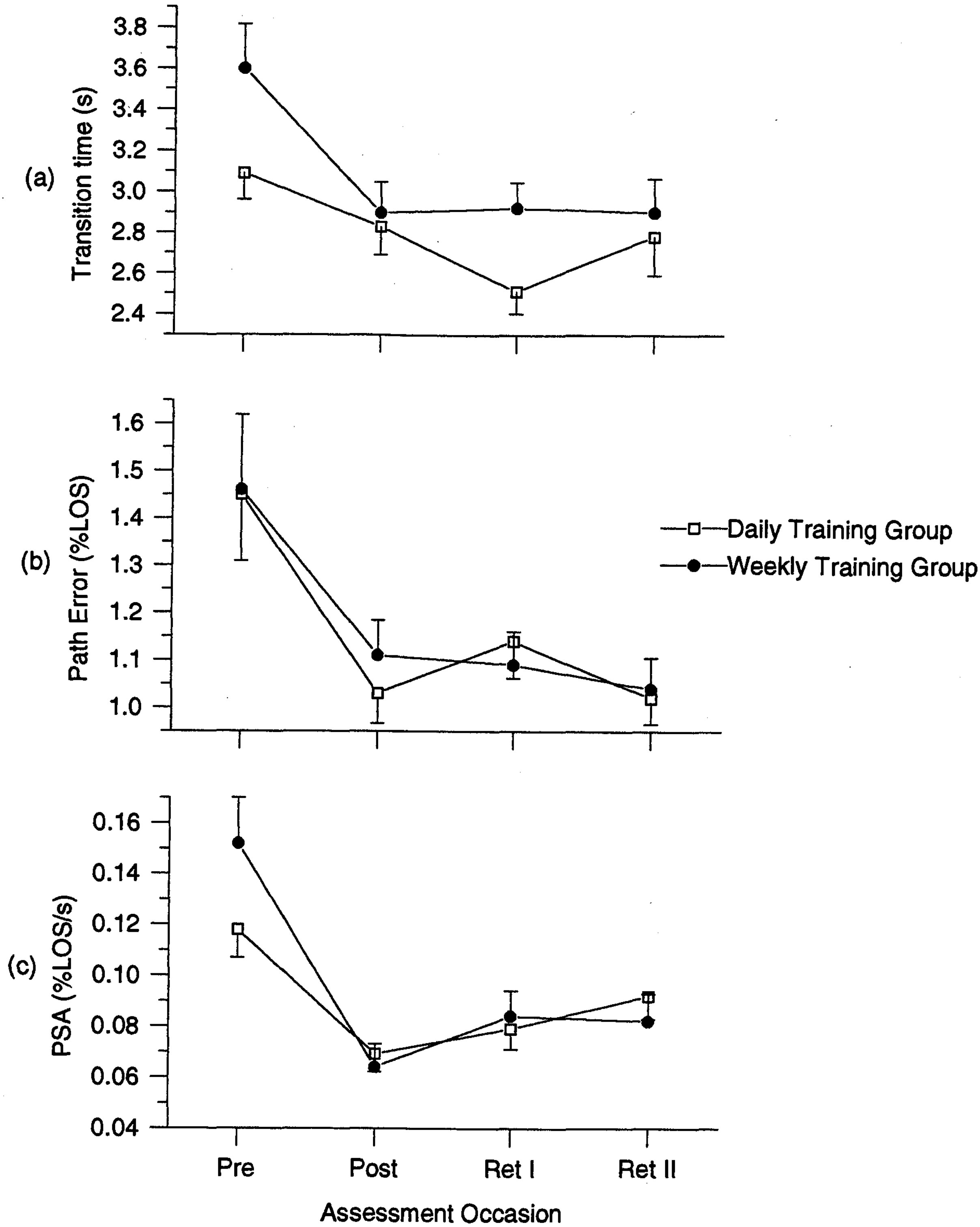

Figure 7: Dynamic variables: (a) transition time; (b) path error and; (c) peripheral sway area (PSA) measured over the four standard assessment occasions for both the daily and the weekly training groups.

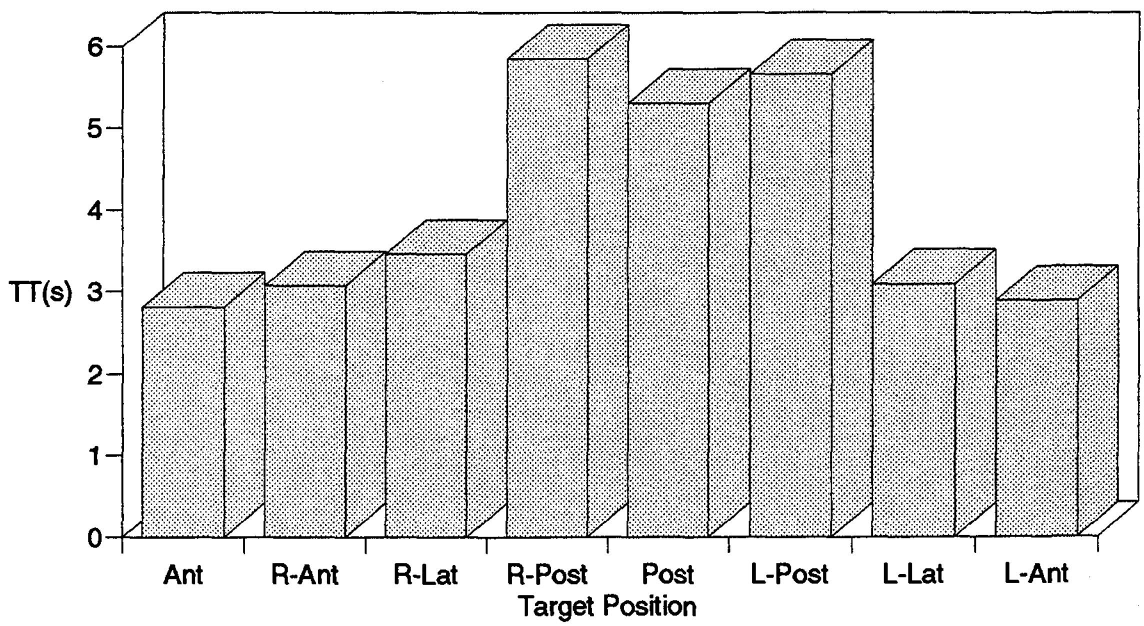

Figure 9: Individual target means for transition time averaged over the four assessment occasions. Abbreviations are as follows: Ant. is anterior, R is right, Lat. is lateral, Post. is posterior, and L is left.

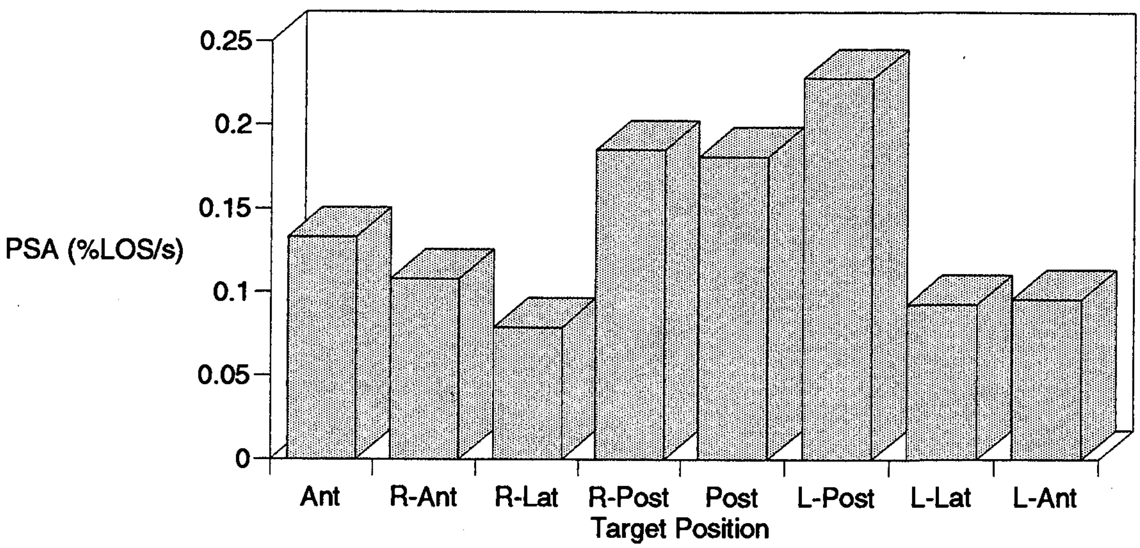

Figure 11: Individual target means for peripheral sway area averaged over the four assessment occasions. Abbreviations are as defined for figure 9.

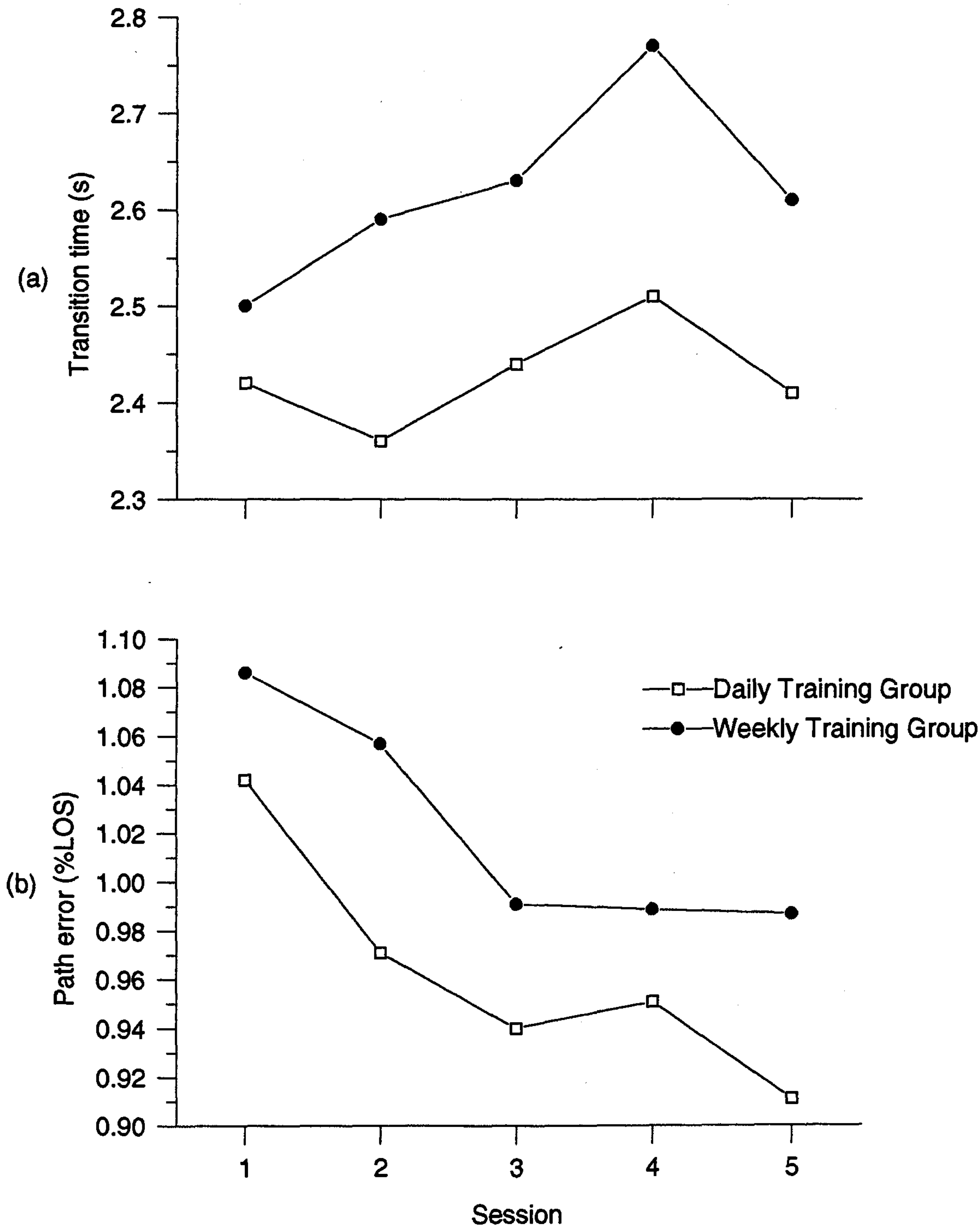

Figure 12: Changes in the dynamic variables: (a) transition time; (b) path error; (c) peripheral sway area (PSA) and: (d) central sway area (CSA) over the five training sessions for the daily and the weekly training groups.

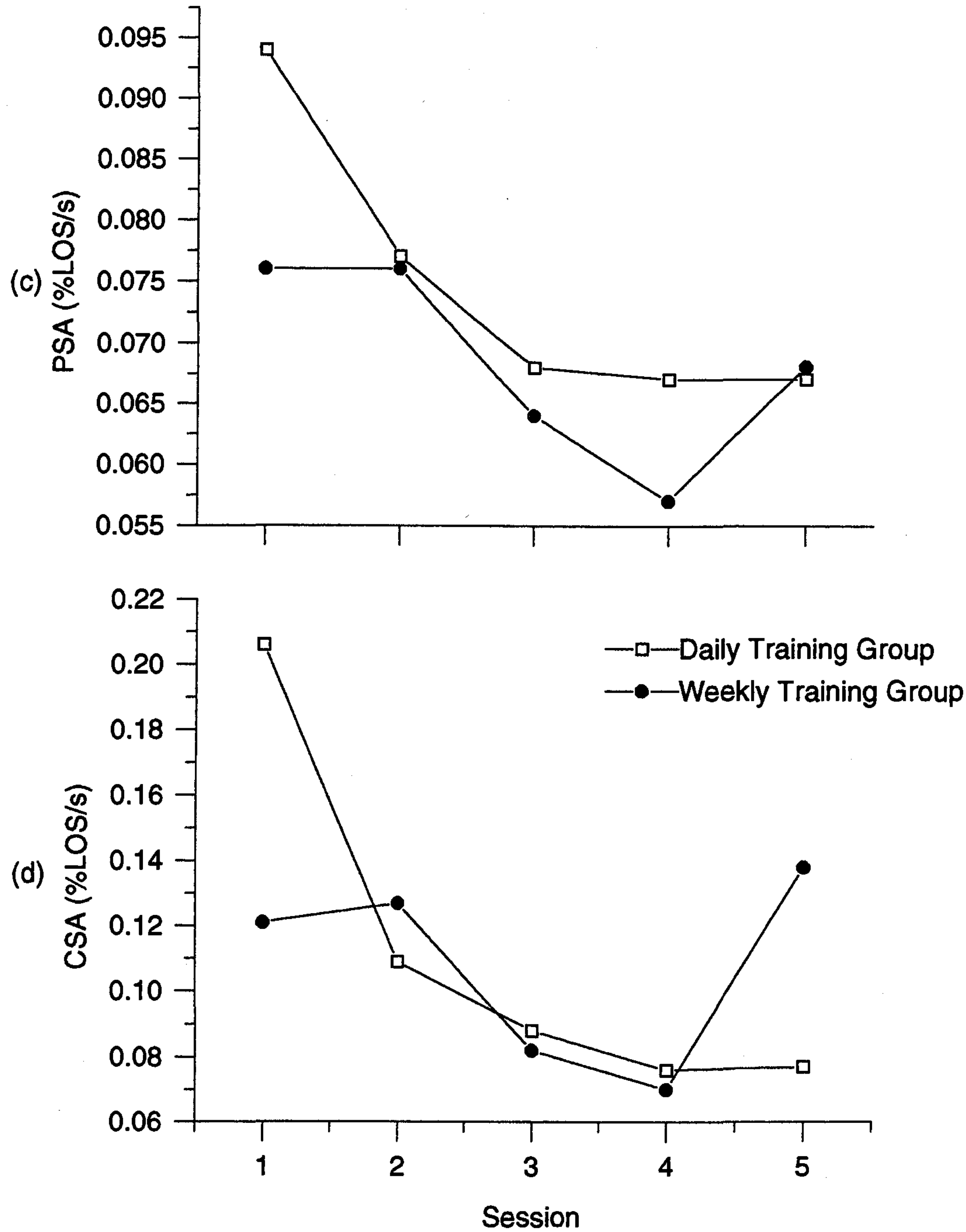

Figure 12: continued.

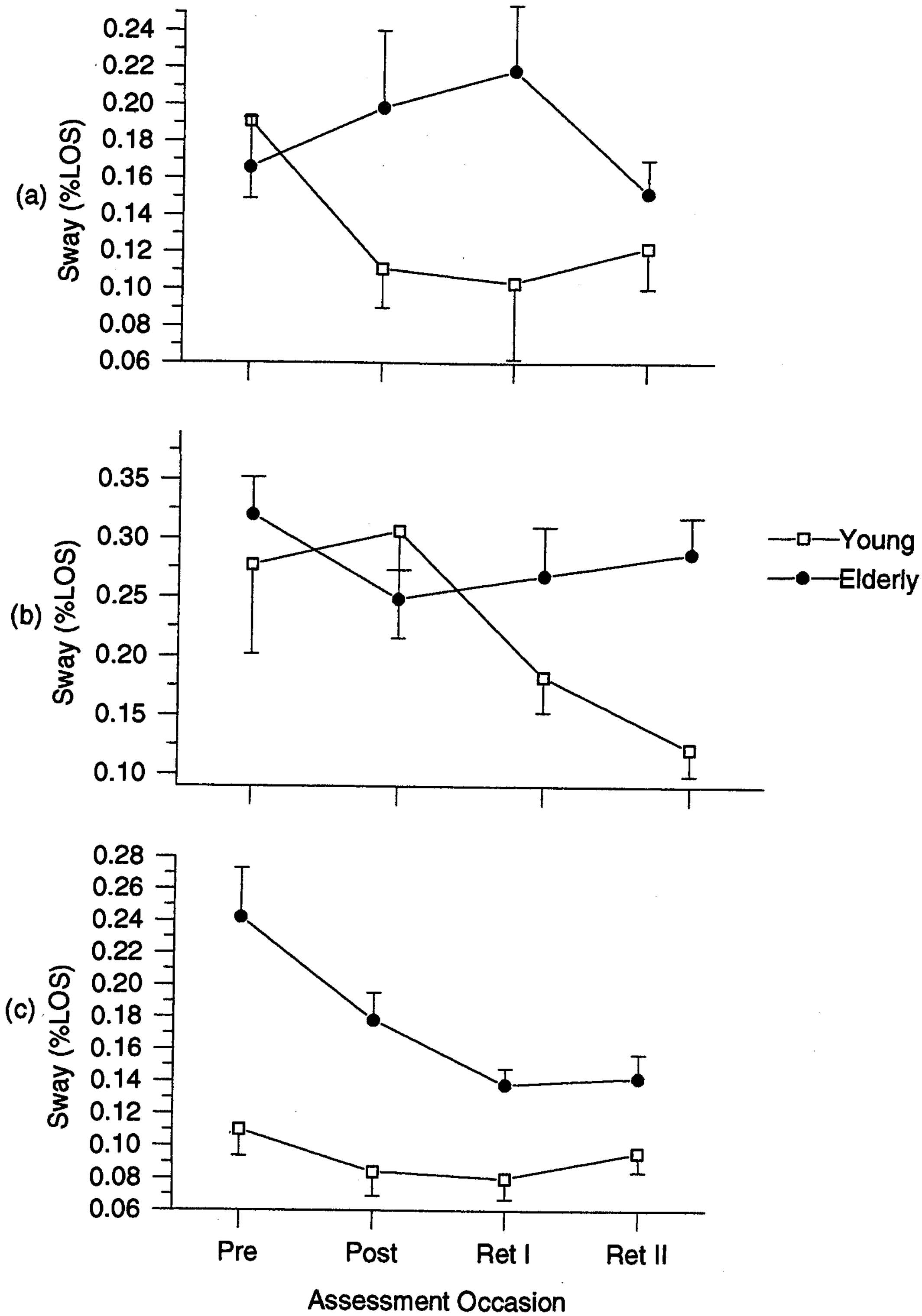

Figure 13: Postural body sway as measured under three separate conditions: (a) eyes open; (b) eyes closed and; (c) with visual feedback of the COG provided. Measurements occur over the four standard assessment occasions, and are shown for the young and elderly groups.

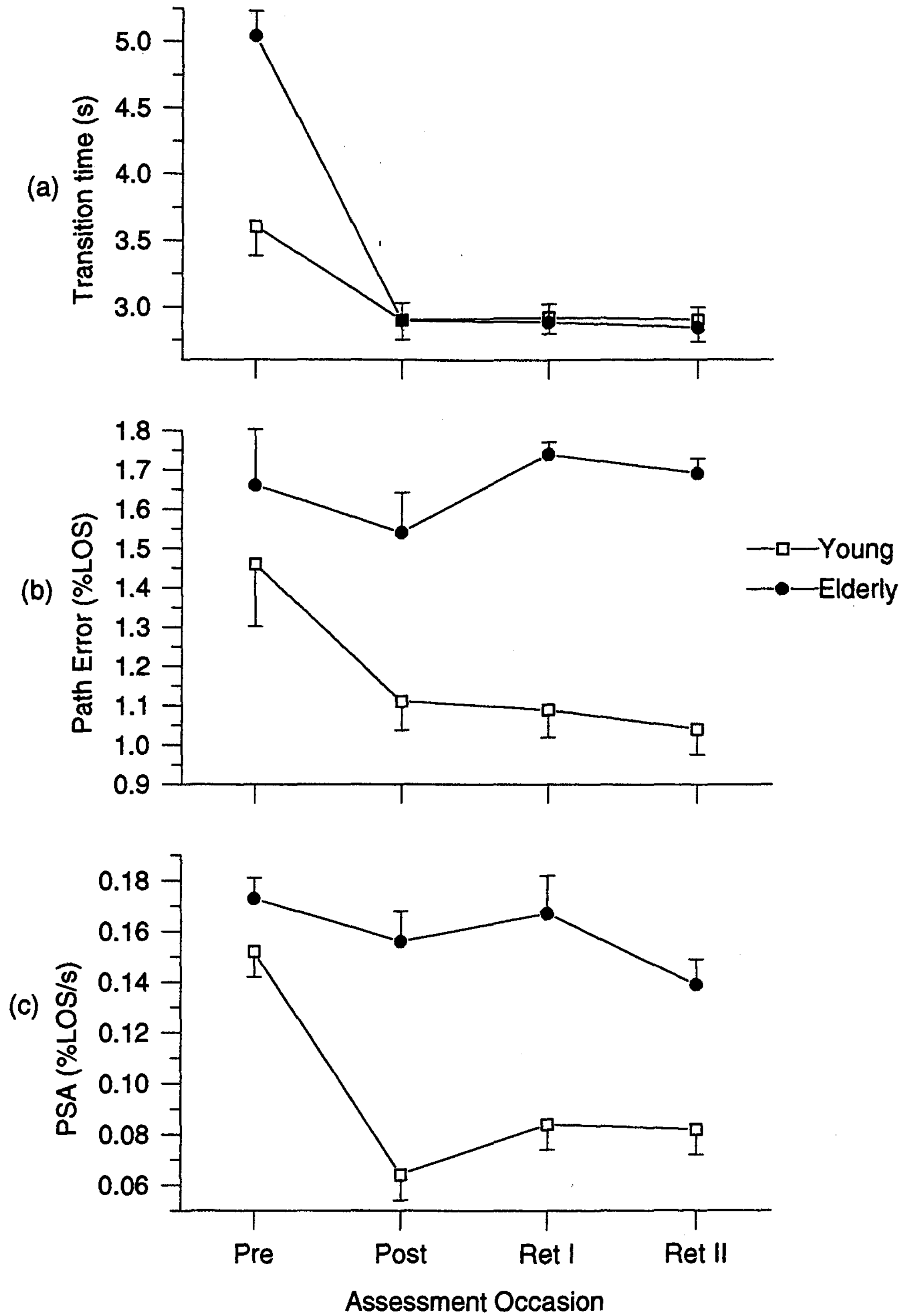

Figure 14: Dynamic variables: (a) transition time; (b) path error and; (c) peripheral sway area (PSA) measured over the four standard assessment occasions for the young and elderly groups.

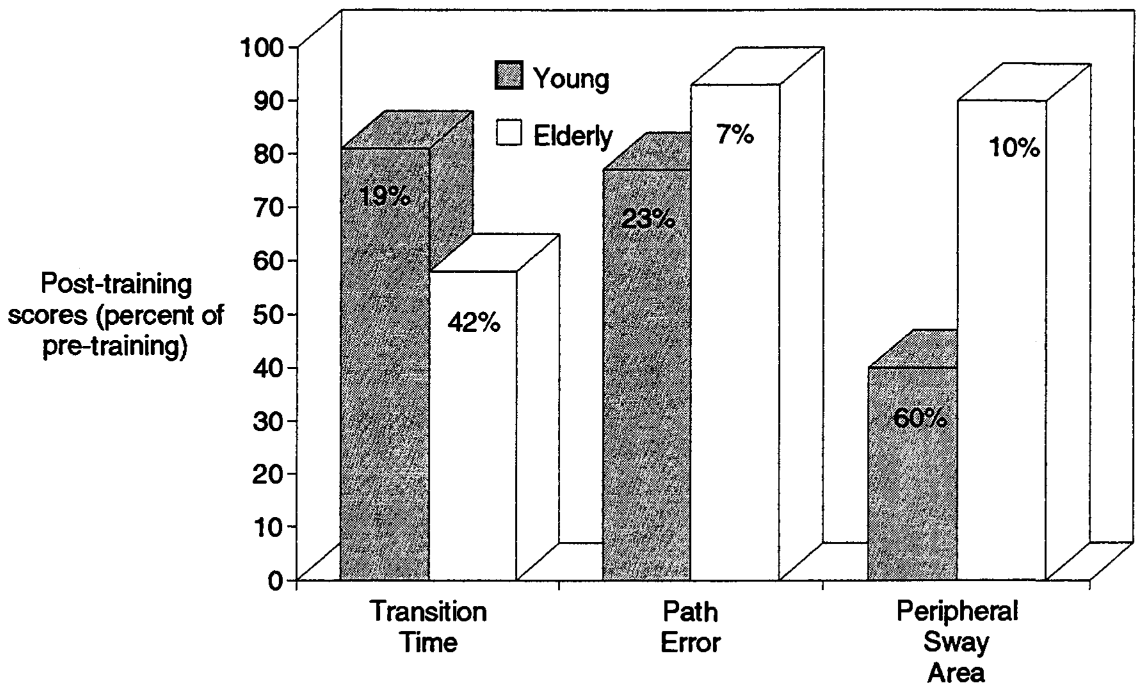

Figure 15: Post-training scores for transition time, path error, and peripheral sway area expressed as apercentage of pre-therapy scores for the young and elderly groups. Percentage values shown on the top of the bars is the actual reduction from 100%.

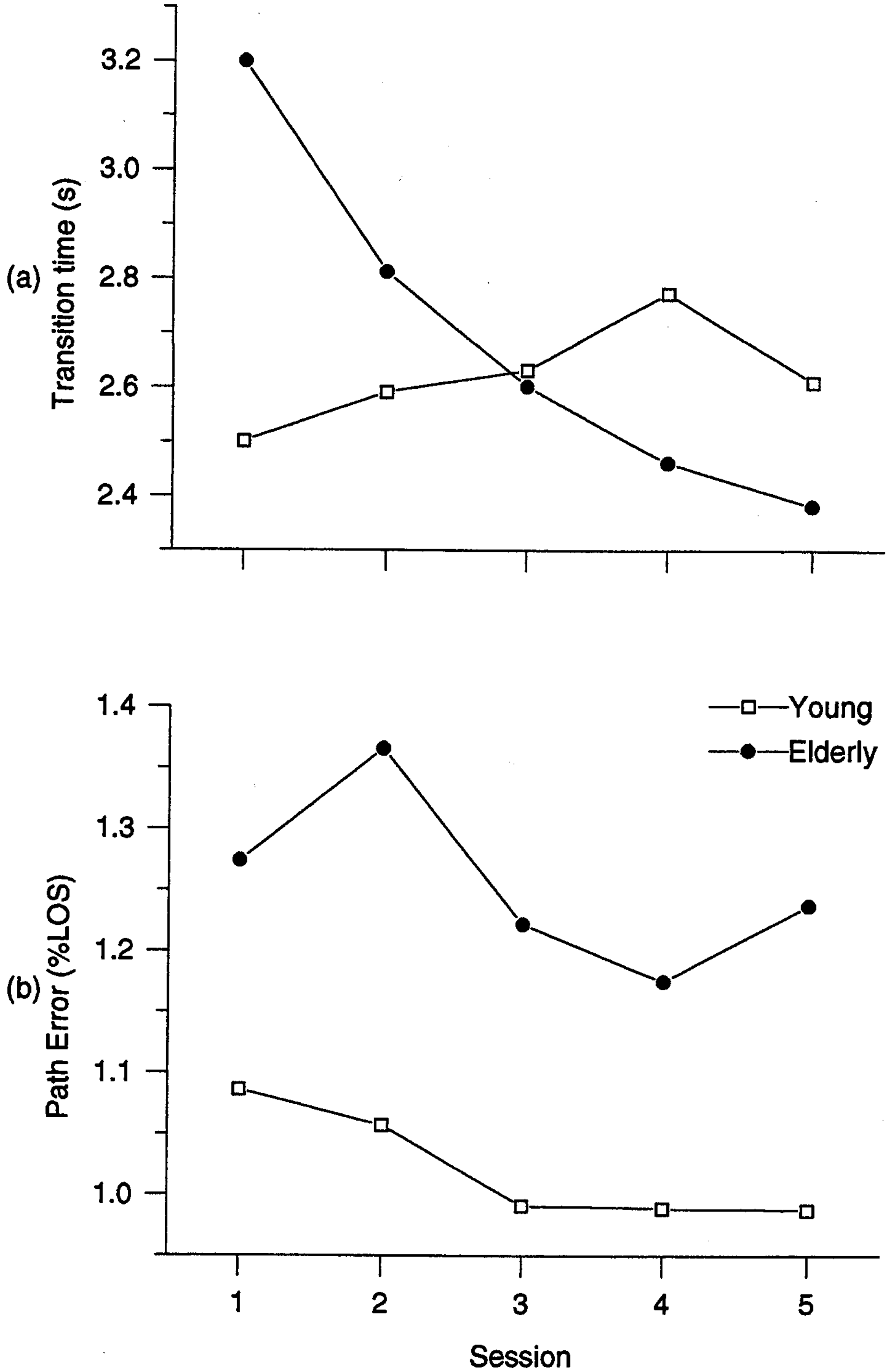

Figure 16: Changes in the dynamic variables: (a) transition time; (b) path error; (c) peripheral sway area (PSA) and; (d) central sway area (CSA) over the five training sessions for the young and elderly groups.

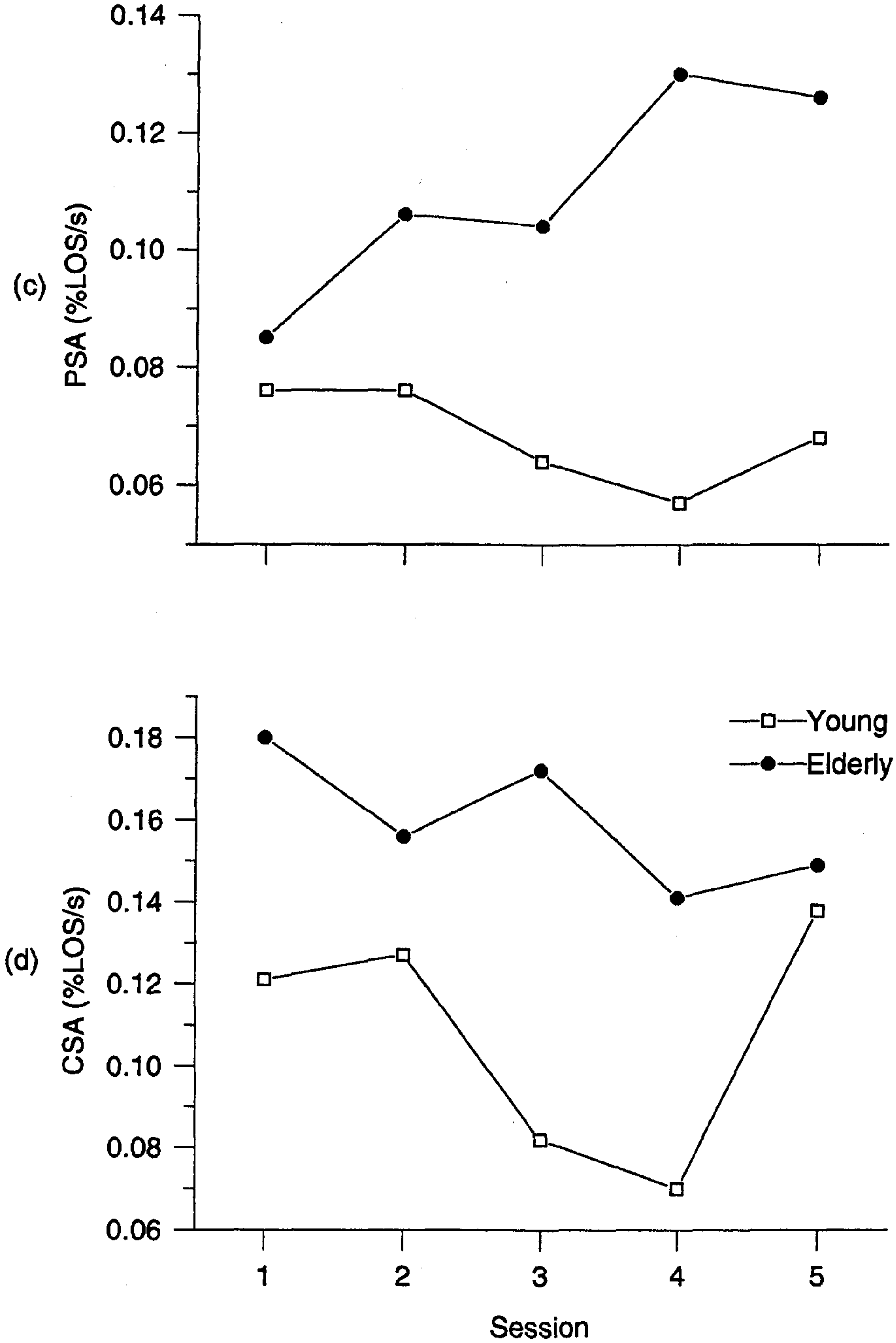

Figure 16: continued.

Appendix A

Training Effects During Repeated Therapy Sessions

of Balance Training Using Visual Feedback.

Abstract

Visual biofeedback of postural sway is currently being investigated as a therapeutic technique to reduce postural instability in selected patient populations. Before the efficacy of this type of therapy can be determined in a clinical setting, the performance curves of a normal population doing the static and dynamic balance training exercises have to be delineated. Two groups of normal subjects were evaluated during a daily and weekly protocol of dynamic balance exercises using visual feedback of their center of gravity (COG) and theoretical limits of stability. Static stabilty in a central position was measured with eyes open, eyes closed, and with visual feedback of the COG in a pre- to post-therapy assessment. No significant change was observed in any of these variables from the pre- to the post-therapy evaluation, as well there was no difference between the scores of both groups Dynamic variables were evaluated in both a pre- to post-therapy assessment, and over the course of therapy. Each of these protocols required the subjects to track targets representing 75% of their limits of stability on a computer screen with their COG. The time taken and the accuracy to move the COG cursor from target to target, as well as the body sway upon reaching the target were evaluated. Transition time and sway area both decreased significantly ($p<0.01$) from the pre- to the post-therapy assessment for both groups, with path error decreasing significantly for the daily therapy group only. No significant difference was demonstrated between groups. Path error and sway area decreased significantly ($p<0.01$) over the course of therapy with a plateau occurring after day 3 for path error, and after day 4 for sway area in both groups. There was no relative change in transition time during the therapy protocol. Performance curves have been delineated for a group with no balance disorders, and there appears to be no difference in performance between the daily and weekly therapy groups.

Key Words: balance, biofeedback, posture control, rehabilitation

Introduction

Sensory feedback, with reference to postural rehabilitation, is a technique that utilizes visual, auditory, or somatosensory feedback to relay information regarding measured body sway. Several studies have reported the use of all three of these modes of sensory input for postural rehabilitation with varying degrees of success(Wannstedt and Herman, 1978; Seeger and Caudrey, 1983; Shumway-Cook et al., 1988; Winstein et al., 1989; Clarke et al., 1990; Hamann and Krausen, 1990; Jobst, 1990).

Force platform arrangements have long been used to quantify postural body sway characteristics for normals (Sheldon, 1963; Shipley and Harley, 1971; Murray and Peterson, 1973; Stribley et al., 1974) and for patients with peripheral and central balance disorders (Dickstein et al., 1984; Diener et al., 1984). Shumway-Cook and colleagues (1988) used a force platform connected to a microcomputer to assist hemiplegic patients in visualizing their center of pressure, and used this information to reduce load asymmetries in stance. This feedback therapy integrated with physiotherapy showed better results for the task than traditional physiotherapy on its own. Hamann and Krausen (1990) showed that normal subjects and patients with peripheral vestibular disorders reduced their body sway over a 10 day training session by visualization of the COG during computerized feedback of sway in the anterior-posterior (AP) direction. They did not, however, differentiate between the learning curves of vestibular patients and normals.

The Balance Master® is a relatively new rehabilitative tool which gives continuous visual feedback of the position of the center of gravity (COG) in relation to the theoretical limits of stability (LOS) as a source of performance information in balance therapy. The LOS is pictured as a cone with its apex projecting from the feet in the standing postion. Biomechanically, if movement about the ankle joints occurred like an inverted pendulum, the LOS would extend to approximately 12^{o} in the anterior-posterior (AP) direction (8^{o} anteriorly and 4^{o} posteriorly), and 16^{o} in the lateral direction (8^{o} to each side) (Nashner, 1989). The area within this cone represents the domain in which the COG can be moved safely without changing the base of support by taking a step or grasping an external object for stability (Shumway-Cook and Horak, 1990). Walking and common daily activities require constant shifting of the COG within the LOS in both the AP and lateral directions (Nashner and Peters, 1990).

Quantitative information can be obtained for monitoring patient progress while performing static and dynamic postural rehabilitative exercises. Postural sway can be monitored in a static central position under different sensory conditions (ie. eyes open or eyes closed), and can also be measured at any peripheral point within the theoretical LOS cone, which gives a measure of postural stability in a more dynamic sense. Transitions between points within the LOS cone can also be monitored for time and accuracy of trajectory, providing further information about dynamic stability.

Treatment strategies involving visual feedback exercises require training over repeated sessions, therefore a practice effect is introduced, which must be taken into account when evaluating any rehabilitative outcome of therapy. Postural exercises using visual feedback of position have been shown to reduce body sway in selected patient populations (Shumway-Cook et al., 1988; Hamann and Krausen, 1990), however, data is needed to assess if body sway is reduced after a series of practice sessions using visual feedback for people without any balance disorders. The normative training effect must be separated from any rehabilitative effect. This information must be considered when observing the performance of patients, and before assessment is made of their progress.

This study was designed to quantify the effect of training on performance for a group of normals performing dynamic balance training exercises using visual feedback of the COG. The purpose of this study was twofold: 1) to quantitatively observe changes in both static and dynamic variables, and determine the criterion of each one to indicate changes in performance in normals, and; 2) to observe performance between two groups of normal subjects representing two possible therapy schedules.

Methods

Subjects

Seventeen subjects participated in the study. Subjects selected had no previous history of neurologic or musculoskeletal disease, injuries that would interfere with performance on the apparatus, and were able to understand and follow instructions. Age range was 20-35 years.

Subjects were divided randomly into two groups. Group I (n=10) comprised 7 females and 3 males with a mean age of 29±4 years, whereas group II (n=7) consisted of 6 females and 1 male with a mean age of 25±2 years. Group I completed one balance training session daily over 5 days, and group II completed one session weekly over 5 weeks.

Apparatus

The Balance Master® system (NeuroCom International, Inc., Clackamas, Oregon) with software version 2.20 was used for this study. The system consisted of 2 adjacent forceplates, each with two strain guages in the AP direction. Total vertical force on the plates was determined by adding the anterior and posterior right and left forces exerted by the subject standing on the force plates. The subject's height of COG (H_{COG}) and LOS were calculated based on their standing height. Once the COG was computed, the system measured AP or lateral sway by sampling the vertical force, filtering out high frequency oscillations, and calculating the deviation from vertical center as determined by H_{COG} (Balance Master® Operator's Manual, 1989). The COG appeared as a cross on the computer screen facing opposite the subject at eye level. The forceplate was calibrated on a regular basis using a standard weight of known mass.

Procedure

Subjects in both groups completed 5 sessions on the Balance Master® using the same experimental protocol. The subjects in group I completed each session at approximately the same time each day. The subjects in group II completed each session within one day at the same time each week. Subjects were lightly dressed and wore stockings on their feet. During each session, the subjects feet were positioned on the Balance Master® forceplate using the recommended foot placement (Balance MasterR Operator's Manual, 1989). They were allowed to splay the feet to a comfortable position, yet the feet were kept symmetrical on both sides of the plates keeping them an equal distance from the x-axis zero position. Foot postition was determined by a grid etched on the forceplate, and the identical procedure for foot placement was followed on subsequent sessions. Subjects were instructed not to move the feet from this position and to keep the arms relaxed at their sides at all times during the session.

The COG cursor was then explained to the subjects, and minimal practice time was given to familiarize the subjects with the COG cursor on the computer screen. Instructions were given to move the COG by rotating the body primarily about the ankle joints, and to introduce hip movement only if needed. Movement about the hip joint introduces horizontal components to the force (17), which are not detected as accurately by the force platforms. The subjects were reminded of this throughout the course of the experiment.

Standard Assessment

A standard assessment was completed by the subjects in the first and last sessions of the study which consisted of four separate tests. The first three tests provided measures of body sway in a static central postion under three different conditions. These were:

1) Standing body sway in a central positon with eyes open (EO).

2) Standing body sway in a central position with eyes closed (EC).

3) Standing body sway in a central position using visual feedback (VF). For this condition, a central target was depicted on the computer screen, and the subjects were instructed to hold the COG cursor "as still as possible" in the center of the target.

These three conditions were measured individually for 20 seconds each, at a sampling rate of 20 Hz (Balance Master Operator's Manual, 1989). The area of body sway was calculated for each condition, and expressed as a percentage of the subject's theoretical LOS.

The fourth assessment exercise provided different measures for movement of the COG to different points within the LOS cone. This exercise displayed 8 targets on the computer screen placed at 45^{o} angles in a circle representing 75% of the subject's calculated LOS, and a central target representing the subject's COG in a vertically erect position (Fig. 1a). After placing the COG in the central target, a peripheral target was highlighted and the subjects were asked to move the COG to the highlighted target. The target was highlighted for 7 seconds before the subjects were required to move the COG back to the central target. Peripheral targets were successively highlighted in a clockwise direction with the subjects returning to the central target before the subsequent peripheral target was highlighted (Fig. 1a). This assessment protocol was chosen because it included evaluation of dynamic postural variables. Three variables were evaluated:

a) Transition time: time in seconds taken to move the COG cursor from the central target to the peripheral target once it was highlighted (failure to reach the target was recorded as a time of 7 seconds).

b) Path error: the calculated area of any deviation from a straight line path going from the central target to the highlighted peripheral target, expressed as a percentage of the subject's theoretical LOS.

c) Peripheral sway area: the amount of body sway calculated after the subjects reached the highlighted peripheral target, expressed as a percentage of the subject's theoretical LOS (failure to reach a peripheral target in the 7 second time limit resulted in no score output for sway area, and an arbitrary score of 1.0% was given).

Therapy Protocol

Subjects completed the therapy protocol for each of the 5 experimental sessions. The therapy protocol required the subjects to move the COG cursor in a clockwise circle for 5 trials and in a counterclockwise circle for 5 trials. Each circle consisted of 8 targets placed at 45^{o} angles representing 75% of the subject's theoretical LOS, however there was no central target.

The subjects were asked to place the COG cursor on the uppermost target (at 0^{o}) and targets were then highlighted sequentially every 5 seconds in a clockwise or counterclockwise direction (Fig. 1b). Similiar variables were evaluated as in the standard assessment (transition time, path error, and peripheral sway area), with the exception that the COG cursor was moved from one target to the next in a circle and not returning to the center, and that the pacing speed was now 5 s instead of 7 s. Five subjects in group I, and 4 subjects in group II completed the clockwise circle trials first and then the counterclockwise circle trials, and the remaining subjects completed the counterclockwise circle trials first to counterbalance the order for statistical purposes. The standard assessment protocol was administered before the therapy protocol during the first session (pre-therapy test) and after the therapy protocol during the last session (post-therapy test).

Subjects were not encouraged to either decrease the time taken to go from one target to the next, or to increase their accuracy at hitting the targets specifically. The only instruction they recieved was to improve their overall performance.

The standing body sway scores (EO,EC, and VF) between groups I and II were compared by calculating the mean difference between the pre-therapy and post-therapy scores, and performing independent t-tests for each body sway variable. The pre- and post-therapy scores for each condition were then combined for both groups and paired t-tests were used to analyze the difference between pre- and post-therapy values.

Paired t-tests were used to evaluate changes in transition time, path error and sway area between the pre-and post-therapy tests of the 4th standard assessment. The mean difference was again calculated between the pre- and post-therapy scores for each variable (transition time, path error, and peripheral sway area), and independent t-tests were used to compare these values between groups I and II.

The circle of targets for the therapy protocol was divided into 4 quadrants to observe the transitions between targets in a more detailed manner. The quadrants, consisting of 2 transitions, were designated as quadrants 1 through 4 (Q1-Q4) as denoted in Fig. 1b. The two scores in each quadrant were summed to obtain a quadrant value. Analysis of performance over the course of therapy accounted for the effects of field (clockwise or counterclockwise circling), quadrant, and session and the interaction between these parameters. A three way analysis of variance (ANOVA) for repeated measures was performed for each variable (transition time, path error, sway area) in both groups. Significance for all parts of the analysis was determined at a 0.01 α-level using the Huynh-Feldt correction factor for degrees of freedom adjustment. Post-hoc multiple comparisons were performed using Tukey's HSD tests.

Results

Standard Assessment

Static Postural Variables

Table 1a gives the means for both groups I and II combined for each static sway condition measured on the pre- and post-therapy occasions. A comparison of the pre- and post-therapy values yields no significant difference, as indicated in the table. Table 1b shows the mean difference between the pre- and post-therapy scores for each group. The mean difference score are positive in the eyes open, and visual feedback conditions indicating a slight decrease in body sway after therapy, while the mean difference scores for body sway with eyes closed are both negative, indicating a tendency for increased body sway, albeit not significantly. There was also no significant difference between groups I and II for any of the pre- or post-therapy values.

Dynamic Postural Variables

For group I (daily protocol), transition time, path error, and peripheral sway area all decreased significantly from the pre-therapy to the post-therapy assessment (Student's t-test). Group II (weekly protocol) demonstrated a similiar trend with significant decreases in transition time and sway area, however there was no significant change in the path error from the pre- to post-therapy tests. Figure 2 shows the post-therapy scores as a percentage of the pre-therapy values for transition time, path error, and peripheral sway area for the dynamic assessment exercise. Averaging the scores of groups I and II, transition time displayed an overall 24.9% decrease, path error a 23.9% decrease, and peripheral sway area a 62.6% decrease.

A comparison of the mean pre- to post-therapy difference scores between groups I and II yielded no significant difference between the two groups.

Therapy Protocol

Figure 3 depicts the scores for each session as a percentage of the score on day 1 for each variable. For group I,no significant change was observed for transition time over the 5 days of therapy (ANOVA), although the amount of path error and sway area decreased significantly. Post hoc analyses (Tukey's HSD) revealed significant decreases between days 1, 2 and 3 for both path error and sway area, with a plateau after day 3 for path error and day 4 for sway area (Fig. 3). The results of group II exhibited a similiar pattern with no significant changes observed for transition time, but significant decreases between weeks 1 and 2 were found for both path error and sway area with subsequent plateaus noted after week 3 for path error and week 4 for sway area (Fig. 3).

The results of the ANOVA showed a field by quadrant interaction for all three variables for both groups, these interactions occurring in quadrants 3 and 4. Table 2 shows the means and standard deviations for transition time, path error and sway area for each quadrant of the clockwise and counterclockwise circles for both groups. Overall, the means for each variable in both groups displayed relative consistency over the quadrants for both directions of circling. However post-hoc analyses revealed significantly larger values for transition time in quadrant 3, and path error in quadrant 4, circling in the clockwise direction for group I. This is supported by experimental observations that subjects had difficulty in reaching the targets in these 2 quadrants circling in the clockwise direction as opposed to circling in the counterclockwise direction. For group II, again there is a significantly large value for path error in quadrant 4 in the clockwise direction.

Discussion

The measure of body sway in a static central position is often used as an indicator of postural stability. This measure recorded on a force platform allows quantitative analysis of postural stability in a static postion, under several conditions of sensory alterations. The present results indicate that dynamic balance training had no effect on static sway measures. For this population, the values for measured body sway under all three conditions (EO, EC, and VF) were initially very low, therefore demonstrated no significant change after a period of balance training. From a study documenting changes in body sway after practice sessions of standing under several altered sensory conditions, Brandt (1981) concluded that "the percentage of improvement through training depends on the amount of initial instability", therefore the present results are in concordance with this statement. The negative mean difference score for body sway in the absence of visual input (EC) indicates a slight reduction of postural stability in this condition after training. It is doubtful that this has any meaning due to the lack of significance when comparing the pre- and post-therapy scores. It is suggested, however, that balance training with constant feedback of the COG position could have led to a dependence on visual cues. A removal of any visual input after a series of practice sessions using visual feedback could account for the mean increase in body sway with eyes closed. The marginal change between pre- and post-therapy values in this condition, however, indicates that this would be a negligible effect.

Unlike the static postural measures, there were significant changes from the pre- to the post-therapy variables measured in the dynamic assessment. There was a substantial change between the pre- and post-therapy scores for transition time and sway area for both groups, and for path error in group I. No significant difference was noted between groups I and II when the pre- to post-therapy differences were compared, and this can be seen in Fig. 2, with similiar trends being displayed between the two groups. This indicates that the frequency of the therapy sessions had no bearing on the performance scores in the standard assessment, up to one session per week, and could have clinical significance when scheduling sessions using this technique.

With transition time and path error having a 24.9% and a 23.9% decrease respectively, from the pre-therapy values, it can be seen that the time and accuracy in moving from a central to a peripheral target improved to the same degree. Sway area as measured at the peripheral targets showed the most pronounced decrease from the pre-therapy value. From this observation, it is clear that repeated therapy sessions effectively increased the subject's "stability" while balancing at the 75% periphery of their theoretical LOS cone, when having moved there from a central position. This 62.6% improvement in peripheral stability has implications for balance retraining in clinical populations using exercises that seem to effectively train dynamic stability.

Although not quantitatively measured, visual observation of the subjects indicated a preference to move the COG cursor primarily about the hip joint as opposed to movement about the ankle joints during the pre-therapy assessment and the initial therapy sessions. Rotating about the ankle joints is a more effective way to move the COG on the Balance Master®, as the only components of the force being applied to the platform are vertical and are more accurately detected by the force platforms. Thus, if movement was being initiated from the hips, a smaller degree of movement was displayed on the computer screen, causing subjects to displace themselves from the equilibrium position farther than needed. Horak and Nashner (1986) argue that movement of the COG should occur about the ankle joints while standing on a large, stable support surface while making small voluntary movements within the theoretical LOS cone. As these volitional movements get larger, one must rotate about the hips to move the COG effectively. Movements outside of the LOS require changing the base of support by taking a step. The exact point within the LOS where movement changes from an ankle strategy to a hip strategy differs between individuals, and is dependent on their own percieved LOS cone. Using this model, subjects were encouraged to move as far as possible by using the ankle joints only, and only when they felt unstable by this mode of movement should they allow movement about the hips. This also introduced a limitation of the Balance Master® itself as a rehabilitative tool, as using the visual feedback to teach effective movement at the hip would not be a reliable source of feedback. Determining the strategy of movement (ankle or hip) was not a primary objective of this study, therefore there is no quantitative data to support these observations.

The clockwise and counterclockwise circles were chosen for the therapy protocol because subjects were challenged to move their COG through several points representing 75% of the entire periphery of their theoretical LOS. Path error and sway area depict traditional "performance curves" for both groups I and II, showing improvement in performance and then a plateau occuring after day 3 for path error and day 4 for sway area. The decrease in sway area again indicates improved stability at the 75% periphery of the LOS cone, however this time it was not approached from a static central position, but from another peripheral position within the LOS cone. The decrease in path error also demonstrates the increased stability while working at the periphery. The improvement in these two variables over the course of therapy indicates a "dynamic stability" attained when working at the outer limits of of the cone.

There were no significant changes observed for transition time over the course of therapy for either of the groups, but there was a significant decrease in transition time from the pre-therapy to the post-therapy test in the standard assessment. This observation can be explained in several ways. Because the subjects were not instructed to decrease the time taken to reach the targets, or to increase the accuracy of hitting the targets specifically, overall interpretation of "improvement in performance" was taken more literally to mean increasing accuracy. This is evidenced by the decrease in path error over the course of the therapy sessions. However, although not significant, both groups displayed small decreases in transition time as well during the therapy sessions (Fig. 3a), showing that as the accuracy improved, the transition time decreased as well. This could explain the post-therapy improvement in transition time from the pre-therapy assessment. Secondly, the pacing speed of the targets being highlighted was 7 seconds for the standard assessment and 5 seconds for the therapy protocol. During the post-therapy assessment, the subjects had been conditioned to the 5 second time limit of the therapy protocol, and therefore moved the cursor more rapidly as opposed to the initial pre-therapy assessment, when they had only been exposed to the 7 second pacing speed.

Significant differences in scores between the clockwise and counterclockwise directions for each variable are observed in Table 2. The difficulty in reaching the targets in Q3 and Q4 while circling in the clockwise direction as opposed to the counterclockwise direction is difficult to interpret. Appropriate calibration of the force plate revealed no difference in the two sides. It has been previously reported that there is no difference in steadiness (body sway) between dominant and non-dominant sides of the body during one-leg stances (Clarke et al., 1990). There has been, however, no documented evidence of sway characteristics during dynamic movement on the force platform in terms of hand or foot preference. There was a right side dominance (hand and foot) for most of the subjects, which could explain the overall difficulty in reaching targets on the left side of the circle. In this case, there would be more stability on the dominant side. This observation was not expected in light of the experimental design, therefore a strong conclusion cannot be made regarding right or left dominance and dynamic balance. The number of left-handed, left-footed people in the study was relatively small, and their results indicated no particular trend in performance when compared to the larger group of right handed, right footed subject. Further testing of this observation would likely be needed in a more random set-up of targets, as opposed to circling in the same direction during the repeated trials, avoiding any compounding of effects.

The main interest of this study was to observe the variability within subjects and evaluate any change in performance based on the three Balance Master® variables studied. Stribley et al. (1974), previously demonstrated no quantitative difference between males and females for sway area as measured on a force platform. However, this was only measured for stance in a vertically stable position, and no information exists for gender differences during dynamic movement around the limits of stability.

From the performance curves for path error and sway area, and the net differences between pre- and post-therapy tests for these two variables as well as transition time, overall improvement in dynamic performance for normals can be inferred. Confidence in movement within the 75% cone of stability increased as subjects became more accurate in reaching peripheral targets, and more stable when executing movements at the periphery of the cone. Because this population had presumably no apparent sensory or motor disabilities, this improvement in performance can be attributed to a training or practice effect. This training effect should be accounted for when performance is evaluated in patient populations utilizing the Balance Master® system therapeutically.

It can be seen from Fig. 3 that the learning curves between groups I and II follow the same pattern. The amount of time between practice sessions appears to have little effect on the performance.

This dynamic evaluation more effectively mimics everyday activities than traditional evaluation of postural characteristics (Wannstedt and Herman, 1978; Shumway-Cook et al., 1988; Winstein et al., 1989; Jobst, 1990). Visual feedback of the COG and LOS allowed subjects to integrate somatosensory and visual information in relation to stance and movement within the theoretical cone of stability. Much information exists that gives values for body sway under different sensory conditions for normative populations. For this type of therapy using visual feedback for postural rehabilitation in a dynamic setting, the learning curves over a course of repeated therapy needed to be established for a population without postural disorders. Although this study is limited in sample size, and cannot be considered a normative study; performance curves have been established, and should be considered before interpreting information from patient populations.

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Table A-1: (a) Pre- and post-therapy body sway scores for each condition, combined for groups I and II, and significance as a result of paired t-test comparison;
(b) Mean difference scores between the pre- and post-therapy body sway scores for both groups in each condition, and the significance as a result of a paired t-test comparison.

(a)

	Postural Sway		
	Eyes Open	Eyes Closed	Visual Feedback
Pre-therapy	0.12	0.18	0.12
Post-therapy	0.11	0.21	0.10
	ns	ns	ns

(b)

	Postural Sway		
	Eyes Open	Eyes Closed	Visual Feedback
Group I	0.02	-0.04	0.01
Group II	0	-0.02	0.01
	ns	ns	ns

ns = not significant at 0.05 α level

Table A-2: Transition time, path error, and sway area for clockwise and counterclockwise circles in the therapy protocol for groups I and II (values are given as mean ± standard deviation).

	Transition Time (s)		Path Error (%LOS)		Sway Area (% LOS)	
Quadrant	Group I	Group II	Group I	Group II	Group I	Group II
Clockwise						
1	2.73±0.93	4.07±0.53	2.23±0.61	2.34±0.57	0.31±0.14	0.35±0.14
2	2.04±0.77 *	3.78±0.78	2.13±0.74	2.17±0.74	0.36±0.12	0.36±0.16
3	3.09±0.7	3.73±0.58	1.96±0.48	2.18±0.46	0.33±0.12	0.42±0.16
4	2.42±0.81	3.84±0.61	2.86±1.01 **	3.22±1.2 *	0.36±0.16	0.34±0.14
Counter-Clockwise						
1	2.15±0.43	3.88±0.68	2.61±0.79	3.18±1.22 *	0.33±0.13	0.35±0.17
2	2.52±0.43	3.55±0.55	2.13±1.00	2.07±0.64	0.36±0.13	0.40±0.18
3	1.94±0.34	3.73±0.51	2.55±1.26	2.10±0.89	0.34±0.15	0.34±0.15
4	2.45±0.46	4.05±0.55	2.39±0.94	2.25±0.76	0.29±0.09	0.32±0.11

* Significant at 0.01
** Significant at 0.05

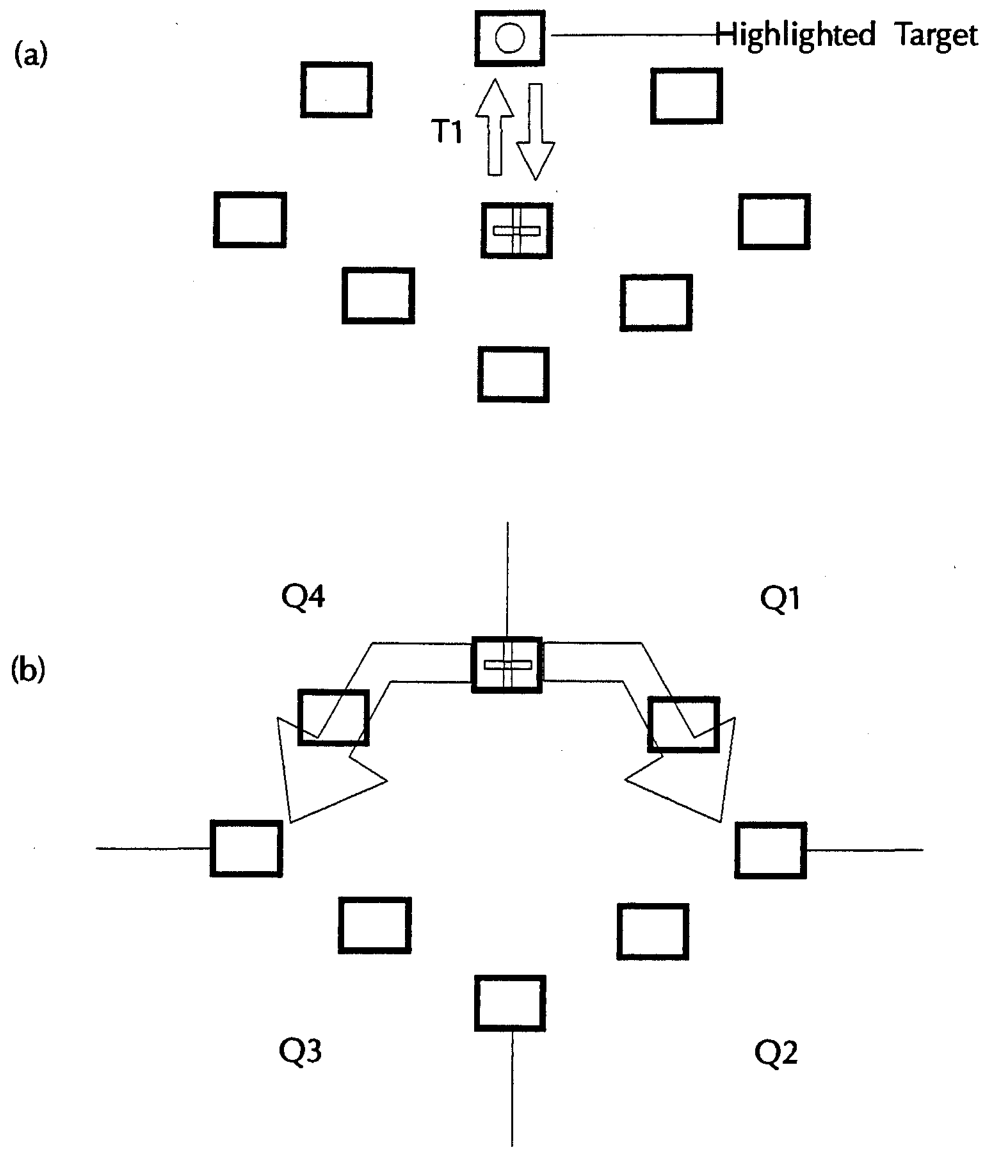

Figure A-1: On-screen computer display target arrangements for: (a) standard assessment protocol showing transition 1 (T1) from the center target and; (b) therapy protocol displaying the quadrant divisions (Q1-Q4). The pattern of COG movements is indicated by the arrows, and COG cursor is indicated by the +.

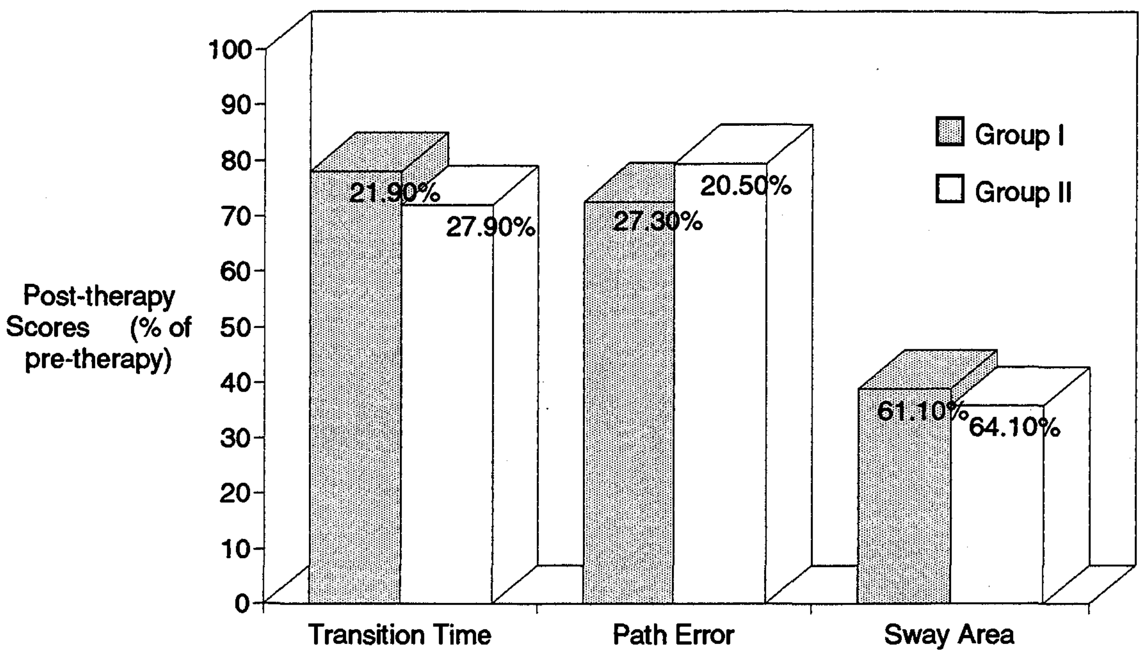

Figure A-2: Post-therapy scores for transition time, path error, and sway area expressed as a percentage of pre-therapy scores for groups I and II. Percentage values shown on top of the bars is the actual reduction from 100%.

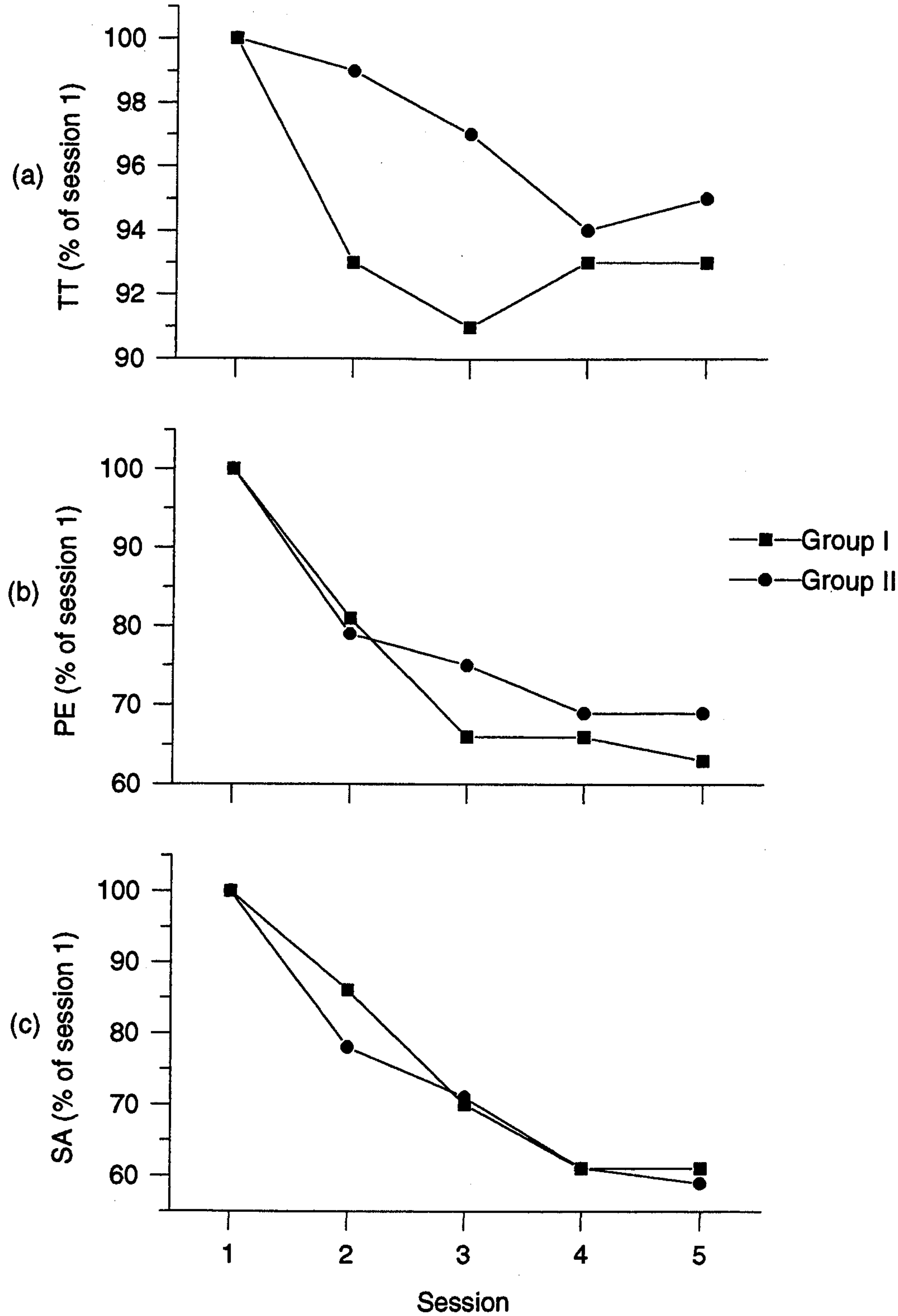

Figure A-3: Mean scores for both groups I and II over the course of therapy expressed as a percentage of the score for session 1 for (a) transition time (s); (b) path error (%LOS) and; (c) sway area (%LOS).

Appendix B

Balance Training Study

Subject Questionnaire

Name: ____

Age: __________ Birthdate: _________________

Height: ________

Medical Information:

Past History:

Do you have any history of:

( ) high blood pressure?
( ) hypertension?
( ) vascular disease?
( ) varicose veins?
( ) operations?
( ) back injuries?
( ) spells of dizziness?
( ) diabetes?
( ) neurological disease?
( ) muscular injury or dysfunction?

If you answered yes to any of the above, please explain:

____

____

____

____

____

____

____

____

____

____

Please describe any history of accidents or disease that **you** think might affect your balance or posture that was not covered in the above questions.

____

____

____

____

____

____

<u>Present Symptoms:</u>

Have you recently had:

( ) chest pains?
( ) shortness of breath?
( ) heart palpitations?
( ) back pain?
( ) swollen, stiff, or painful joints?
( ) muscle or tendon injury?

If you answered yes to any of the above, please explain:

____

____

____

____

____

____

Are you currently on any medication? Yes( ) No( ) If yes, please describe:

____

____

____

____

Are you physically active? Yes( ) No( ) If so, for how long and how many times per week do you partake in physical activity?

____

What physical activities do you do?

____

____

Do you wear corrective lenses? Yes( ) No( )

Do you feel that your vision is adequate?

____

____

____

Thank-you for filling in the medical questionnaire.

Signature:____

Date: ____

Appendix C

ANOVA Tables for Statistics

1. Gender Effects

Static Variables

Sway - Eyes Open

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	0.00042	1	0.00042	.0.05	0.8282
Assessment	0.02021	3	0.00674	2.14	0.1066
Sex x Assessment	0.00827	3	0.00276	0.88	0.4599

Sway - Eyes Closed

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	0.01655	1	0.01655	0.35	.05597
Assessment	0.05362	3	0.01787	1.48	0.2316
Sex x Assessment	0.01036	3	0.00345	0.29	.08357

Sway - Visual Feedback

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	0.00005	1	0.00005	0.01	0.9094
Assessment	0.00523	3	0.00174	1.79	0.1613
Sex x Assessment	0.00440	3	0.00147	1.5	0.2252

1. Gender Effects - Continued

Dynamic Variables

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	1.85560	1	1.85560	5.46	0.0320
Assessment	4.33898	3	1.44633	7.89	0.0002
Sex x Assessment	0.52310	3	0.17437	0.95	0.4229

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	0.00641	1	0.00641	0.04	0.8430
Assessment	2.16370	3	0.72123	11.62	0.0000
Sex x Assessment	0.03037	3	0.01012	0.16	0.9207

Peripheral Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Sex	0.00013	1	0.00013	0.07	0.8007
Assessment	0.04939	3	0.01646	19.35	0.0000
Sex x Assessment	0.00346	3	0.00115	1.36	0.2669

2. Practice Schedule Effects

Static Variables

Sway - Eyes Open

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.02517	1	0.02517	3.47	0.0797
Assessment	0.02275	3	0.00758	2.7	0.0556
Group x Assessment	0.02533	3	0.00844	3	0.0389

Sway - Eyes Closed

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.17100	1	0.17100	4.54	0.0480
Assessment	0.05847	3	0.01949	1.68	0.1837
Group x Assessment	0.03430	3	0.01143	0.98	0.4079

Sway - Visual Feedback

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00441	1	0.00441	1.24	0.2812
Assessment	0.00492	3	0.00164	1.63	0.1939
Group x Assessment	0.00290	3	0.00097	0.96	0.4178

2. Practice Schedule Effects - continued

Dynamic Variables

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	1.46053	1	1.46053	4.02	0.0611
Assessment	4.34265	3	1.44755	8	0.0002
Group x Assessment	0.64542	3	0.21514	1.19	0.3231

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00535	1	0.00535	0.03	0.8564
Assessment	2.14302	3	0.71434	11.56	0.0000
Group x Assessment	0.04334	3	0.1445	0.23	0.8725

Peripheral Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00076	1	0.00076	0.39	0.5428
Assessment	0.04974	3	0.01658	20.44	0.0000
Group x Assessment	0.00548	3	0.00183	2.25	0.0935

2. Practice Schedule Effects - continued

Comparison of Targets

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	21.19045	1	21.19045	3.78	0.0686
Assessment	73.65830	3	24.55277	8.41	0.0001
Group x Assessment	7.77801	3	2.59267	0.89	0.4537
Target	925.95398	7	132.27914	94.99	0.0000
Target x Group	11.65818	7	1.66545	1.2	0.3104
Assessment x Target	50.42307	21	2.40110	3.05	0.0000
Assessment x Target x Group	15.31487	21	0.72928	0.93	0.5561

2. Practice Schedule Effects - continued

Comparison of Targets

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.12843	1	0.12843	0.06	0.8117
Assessment	35.28596	3	11.76199	11.50	0.0000
Group x Assessment	1.30336	3	0.43445	0.42	0.7360
Target	263.3666	7	37.62381	35.82	0.0000
Target x Group	9.71303	7	1.38758	1.32	0.2461
Assessment x Target	44.52016	21	2.12001	2.17	0.0023
Assessment x Target x Group	41.36834	21	1.96992	2.02	0.0054

2. Practice Schedule Effects - continued

Comparison of Targets

Peripheral Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00337	1	0.00337	0.11	0.7446
Assessment	0.80371	3	0.26790	19.13	0.0000
Group x Assessment	0.10510	3	0.03503	2.5	0.0697
Target	1.87807	7	0.26830	32.18	0.0000
Target x Group	0.08866	7	0.01267	1.52	0.1672
Assessment x Target	0.29490	21	0.01404	1.46	0.0892
Assessment x Target x Group	0.13726	21	0.00654	0.68	0.8546

2. Practice Schedule Effects - continued

Results over Training

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.81987	1	0.81987	1.32	0.2681
Session	0.36490	4	0.09123	2.99	0.0250
Group x Session	0.08773	4	0.02193	0.72	0.5817

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.07744	1	0.07744	0.85	0.3704
Session	0.15638	4	0.03910	2.5	0.0508
Group x Session	0.00782	4	0.00195	0.13	0.9729

Periperhal Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00093	1	0.00093	0.24	0.6331
Session	0.00625	4	0.00156	3.99	0.0060
Group x Session	0.00118	4	0.00030	0.75	0.5591

Central Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.00025	1	0.00025	0.02	0.8976
Session	0.08856	4	0.02214	2.25	0.0739
Group x Session	0.05034	4	0.01259	1.28	0.2886

3. Age Effects

Static Variables

Sway - Eyes Open

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.05036	1	0.05036	2.28	0.1490
Assessment	0.01663	3	0.00554	1.51	0.2242
Group x Assessment	0.05487	3	0.01829	4.97	0.0042

Sway - Eyes Closed

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.06552	1	0.06552	1.56	0.2283
Assessment	0.10797	3	0.03599	2.36	0.0826
Group x Assessment	0.12163	3	0.04054	2.66	0.0582

Sway - Visual Feedback

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.12896	1	0.12896	23.36	0.0002
Assessment	0.04980	3	0.01660	8.25	0.0001
Group x Assessment	0.02119	3	0.00706	3.51	0.0217

3. Age Effects - continued

Dynamic Variables

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	2.13413	1	2.13413	3.96	0.0629
Assessment	29.00535	3	9.66845	67.1	0.0000
Group x Assessment	7.75547	3	2.58516	17.94	0.0000

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	4.35083	1	4.35083	25.69	0.0001
Assessment	0.60376	3	0.20125	3.43	0.0238
Group x Assessment	0.63592	3	0.21197	3.61	0.0193

Peripheral Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.07500	1	0.07500	34.31	0.0000
Assessment	0.03448	3	0.01149	10.48	0.0000
Group x Assessment	0.01430	3	0.00477	4.35	0.0084

3. Age Effects - continued

Results over Training

Transition Time

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.11984	1	0.11984	0.15	0.7063
Session	1.31300	4	0.32825	4.92	0.0015
Group x Session	3.16654	4	0.79163	11.87	0.0000

Path Error

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	1.28604	1	1.28604	16.74	0.0008
Session	0.22620	4	0.05655	3.6	0.0102
Group x Session	0.04886	4	0.1222	0.78	0.5439

Peripheral Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.04218	1	0.04218	7.05	0.0166
Session	0.00347	4	0.00087	1.26	0.2958
Group x Session	0.01158	4	0.00289	4.19	0.0043

Central Sway Area

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F - VALUE	P - VALUE
Group	0.06415	1	0.06415	4.94	0.0402
Session	0.02415	4	0.00604	1.05	0.3886
Group x Session	0.01901	4	0.00475	0.83	0.5136