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POSTURAL CONTROL IN CHILDREN AND YOUNG ADULTS

A Thesis in

Kinesiology

By

Sheri Anne Hale

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The thesis of Sheri Anne Hale was reviewed and approved* by the following:

Jay Hertel
Assistant Professor Kinesiology
Thesis Adviser
Chair of Committee

Craig Denegar
Associate Professor Kinesiology

Karl Newell
Professor Kinesiology

Byron Jones
Professor of Biobehavioral Health/Pharmacology

Phillip Martin
Professor of Kinesiology
Head of the Department of Kinesiology

*Signatures are on file in the Graduate School.

ABSTRACT

Postural control is essential in functional performance from infancy through adulthood. Despite the importance of postural control, researchers do not have a thorough understanding of postural control in school-aged children and young adults. The purposes of these studies were to investigate age-related postural control differences and the efficacy of a balance intervention program in improving postural control among six and seven year old children.

Sixty-two subjects participated. They were classified into three age groups 1) 19-20 years (N=16), 2) 9-10 years (N=15), and 3) 6-7 years (N=31). Subjects completed postural control testing including: 1) Center of Pressure Velocity (COPV), 2) Functional Reach, 3) Berg Balance Scale, 4) Pediatric Balance Scale, and 5) Activities-specific Balance Confidence (ABC) Scale. The six-seven year old children were then assigned to a training group that completed a six-week balance intervention program (N=12), or a control group (N=14). Following the intervention period, subjects repeated the testing.

An analysis of variance (ANOVA) was performed to compare means at baseline among the three age groups. A repeated measures ANOVA was performed to examine the efficacy of the intervention.

Significant age-related differences were found for all measures. Post hoc testing revealed that the young adults scored significantly better than the 9-10 year old children in all dependent variables except the Berg Balance Scale and Pediatric Balance Scale. They scored better than the 6-7 year old children in all measures. The 9-10 year old children scored better than the 6-7 year old children in all variables except left leg stance COPV and the ABC Scale.

Following the training program, no statistically significant differences were noted except for a main effect for time in the functional reach test. Subjects reached further during post-testing than they did at baseline. Despite the lack of statistically significant changes, there were moderate to strong effect sizes among the training group suggesting that more research is needed to examine the efficacy of balance training among healthy children.

These results support previous reports of age-related postural control differences. Despite the lack of statistically significant improvements associated with the training program more research in this area is warranted.

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CHAPTER 1

INTRODUCTION

Background

Postural control is an essential aspect of neuromuscular development in humans. It is essential for the performance of all levels of tasks from infancy through adulthood. Postural control is one component of tasks such as sitting upright, crawling, walking and high level athletic activity. Children and adults continue to develop postural control as they engage in higher levels of activity and begin to experience more unpredicted external perturbations.

While postural control allows us to function and be mobile, balance deficits limit mobility and also be associated with injury. Despite the importance of postural control, we do not have established measures or standards for postural control for school-aged children through adulthood. Neuromuscular development from school age into adulthood is not well understood.

It is therefore important for us to establish realistic milestones to evaluate the development of postural control in order to allow us to identify children at risk for decreased functional mobility and/or injury.

In addition to identifying at risk children, it is important to examine our ability to positively influence postural control in the developing child. If, in fact, postural control is modifiable, an effective balance training program needs to be established to help improve functional mobility and prevent injury among school-aged children.

Purposes

The purposes of these studies were to: 1) investigate age-related differences in static and dynamic postural control and 2) examine the efficacy of a 6-week balance intervention program designed to improve postural control among six and seven year old children.

Experimental Hypotheses

In the first study, it was hypothesized that: 1) young adults would demonstrate greater postural control than the six and seven year old children in all performance measures, 2) Performance differences would be identified between the nine and ten year old children when compared to the six and seven year old children in some measures, and 3) Performance differences would be identified between the young adults children when compared to the nine and ten year old children in some measures.

For the second study, it was hypothesized that subjects completing the six week balance training program would improve postural control more than the subjects that did not complete the balance intervention program.

Operational Definitions

1. ABC: Activities-specific Balance Confidence Scale
2. ANOVA: Analysis of variance
3. BOS: Base of support
4. Control Group: Group of six and seven year old children that did not participate in training

5. COP: Center of pressure
6. COPV: Center of pressure velocity
7. COV: Coeffficient of variation
8. Dominant Limb: The limb with which one would kick a ball
9. Dynamic Balance: Maintenance of the center of mass within one's base of support during functional activity
10. EC: Eyes closed
11. EMG: Electromyography
12. EO: Eyes open
13. SD: Standard deviation
14. SLS: Single-leg stance
15. Static Balance: Maintenance of the center of mass within one's base of support while attempting to keep the body at rest
16. Training Group: Group of six and seven year old children that completed a six-week balance intervention program at school

Assumptions

It was assumed :

1. Subjects and/or their parents completed all questionnaires accurately.
2. Subjects demonstrated maximal effort during testing and training
3. Subjects understood the ABC Scale

Limitations

1. Outside activity was not controlled in these studies.
2. Subject population was limited to three age groups.
3. Subjects were healthy and therefore results may not be generalizable to individuals with illness, injury, or special needs.

CHAPTER 2

LITERATURE REVIEW

Defining Postural Control

Postural control has been defined as "the ability to maintain the body's center of gravity over the base of support during quiet standing and movement."[1] It is important to recognize both components of postural control that are outlined in the definition. Postural control is both a static and dynamic activity. Static postural control serves to maintain the body in an intended position while resting. During dynamic activities, postural control enables one to "progress through an intended movement without losing balance."[2] As a result, one's postural system must: 1) maintain a steady stance in a gravity rich environment, 2)produce responses that anticipate volitional movements, and 3) be adaptive.[2]

Neurophysiology of Postural Control

Postural control is dependent upon many levels of nervous system control. In order to maintain postural control, afferent input from the visual, vestibular, and somatosensory systems is critical.[3-6] When the input from these three systems is in conflict, postural control becomes more challenging, requiring filtering, integration and interpretation of the conflicting input.[2, 6] The efferent activations resulting from and preceding the afferent information are also essential to postural control. Postural control is not typically viewed as an attention-demanding task. More recently however, evidence suggests that attention is an important component of postural control.[4, 7, 8]

The vestibular system senses movement of one's head and position with respect to gravity. The coordination of head and eye movements is also a function of the vestibular system.[2] The somatosensory system is responsible for providing information regarding the location of body parts with respect to one another and support surfaces. The somatosensory system also provides information about volitional movements, allowing for feedback control of posture. The visual system offers much information about the location of objects and support surfaces. The role of the visual system becomes more important when the somatosensory system is impaired.

In addition to several body systems contributing to balance, various regions of the brain are involved. The spinal cord is also an essential component of postural control. While the spinal cord serves to deliver afferent and efferent information, it also serves several other purposes in the maintenance of postural control. The spinal cord mediates many reflexes that contribute to postural control. Central pattern generators are also proposed to stem from the spinal cord and contribute to postural control.

Afferent input for specialized senses including balance information travels to the brainstem, which serves as a relay station. The brainstem is also involved in the descending neural activity, as the medial and lateral descending pathways extend from the brainstem. While the lateral pathway serves the extremities, the medial pathways provide efferent output to the axial and proximal musculature.[2,9] The cerebral cortex also plays a role in the maintenance of postural control. It is the cerebral cortex that coordinates and executes volitional motor activity. Evidence of cerebral cortex involvement in postural control is also provided by the cognitive task interference literature. The cerebellum is thought to be involved in learning and adaptation. The role of the cerebellum in learning is controversial. There is evidence to support that much of the memory of learning is handled by the brainstem. The cerebellum also contributes to the planning of motor tasks. It is also thought that the cerebellum is also a key structure in modifying actions through constant analysis of information and comparing one's movements with the target movement. The basal ganglia are also believed to be involved in the planning and coordination of smooth movements and maintenance of upright posture.[2]

Postural equilibrium is achieved through feedforward and feedback control. Feedback control is most often used with non-predicted disturbance in balance. This is the body's mechanism to correct for a disturbance in balance. In contrast, the feedforward control is an anticipatory mechanism. This mechanism is utilized with predicted disruptions in balance, as with volitional movements. Rather than correcting for a disturbance, feedforward control serves to prevent a loss of balance through counterbalancing movements.[2]

Feedforward and feedback control depend upon efferent nervous activity to stimulate muscle contraction. The musculoskeletal system, like the brain and spinal cord is of great importance in maintaining an upright position. It is suggested that efferent activity of the central nervous system produces synergistic muscle patterns to maintain postural control. Most commonly these patterns are described as ankle and hip strategies.[10] A stepping strategy is also seen, particularly in response to external perturbations that displace one's center of gravity outside of the base of support. These perturbations require quick responses and often result in a step.[11]

Until recently, it was accepted that the ankle strategy is used to recover from slow velocity perturbations while the hip strategy is used for higher velocity and more displacing perturbations. More recent research shows that both strategies are present when recovering from perturbations. Therefore, some researchers propose a mixed strategy.[12, 13] Though both strategies may be present, Okada et al.[13] reported an increased reliance on the hip strategy among the elderly population.

Age Related Changes in Balance

In 1976, Shambes conducted a study investigating age related changes in postural control. Children ages four and eight years completed six developmental tasks and electromypgraphic, center of gravity, and photographic data were collected. The eight year old children demonstrated: 1) greater postural control, 2) more definitive muscular localizations, 3) and smaller degrees of motor activity during tasks requiring upper and lower extremity support of the trunk.

These results were supported by Wolff and colleagues[14] who examined postural control among children ages 5 to 18 years. The authors measured various center of pressure measures in standing with the eyes open and the eyes closed. It was reported that all center of pressure scores improved with age and in the eyes open condition.

While Slobounov and Newell[15] also found improved postural control in the eyes open condition, they suggest that postural control deficits related to decreased visual input may be greater in younger children. In their study, they examined the effects of visual condition and the single leg versus bipedal stance on postural control among three and five year olds. They reported that the three year old age group was more effected by more challenging task constraints. These authors also noted that the two groups of children used different balance strategies during more difficult tasks. While all children attempted to limit the degrees of freedom, only the five year old children demonstrated compensatory movement patterns.

These authors conducted a similar study examining the effects of base of support, visual condition, and skill level on postural control and balance strategies in adults.[16] They found that among adults, skilled subjects employed fewer compensatory movement patterns. This is an interesting contrast to the findings in children where only the older children utilized these compensatory movement patterns.

Streepey and Angulo-Kinzler[17] examined age related differences in postural control during the completion of tasks of graded difficulty. Three groups of subjects completed the balance testing. The youngest group was comprised of six year old children. The second group was ten and eleven year old children. The third group was adults. Center of pressure (COP) measures and reach distance were recorded as the subjects completed reaching tasks in three different directions to two different distances. No significant age related differences were identified in the: 1) initial position of the COP, 2) excursion of the COP, 3) amplitude of COP movement during the least difficult and most difficult tasks. During moderately difficult tasks, the ten and eleven year old children performed similar to the youngest subjects for some of the tasks while performing similar to the adults in other tasks.

In addition to age related changes in postural control, Riach and Hayes.[18] also suggest there are gender differences in postural control among children. Seventy-six children between the ages on two and fourteen completed postural sway testing under different conditions. Decreases in postural sway were seen with age. While the boys began with greater sway, their sway improved at a greater rate when compared to the girls. Romberg quotients were used to estimate the influence of eye-closure on postural control. These quotients were low compared to the adult population suggesting that children utilize visual cues differently than do adults. These authors suggest that after the age of seven, children begin to adopt balance strategies similar to that of adults.

Similar gender differences were previously identified by Odenrick and Sandstedt[19] in 1984. Postural sway measures with the eyes open and the eyes closed were gathered for sixty-four healthy children between the ages 3.5 and 17 years. Among children younger than ten years, boys demonstrated decreased postural control when compared to girls. However, sway amplitude decreased with age among the boys but not the girls.

Among adult subjects, several authors have reported detrimental effects of aging on postural control.[20, 21,22] Hageman et al.[22] conducted a study to identify age and gender related changes in postural control measurements. Subjects were divided into two age groups: 1) 20-35 years and 2) 60–75 years. Subjects then completed force platform measures using the Balance Master system and the functional reach test. The results showed that gender was not related to any of the balance measure scores. Age, however, was related to all measures. The older population had greater areas of sway on the forceplate. When completing the functional reach test, older adults demonstrated longer movement times, longer path lengths and shorter reaching ability when compared to the younger population.

Matheson and colleagues[21] also demonstrated age-related deficits in postural control. Matheson recruited three groups of subjects: 1) 18-39 years, 2) 40-59 years, and

3) 60 years or older. Subjects were tested using the Clinical Test of Sensory Interaction and Balance protocol. The deficits found with aging were greater with increases in task difficulty.

While several authors have demonstrated age-related declines in postural control, the reason for this decline is still debated. Much of the recent literature addresses the potential mechanisms for this decline. It is thought that disease and/or age related degradation of the nervous system may lead to the balance deficits seen among older adults.[3] Researchers are now trying to identify what specific neural mechanisms are involved in deteriorating postural control.

Moreover, it has been established that dysfunctions in the peripheral systems play an integral role in balance deficits seen in the elderly. Elderly people have a greater loss of balance than do younger adults after disruptions in visual and proprioceptive inputs.[7] Older people are also known to have afferent input deficits related to declines in vibratory sensation, the number of vestibular hair cells, and visual acuity. The motor output is also affected due to slowing of nerve conduction velocity, a reduction in the number of motor units, and a reduction in muscle mass.[23]

Melzer and colleagues[4] aimed to answer the question of whether central, cognitive processes have a role in maintaining posture. They also investigated how this process may be different between older and younger adults. Forty subjects (20 old, 20 young) participated in this study. Bipedal force plate data including center of pressure (COP) path, elliptical area, anteroposterior sway, mediolateral sway, and mean center of pressure velocity (COPV) were collected. Surface electromyography (EMG) signals were gathered from the tibialis anterior and soleus muscles. Subjects were tested under the following conditions: 1) eyes open (EO), wide base of support (BOS), no Stroop 2) EO, narrow BOS, no Stroop 3) EO, wide BOS, Stroop test 4) EO, narrow BOS, Stroop test.

Results demonstrated that older adults had greater COP path results than did the younger adults, in all testing conditions. This confirms the notion that younger adults do have better postural control than do older adults. When looking at the effects of a cognitive task on postural control, older and younger adults showed similar disruption in postural sway. In the wide BOS condition, COP path, elliptical area, COPV, and mediolateral sway all increased significantly in both age groups when the modified Stroop test was added. Older subjects also demonstrated significant anteroposterior sway increases. When completing the trial under the narrow BOS condition, COP path and COPV increased in younger subjects when the modified Stroop test was added. In the older population, there was a significant decrease in the elliptical area and mediolateral sway when the modified Stroop test was added.

From these results, the authors conclude that older subjects have decreased postural control when compared to young adults. In addition, they suggest that postural control does in fact depend upon cognitive processing. They attribute the postural control deficits during cognitive tasks to resource competition, suggesting that the cognitive task interfered with postural control performance. They propose that processing resources are limited. When resource competition occurs, there is task interference, which presents as motor task difficulty and a lack of task automacity. When comparing the age groups, they purport no differences in the task interference seen.

The EMG data also revealed interesting results. When performing the modified

Stroop test and standing with a narrow BOS, older subjects produced increased activity and decreased frequency of the anterior tibialis and soleus when compared to younger adults. The authors attribute this increased activity in older adults to a co-contraction of the lower extremity agonists and antagonists. They explain that older adults rely on this mechanism to decrease their postural sway by stabilizing the ankle joint. This is most noted in the more challenging conditions, such as a narrow base of support. In these conditions, the elderly population had decreased variability. The authors suggest that this does not reflect improved postural control but rather an increased effort to stabilize the joint due to great postural control demands.

While several authors have looked at the role of cognitive processing in postural control, Brown et al.[8] took the next step to look at postural recovery. Twenty-five adults volunteered to complete the study (older=10, younger=15). Subjects stood in bipedal stance with each foot on a separate force plate. During half of the trials, they were instructed to count backwards as quickly and accurately as possible by threes from a random number greater than 100. The force plates were programmed to deliver unexpected perturbation at varying speeds and in varying directions. In order to minimize the effect of anticipatory effects, some trials did not include a perturbation. Kinematic data was gathered using 2 cameras providing a sagittal view. Only data from the posterior translation of the force plate was analyzed and reported.

They reported that postural recovery is attentionally demanding for both younger and older adults. While the accuracy of the math task was unaffected by the perturbation, the time taken was greater in both older and younger adults following the perturbation. This indicates that increased attentional demands created by the disruption in postural control led to a decrease in attention dedicated to the math task. Prior to perturbation, there was no significant difference between the subtraction duration between younger and older adults. In contrast, the subtraction duration of older adults was significantly greater than that of younger adults following perturbation. This indicates that older individuals have greater attentional demands for postural recovery.

When looking at the attentional demands of each balance strategy, no significant differences were found in either age group. However, there was a trend indicating greater attentional demands for the stepping strategy compared to the ankle strategy in older adults. Brown et al.[8] also reported a difference in balance strategy choice when no math task is involved. Older adults use a stepping strategy more often than do younger adults. However, when a math task is added, there is no significant change in the strategy chosen by either age group. This finding was of special interest. It was reported that a stepping strategy appears to be more attention demanding than an ankle strategy in the elderly. However, elderly people prefer the stepping strategy, which may put them at a higher risk for a loss of balance. The conclusions outlined in this paper were: 1) recovery from an unexpected perturbation does require attentional resources, and 2) the extent of the attentional resources required may depend on age and balance strategy.

Similarly, Brauer et al.[24] examined the attentional demands of balance recovery following a perturbation in balance-impaired elderly adults. They also examined the effects of performing a cognitive task while recovering from a disruption of balance. Fifteen healthy older adults and thirteen adults with balance deficits volunteered for this study. Perturbations were delivered through sudden displacements of the force plate. Subjects were asked to react to the perturbations under two conditions. In the control condition, there were no other tasks involved. However, in the remaining trials, subjects were asked to produce a verbal response to auditory tones while recovering from perturbations. They found that both groups of adults performed better on the cognitive task in the single-task condition compared to the dual-task condition. This difference was more apparent in the subjects with balance deficits. From this they concluded that balance recovery is an attention demanding task and subjects with balance deficits are more affected by attention demanding task interference than those without balance deficits. They also examined the ability to recover balance when completing a cognitive task. While subjects with balance deficits produced slower and less effective responses to perturbations while completing the cognitive task, no differences were seen in the healthy, older adults. This also supports the hypothesis that balance impaired individuals are more affected by attention demanding task interference.

Another study was conducted to examine the attentional demands of postural control following perturbation. Teasdale and Simoneau[7] studied performance on a cognitive task while sensory information was disturbed or removed and then reintegrated while standing. Eight older adults and eight young adults stood on a forceplate and were asked to respond verbally to an auditory stimulus. During this time, subjects' sensory input was altered and then reintegrated. Postural control measures were taken immediately upon sensory disturbance and then seconds after to capture temporal adaptation. The authors found that both groups demonstrated increased COPV when proprioceptive information was reintegrated. This finding was stronger among the older adults. Reaction time to the visual stimulus was also increased in both groups during proprioceptive reintegration when vision was also disrupted.

A follow-up study was conducted by Shumway-Cook and Woollacott[25] to examine the following: 1) the effect of sensory environment on postural stability in different age groups while performing an attention demanding task, 2) the stability of older adults with balance deficits while performing an attention demanding task with altered sensory input, and 3) the attentional demands of maintaining balance with decreased visual cues compared to decreased somatosensory cues. Fifty four subjects participated in this study. Subjects were grouped by age (<45 years and >64 years). The older adults were further categorized into healthy older adults and adults with a history of falls and balance deficits. Subjects completed two sessions of balance testing. In the first session, subjects completed the Activities-Specific Balance Confidence (ABC) Scale, the Berg Balance Scale, and the Dynamic Gait Index. During the second session, subjects completed postural control measurements on a forceplate with altered sensory conditions: 1)firm surface, eyes open, 2) firm surface, eyes closed, 3) firm surface, optikinetic stimulation, 4) sway referenced surface, eyes open, 5) sway referenced surface, eyes closed, 6) sway referenced surface, optikinetic stimulation. During half of the trials, subjects were asked to simultaneously respond to an auditory stimulus by identifying if it was a high or low tone. Dependent measures were center of pressure sway and speed and accuracy of the verbal responses. The authors reported no effect of the auditory task on postural control in young adults for any of the sensory conditions. In the healthy older adults, postural control was diminished when the auditory task was added and both the visual and somatosensory cues were absent. Older adults with balance deficits demonstrated diminished postural control when the auditory task was added regardless of sensory condition. As the sensory conditions became more challenging, older adults became less able to maintain upright posture while completing the auditory task.

Rankin et al.[23] conducted a study to further explain the results seen in the Brown[8] study. The purpose of this follow-up study was to explain why older adults step more frequently in multi-task conditions despite the increased attentional demands associated with stepping. This group examined the changes in the neuromuscular response characteristics of postural control during attention demanding tasks. Twenty-six participants (14 young adults, 12 older adults) completed the study. No subject had more than two falls in the previous six months and none had uncontrolled cardiovascular disease or diabetes. Additionally, all were free of musculoskeletal, cognitive, and neurological disorders. The subjects stood in bipedal stance on a movable platform. They were instructed to count backwards as quickly and accurately as possible by 3s from a random number greater than 100. The force plates were programmed to deliver unexpected perturbation at varying speeds and in varying directions. In order to minimize the effect of anticipatory effects, some trials did not include a perturbation.

EMG data were collected from the gastrocnemius (GA), tibialis anterior (TA), biceps femoris, rectus femoris, erector spinae, and rectus abdominus muscles. Data were only reported and analyzed for the posterior translation trials. Data was also limited to only those that use an ankle strategy (6 older adults, 7 young adults).

There was no significant difference found in onset latency of the the GA or TA in either subject group following perturbation. When the subject groups were combined, the cognitive task does appear to affect the magnitude of the response recorded by the EMG. This decline is seen in the 350-500ms time period for the GA and the 150-350 ms time period for the TA. They also report a significant age by task interaction in muscle response amplitude for the GA. Again, this is seen at 350-500ms. The older adults demonstrated a greater reduction in amplitude than did the younger adults. From these results, the authors concluded the decrease in muscle activity seen results from task interference, which is more prominent in the older population. They suggest that less attentional capacity was dedicated to postural control resulting in reduced muscular activity.

This idea of cognitive interference has been examined in children as well.[26] Twenty-seven children aged five to seven performed the following tasks: 1) walking alone, 2) walking while identifying pictures, 3) walking while identifying sounds, and 4) walking while remembering a set of numbers. Much like the adult population, cognitive tasks seemed to interfere with motor performance. Gait speed, cadence, and step length were all affected by these cognitive tasks. Identifying sounds seemed to be the most interfering while memorization was least interfering.

Peterka and Black[6] examined the role of visual cues and somatosensory cues across the lifespan. Subjects aged 7 to 81 participated in this project (n=214). Each subject completed 6 tests that challenged balance with vision altered or absent and somatosensory cues altered. When the support surface was solid, no significant age-related deficits were detected regardless of visual condition. When visual cues were altered, sway increases were most drastic in the older population. Children under the age of 15 struggled with alteration in somatosensory information.

Another group also investigated the role of visual and somatosensory cues across the lifespan. When studying subjects from six to ninety years old, they found that the children and the elderly demonstrated the most sway. Equilibrium appeared to be most established at the age of 50 years. The elderly were most dependent on the visual system while children were most affected by disturbances in the pressoreceptors and proprioceptors.[27]

Foudriat and colleagues[28] also studied the effects of altered sensory environments on postural control. Eighty-two healthy children between the ages of three and six participated in this study. When examing postural control with a fixed sensory environment, these authors reported an improvement in postural control between the ages of four and five years. In contrast, age-relaed improvements seen in the dynamic environment condition were more complex. No significant differences were identified among age groups during stance on a compliant surface with the eyes closed at all sway gains. At the age of three years, children demonstrated the ability to ignore misleasding sensory input.

Joint position sense has also been identified as another factor related to declines in postural control seen in older adults.[3] Older adult subjects were tested for threshold joint position sense (TJPS) at the knee (flexion/extension) and the ankle (plantarflexion/dorsiflexion). Subjects then completed postural control measurements on a forceplate. Postural control testing was done with eyes open and eyes closed in bipedal stance. Perturbations of the support surface were introduced randomly during the trials. In addition to the COP data gathered, EMG data were also collected. Subjects with decreased knee TJPS produced greater variances in COP data with the eyes open. Similar results were reported for decreases in ankle TJPS. Interestingly, in the trials where a perturbation force was introduced, decreases in TJPS did not appear to affect subjects' protective responses.

The effects of fear and anxiety on gait patterns have also been studied when trying to explain age-related deficits in postural control. Brown et al.[29] studied thirty-one adults (16 young, 15 old) walking at a self-selected speed under four different conditions: 1) unconstrained walking on floor, 2) walking on a 0.15m wide platform, 3) walking on a wide, elevated (0.60m) platform, and 4) walking on a 0.15 m wide platform that was elevated 0.60m. The authors reported significant changes in gait patterns and muscle activation patterns in both groups when postural threat increased. While both groups demonstrated altered patterns, between group differences were also present. Older adults did not respond to postural threats in the same way younger adults did. The authors suggested that these different response patterns reflect different central set modifications that are seen with heightened anxiety.

Gill and colleagues[20] measured differences in trunk sway between three different age groups: 1) 15-25 years, 2) 45-55 years, and 3) 65-75 years while completing stance tasks, stance related tasks, and gait tasks. Different visual conditions and support surfaces were included. The authors found significant differences in trunk sway among the three groups. The elderly population had greater angular sway and angular velocity than the two younger groups during the stance and stance related tasks. During the gait tasks, the middle age group demonstrated the smallest velocity ranges followed by the elderly population. The younger population had the greatest velocity range.

Hay and Redon[30] also investigated age related changes in postural control. They examined feedforward and feedback control through development in children. Children were divided into three age groups: 1) 3-5 years, 2) 6-8 years, and 3) 9-10 years. There was also an adult group that participated. Subjects stood in bipedal stance on a forceplate with their eyes closed while holding a load. During the trials, subjects were unloaded after a warning signal. Subjects either experienced self-initiated unloading, or externally imposed unloading. When subjects were unloaded the COP shifted posteriorly regardless of age. This displacement was smaller with self-initiated unloading. The differences in displacement did appear to be age dependent. The feedforward mechanism seemed to become increasingly more developed from age 3 to age 8. In the youngest age group, there was a very small difference between the self-initiated and externally initiated unloading. This difference was most pronounced in the 6-8 year olds, as self-initiated unloading resulted in very minimal posterior displacement of the COP. The 9-10 year olds, as well as the adults had a smaller difference than the 6-8 year olds, but larger than that seen in the 3-5 year olds. The authors suggested that this does not mean our feedforward systems become less efficient with age. Rather, it likely reflects an increased tolerance for imbalance and more confidence with our balance as we become older. Though the 6-8 year olds had the smallest disturbance, they were also the most inconsistent suggesting that the accuracy of the feedforward system and its coordination with the feedback system were still developing. Interestingly, the tasks requiring mostly feedback control did not result in age-related differences.

Several other authors have also found differences in responses to postural disturbances among age groups.[13,11, 31] Okada et al.[13] reported slower and larger hip and ankle movements in response to perturbation among the older group (67-72 years). In general, the younger population (19-22 years) relied more on ankle movements while the older adults relied on hip movements to control postural stability.

Compensatory stepping in response to perturbations has also been examined.

McIlroy and Maki[11] recruited 14 subjects aged 22 years to 81 years. Subjects stood on a platform and experienced forward and backward perturbations. Forceplate and kinematic measures were evaluated. Though the first step was very similar between the age groups, the older adults (65 years–81years) were much more likely to take several steps to recover from a loss of balance. These additional steps seemed to preserve lateral stability. This trend was not seen in the younger adults. Interestingly, the older adults were less likely to produce anticipatory lateral movements.

Rogers et al.[32] further examined the idea of lateral stability. Fifty adults (12 young, 20 older non-fallers, 18 older fallers) participated in this study. Forward stepping was produced through an anterior pull delivered to the waist. Measurements included kinetic and kinematic characteristics of the first step. No significant differences were noted in the anticipatory activity. However, fallers did demonstrate increased lateral motion and lateral foot placement with the first step when compared to young adults and older adult, non-fallers. The fallers also had a longer first-step duration and earlier lift-off.

Hall and colleagues[31] specifically addressed ankle torque production following perturbation. Nineteen young adults (21 – 35 years) and 21 older adults (65 – 85 years) experienced posterior and anterior perturbations at random velocities and amplitudes. Investigators studied the maximum ankle torques produced and the change of ankle muscle torque. Older adults were not as effective as the younger adults in managing the posterior perturbations at 80 cm/s (p=.012). There were no significant differences in ankle muscle torque characteristics between age groups. The authors concluded that the age-related differences seen with recovery from perturbation are not related to ankle muscle torque production.

Sloboúnov and colleagues[33] also examined contributions to decreased postural control among the elderly population. They measured time to the boundary of instability and the ratio of the total area of center of pressure excursion to the area within the stability boundary in older adults during quiet stance under various sensory conditions and postures. The authors reported a decrease in the time to boundary measurement and an increase in the ratio. Together, these findings suggest a narrowing of the margins of stability with aging, which may increase instability in upright stance. These results were supported by findings reported by van Wegan et al.[34]

Measuring Balance

There are several accepted measures of balance and postural control that are commonly used in clinical practice and for research. Tests are frequently divided into measures of static balance and measures of dynamic balance. The measures include subjective and objective functional performance measures as well as self-report measures.

One such self-report measure is the Activities-specific Balance Confidence (ABC) Scale. This scale was developed for use among older adults to help identify fears of falling.[35] Subjects score 16 items from 0 to 100% according to their confidence in safely completing the task (see table 1 and figure 1). The 16 scores are then averaged to compute a total percentage. Greater scores indicate increased confidence.

Table 1. ABC Scale

Items Description
Walk around the house
Walk up or down stairs
Bend over and pick up a slipper from the front of a closet floor
Reach for a small can off a shelf at eye level
Stand on your tip toes and reach for something above your head
Stand on a chair and reach for something
Sweep the floor
Walk outside the house to a car parked in the driveway
Get into or out of a car
Walk across a parking lot to the mall
Walk up or down a ramp
Walk in a crowded mall where people rapidly walk past you
Are bumped into by people as you walk through the mall
Step onto or off of an escalator while you are holding onto a railing
Step onto or off of an escalator while you are holding onto parcels such that you cannot hold onto the railing
Walk outside on icy sidewalks

Figure 1. ABC Rating Scale

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
no confidence								completely confident		

In order to examine reliability and internal consistency, Powell and Myers[35] performed a test-retest study. They concluded that the ABC is reliable over a 2 week period (r=.92). They further concluded that the scale had high internal consistency with Cronbach's alpha = .96. Research also suggests that ABC scores are related to measures of function. Myers et al[36] reported that ABC scores have moderately strong correlations to posturography measures. They also reported a significant correlation between ABC scores and walking speed (r = .56). In a later study by Myers et al.[37] it was reported that subjects with greater mobility report higher ABC scores than do those with low mobility at baseline and a year later. The authors also discovered that subjects who experienced a near-fall episode in the 12 month period studied reported lower ABC scores at baseline and follow-up. This suggests that the ABC scale may have use as a predictive measure of near-falls. Myers and colleagues also found one's ABC score to be significantly correlated to Timed Up and Go scores (r = -.92) and gait speed (r = .47). They also found ABC scores correlated to age (r = -.29), and total number of health problems (r = -.30). Other characteristics that were significantly related to ABC score included: gender ($p < .002$), education ($p < .0005$), perceived health status ($p < .0005$), current smoker ($p < .003$), weight perception ($p < .008$), medication use ($p < .003$), health limitations (p <n .0005), level of physical activity ($p < .0005$), and perception of the importance of exercise ($p < .0005$). In another study by Myers el al.[37] it was reported that ABC scores correlated with Performance Mobility Assessment scores (r = .78) and Timed Up and Go scores (r = -.59).

Relationships between ABC scores and other characteristics were also examined among adults undergoing total hip or total knee arthroplasty. Prior to surgery, the ABC score was found to be significantly related to gait speed (r = .65), functional ratings (r = .49), pain ratings (r = -.35) and depression scores (r = -.33). Subjects with restricted activity levels also scored lower on the ABC scale. Six weeks post-operatively, ABC scores had declined but were still correlated to gait speed (r = .60). Self-reports of walking distances were also correlated to ABC score (r = .44). During the 6 month follow-up, ABC scores had increased compared to baseline by 59%.[37]

The ABC scale has been found to be sensitive to change. Myers et al[37] administered the ABC scale to 63 older adults involved in an exercise intervention study. The scale was administered at baseline, 11 weeks into the program and 26 weeks into the program. There was a significant group by time interaction found. At baseline, there were no differences in ABC scores between groups. However, at both 11 weeks and 26 weeks into the program, the exercise group reported improvements in balance confidence while the control group reported declines in balance. These results were supported by similar trends in functional performance measures.

From the results of the four studies published by Meyers et al[37], they concluded that the ABC scale may also be used as a discriminative and evaluative tool. They suggest that scores above 80 are seen in highly-functioning older adults, scores above 50 and below 80 are most common in those with moderate levels of activity. Adults scoring less than 50 are most often low functioning.

Functional performance measures have also become an important aspect of balance assessment. The functional reach test was developed by Duncan and colleagues[38] to examine the margin of stability.[39] Subjects are asked to stand with their arms held in front of them (see figure 2). Subjects then reach as far as they can without taking a step (see figure 3). The distance reached in inches, is the score recorded. The functional reach test was shown to have intersession (ICC = .92) and interrater reliability (r = .98).[38]

Figure 2. Functional Reach Position 1

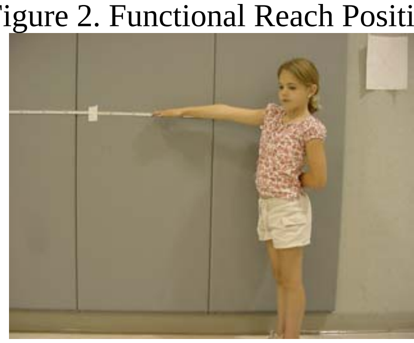
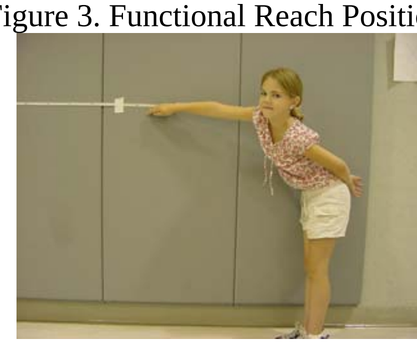


Figure 3. Functional Reach Position 2



Validity of the functional reach test has also been examined by several authors. Weiner et al.[40] examined concurrent validity by investigating the correlation between functional reach scores and physical frailty. They reported strong correlations between functional reach scores and walking speed (r=.71), social mobility (r=.71), instrumental activities of daily living index (r=.66), tandem walk (r=.67), mobility skills (r=.65), and single leg stance (r=.64). It has also been correlated to center of pressure excursion (r=.71).[38]

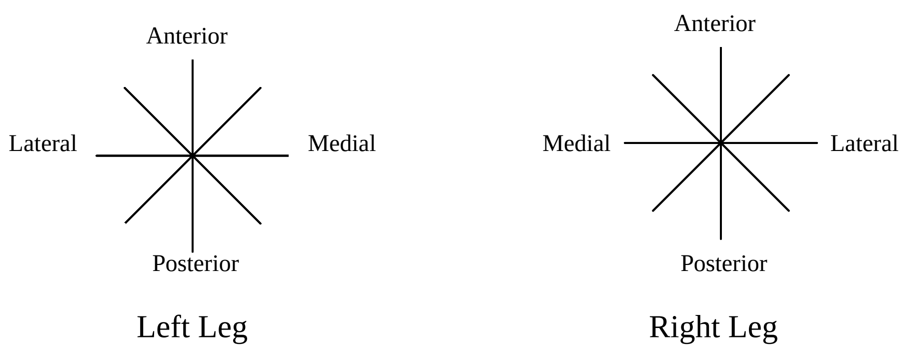
Duncan et al.[41] demonstrated predictive validity in elderly male veterans. The functional reach test was found to be predictive of falls and was also associated with recurrent falls. It has been found that those subjects that reach less than ten inches have an increased likelihood of falling in the next six months.

The Functional Reach Test has also been reported to be sensitive to change following rehabilitation.[42] The sensitivity to change was measured among subjects that were receiving physical therapy services 5 times per week during their inpatient stay at a veterans hospital. Control subjects included inpatients that were not receiving physical therapy services. The Functional Reach Test, 10-foot walking time, the Duke hierarchial mobility skills protocol, and a portion of the Functional Independence Measure were administered at baseline and every four weeks thereafter. The last assessment was completed the last day of rehabilitation. The control group was tested on two different occasions, four weeks apart. The rehabilitation group showed greater improvements than the control group in walk time, mobility skills score, and FIM score ($p < .001$). When examining the change in functional reach scores, both groups demonstrated improvement but only the rehabilitation group improved significantly ($p < .001$).

The functional reach test has also been examined for use among healthy children ages 5 – 15 years. Donahoe et al[43] reported reliability in this population. An adapted version of the functional reach test has also been examined for use in children.[44] The pediatric reach test (PRT) includes reaching in the anterior and lateral directions while sitting and standing.[44] Intersession reliability was reported to range from an ICC value of .54 to .88. Interrater reliability was found to be similar (ICC = .50 to .93). The researchers found moderate to high correlations between the PRT and force platform measures of limits of stability (r = .42 to .77). They also found the standing portion of the PRT was related to force plate measures during quiet stance (r=-.79) and age (r=.83). Among those children with cerebral palsy, PRT scores also correlated with Gross Motor Function Classification System level (r_s = -.88).

Another proposed measure of dynamic balance is the star excursion balance test (SEBT). Subjects are asked to balance on one foot while reaching as far as possible with the other leg. Subjects reach in eight directions including: anterior, anterior-medial, medial, posterior-medial, posterior, posterior lateral, lateral, and anterior lateral (see figure 4).

Figure 4. Star Excursion Balance Test



Kinzey and Armstrong[45] conducted a reliability study and reported ICC values ranging from 0.67 to 0.87 when examining four directions. Hertel et al.[46] examined intratester and intertester reliability over two days. On day one, intratester reliability ranged from ICC=.78 - .96 and intertester ICC values ranged from .35 -.84. Intratester ICCs ranged from .82 - .96 and intertester ICCs were .81 - .93 on day two. This supports the recommendation by Kinzey and Armstrong[45] to allow six practice trials to minimize a learning effect.

Gribble and Hertel[47] examined the role of foot type, height, leg length, hip external rotation range of motion (ROM), hip internal rotation ROM, and ankle dorsiflexion ROM on reach distances while performing the star excursion balance test. Gribble reported significant correlations between height and reach distance (r=0.1 to 0.44) as well as leg length and reach distance (.14 to .48). No other variables were significantly correlated to reach distances. Based on these data, it is recommended that SEBT reach distances are normalized to leg length.

The SEBT has also been found to be sensitive in detecting the presence of dysfunction in subjects with chronic ankle instability (CAI). Subjects with CAI had significantly greater reach distances when standing on their uninjured limbs when compared to their reach distances when standing on their injured limb. When comparing healthy controls to those with CAI, similar findings were reported. Subjects with CAI had shorter reach distances when standing on the injured limb than did the healthy controls when standing on the matched limb.[48]

Evidence suggests that the SEBT is also sensitive to change following rehabilitation among subjects with CAI. In a study by Hale and Hertel[49] subjects with chronic ankle instability were assigned to either an ankle rehabilitation group or a control group. An additional group of healthy controls was also studied. The control groups received no rehabilitation and were instructed to continue with normal activity. All subjects were tested before and after the four week rehabilitation program. A significant time by group interaction was identified. The rehabilitation group demonstrated greater improvements than did the control groups when performing the SEBT.

Another performance based measure is the Berg Balance Scale. This scale is unique in that it is comprised of 14 items that range from static activities to dynamic activities (see table 2 and figures 5-6). Each task is scored on a 5 point, ordinal scale. There are specific scoring criteria for each item. The total points are added to calculate the composite score.

Table 2. Berg Balance Scale

Item Description
Sitting to standing
Standing unsupported
Sitting unsupported
Standing to sitting
Transfers
Standing with eyes closed
Standing with feet together
Reaching forward with outstretched arm
Retrieving object from floor
Turning to look behind
Turning 360 degrees
Placing alternate foot on stool
Standing with one foot in front
Standing on one foot

Figure 5. Tandem Stance

Figure 6. Turning to look Behind

This scale has been shown to be valid and reliable. The intra and interrater reliability were reported to be ICC=.97 and ICC=.98 respectively.[50] Thorbahn and Newton[51] reported lower interrater reliability (r_s=.88).

The Berg Balance Scale was also found to be correlated to several other balance measures including the Barthel Index (r =.67), the Timed Up and Go Test (r = -.76), amount of assistance required for ambulation (r= -.75), the Balance sub-scale of the Tinetti (r=.91), and postural sway (r = -.55).[50]

It has been suggested that a score of 0 - 20 is indicative of a high risk for falling. Subjects who score 21-40 are thought to have a medium risk for falling. Higher functioning adults with a low risk of falling typically score 41-56. Interestingly, conflicting data were presented by Thorbahn and Newton.[51] They found that those scoring 31 – 45 had the highest rate of falls. They suggested that those scoring 31-45 may participate in higher risk activities than those scoring less than 31. The authors hypothesized that despite the significant physical limitations those subjects scoring less than 31 have, they fall less because they are less active and utilize assistive devices.

Berg and colleagues[52] reported that a score of less than 45 is also predictive of a future fall. Thorbahn and Newton[51] supported these results reporting a specificity of 96% and a sensitivity of 53% in identifying risk for future falls with a cutoff of 45 points. Using a cutoff score of 45, the Berg Balance Scale has been demonstrated to be both sensitive (84%) and specific (78%) in identifying subjects that would benefit from physical therapy.[53] The sensitivity results reported by Berg are in sharp contrast to those reported by Thorbahn and Newton.[51] When reviewing these results, it is important to keep in mind the prevalence of falls. This was not reported in the Berg study. However, of the fifty-four subjects that reported data about falls during the Thorbahn study, eleven subjects reported at least one fall during the study.

Berg and colleagues[50] also examined the correlation between functional measures and walking aides used by subjects. They found that the Berg Balance Scale was the most sensitive measure in discriminating between subjects using different walking aids. Similar results were reported by Thorbahn and Newton[51] who concluded that the Berg Balance Scale demonstrates a moderately strong ability to predict one's use of an assistive device.

The effects of activity level on Berg Balance Scale scores are unclear. Several authors have investigated this relationship but have reported conflicting results.[51] Research by Thorbahn and Newton[51] suggests that activity level is not related to Berg Balance Score. However, more research is needed in this area.

A modification of this test, the Pediatric Balance Scale is reported to have good test-retest reliability (ICC = 0.998) and good interrater reliability (ICC = 0.997) when used in school aged children with minor to moderate motor impairments.[54]

Static postural control is often measured using a force plate. Force platforms contain at least three individual force-measuring devices that allow researchers to quantify vertical ground reaction forces and horizontal moments. From these moments and forces, one can compute COP. Using the COP, researchers can gather several other measures including mean displacement, length of sway path, length of sway area, amplitude, frequency, and excursion velocity.[55]

Relationship Between Static and Dynamic Balance

While many researchers now recognize static and dynamic balance as separate entities, there is little research investigating the relationship between static and dynamic balance. Initial indications suggest that dynamic balance measures and static balance measures are not correlated. Riemann et al.[56] examined the relationship between SEBT scores and single leg postural control tasks and reported no significant relationship. They reported similar results when examining the relationship between single-leg stance and a single-leg hop test. A more recent study resulted in similar findings.[57] Static, dynamic, and clinical tests of postural control were used. The static task involved single-leg quiet stance. The dynamic activity was a lateral step-down task. The SEBT was used as the clinical measure. The correlation between the static and dynamic measures was weak ($r=.10$). The SEBT and the static measure were also weakly correlated ($r = -.05$). Surprisingly, the dynamic task and the SEBT were also weakly correlated ($r = .12$).[57]

A study by Hale and Hertel[58] provided further support for the hypothesis that static and dynamic balance measures are not related. It was reported that there was no relationship between SEBT scores and COPV scores among healthy subjects and subjects with CAI. These authors also concluded that there was no significant relationship in treatment effects for these two measures following four weeks of supervised rehabilitation among subjects with CAI.[58]

The relationship between balance and walking function in children with cerebral palsy was investigated by Liao et al.[59] The authors reported no significant correlation between static balance measures and walking function in healthy children or children with cerebral palsy. Among the non-disabled children, there was also no significant correlation between dynamic measures and walking function. However, a significant relationship between dynamic balance measures and walking function was found in the children with cerebral palsy. These results provide interesting information regarding the correlation between balance measures and functional mobility.

The relationship between static and dynamic balance measures was also examined in healthy children.[60] Fifty girls ages 11 to 13 years participated in the study. Subjects completed three static balance measures: 1) stork stand, both legs, 2) diver's stand, 3) stick test; and three dynamic measures: 1) sideward leap, 2) bass stepping stone test, 3) balance beam test. Pearson product correlation coefficients were calculated between all measures. The only significant relationship found was between the sideward leap and the bass stepping stone test ($r=.31$). Though this relationship is statistically significant ($p<.05$), it is a weak correlation that does not provide much predictive value. The results of these studies support the hypothesis that static balance measures and dynamic measures provide clinicians and researchers with different information, as they appear to be measuring different factors. It also appears that individual dynamic measures are measuring separate tasks and provide different information.

Efficacy of Balance Training Programs

Several authors have examined the effects of balance training programs on various dependent variables.

Balance Training Programs for Children

The efficacy of balance training programs for children is not well understood. There is little research addressing this research question. Most of the balance intervention studies involve the elderly population. Wang and Chang[61] specifically studied the effects of a jumping skill program on balance during gait among children with mental retardation (MR) and Down Syndrome (DS). The balance sub-test of the Bruininks Oseretsky Test of Motor Proficiency (BOTMP) was administered to 14 children with MR or DS. It was also administered to 61 typical children. The authors used the Motor Skill Inventory (MSI) to assess jumping skills. Subjects then participated in a jumping skills program three times a week for six weeks. After the jump training program, children improved in the beam walk ($p=.018$) and floor walk ($p=.009$) portions of the BOTMP. Improvements were also seen in the MSI levels for both horizontal ($p=.018$) and vertical jumps ($p=.008$). Improvements in vertical jump distances were also statistically significant ($p=.008$).

Improvements in balance following an intervention program were also reported by Shumway-Cook et al.[62] In this study six children with cerebral palsy completed 5 days of perturbation training on a NeuroCom moveable forceplate system. The children were tested on the NeuroCom system before, during, and after the training program. The researchers gathered time to stabilization and area per second data. All subjects demonstrated improvements in time to stabilization and center of pressure area during and after training. Interestingly, these changes were maintained at the 30 day follow-up as well.

Sveistrup and Woollacott[63] conducted another intervention study aimed at investigating the effects of a training program on aspects of postural control, specifically activation patterns of postural muscles. Fifteen infants completed the study. Subjects were tested twice, five days apart. Between testing, a training group participated in platform perturbation training while the control group reported to the lab each day but did not participate in perturbation training. Elecromyogram data suggested that the infants in the training group had: 1) increases in probability of activating functionally appropriate muscles, 2) increased number of functionally appropriate postural muscles activated in a single trial, and 3) no significant changes in mean postural muscle onset latencies or number of trials with antagonist muscle coactivation. The authors concluded that training may affect automatic postural responses during development. This may help to explain why other authors have seen an improvement in scores on functional measures of balance.

Balance Training Programs for Healthy Adults

Balance training programs are often implemented as a preventive measure. Soderman and colleagues[64] investigated the efficacy of one of these programs. Thirteen soccer teams were randomized to either an intervention group or a control group. Players in the intervention group, were instructed in a 10-15 minute progressive training program using a balance board. Muscle flexibility and postural sway were measured during pre and post season. When comparing these characteristics, there were no differences between the two groups. There were also no significant differences found in regard to the number, incidence, or type of lower extremity injuries experienced by the two groups. The incidence of "major" injuries was found to be higher among the training group than the control group. This study suggests we cannot control risk for lower extremity injury with balance training programs.

Tropp et al.[65] reported conflicting results. They studied 450 Swedish soccer players. Subjects were randomly assigned to one of three groups: 1) control, 2) orthosis, or 3) coordination training program. The training program was performed on an ankle disk . During the first 10 weeks of the program, participants completed the program five times per week. After the first 10 weeks, subjects completed five minutes of training three times per week. The authors then recorded the incidence of ankle injures among: 1) injured subjects, balance training, 2) injured subjects, no balance training, 3) uninjured subjects, balance training and 4) uninjured subjects, no balance training. When examining those without a history of ankle injury, balance training was found to decrease the incidence of ankle sprain. Among those with a history of ankle sprain, balance training did appear to be a useful prophylactic tool.

Cox and colleagues[66] examined the effects of a balance training program on postural control in healthy adults. Twenty seven recreational athletes participated in this study. There were two training groups based on training surface. The authors reported no significant differences in pretest and posttest measures of postural control. Furthermore, no differences were found when comparing the two training groups.

Hoffman et al[67] also examined the effects of balance training on postural control. Twenty-eight subjects participated in this study and completed single leg stance postural control testing on a force plate. This testing was done at baseline and repeated following a balance training program. The training program was administered three times per week for 10 weeks on the Biomechanical Ankle Platform System (BAPS). At follow-up, the training group demonstrated improved postural control when compared to the control group.

Effects of Balance Training Among Older Adults

Due to the high incidence of falls among the elderly and the detrimental effects of these falls, much research has been dedicated to fall prevention. Several authors have investigated the effectiveness and/or efficacy of balance training programs in the elderly population. Rogers et al.[68] evaluated the effects of a 10-week training program on postural sway and functional reach among subjects 61 – 77 years of age. Subjects participated in a group training program for 60 minutes each session and met two times per week. Functional reach did improve by approximately 20% which was statistically significant. Several measures of postural sway also improved. This study suggests that static and dynamic balance can be improved in the elderly population following an appropriate training program.

Results reported by Lord et al.[69] also support the use of exercise programs to improve postural control. Forty-two older women were involved in this study. Half of the woman participated in a 12 month exercise program and were compared to 21 older adult woman that did not participate in any exercise program. The active woman had lower body mass index scores, greater quadriceps strength, decreased reaction time, and decreased sway on an unstable surface when compared to the sedentary woman.

Lichtenstein and colleagues[70] conducted a similar study that yielded similar results. Fifty woman over the age of 65 participated in the study. Approximately half of the woman completed a 16 week exercise program which addressed balance, flexibility, and reaction time. The exercise group participated in three one hour sessions per week. Upon completion of the training program, there were no between group differences in areas or velocities for the eyes open, bipedal stance condition. The exercise group had decreased COP areas in single leg stance with the eyes open compared to the control group. Interestingly, the control group had a smaller area in single-leg stance with the eyes closed when compared to the exercise group.

Lord[71] also examined the effects of a 12 month exercise program on dynamic stability, strength, reaction time, and neuromuscular control. Participants in the exercise group completed 1 hour of group exercise twice a week. The exercise protocol included aerobic exercise, balance exercises, coordination tasks, strengthening exercises, stretching, and relaxation. The control group did not participate in any structured exercise program. Upon completion of the exercise program, the exercise group performed significantly better in maximal balance range and coordinated stability tests when compared to the control groups. The two groups were not significantly different at baseline. This data supports the hypothesis that dynamic postural control can be improved with exercise training.

In a similar study by Lord and Castell,[72] 44 subjects aged 50 – 75 years participated. Quadriceps strength, reaction time, neuromuscular control, and body sway were measured. A subset of participants completed a 10 week exercise program. During follow-up testing, the exercise group's scores for quadriceps strength, reaction time, body sway on a firm surface with the eyes closed, and body sway on an unstable surface with the eyes open and closed, had improved compared to baseline. The non-exercisers however did not improve in any of the measures.

Shumway-Cook and colleagues[73] examined the effects of a multidimensional exercise on several measures of function. There were 105 participants in the study. Subjects were community dwelling adults over the age of 65 with a history of at least 2 falls in the 6 months prior to the study. Subjects were either in the control group, the fully adherent exercise group, or the partially adherent exercise group. Those that were classified as fully adherent attended outpatient physical therapy twice a week for 8 to 12 weeks. In addition, they exercised at home 5 to 7 times per week. In contrast, the partially adherent group attended less than 75% of their physical therapy sessions and exercised independently only 4 times per week. Subjects were tested using the Functional Balance Test, Balance Self-perceptions Test, Dynamic Gait Index, Tinetti mobility test, three-minute walk test, and fall risk. The exercise groups showed a significant improvement in all measures when compared to the control group. The only differences between the treatment groups were seen in the Dynamic Gait Index and fall risk.

The effects of a multidimensional program on balance were also studied by Harada et al.[74] Twenty-seven older adults with balance deficits and decreased functional mobility participated in a physical therapy (PT) program two to three times per week for four to five weeks. The PT protocol addressed individuals' physical and functional limitations identified during a comprehensive evaluation. Exercises were aimed to improve mobility, stability, controlled mobility, and skill, a common paradigm used in PT. Upon completion of the PT program, subjects demonstrated improvements in the Berg Balance Scale (p=0.0003), and the Tinetti balance subscale (p=0.01). These improvements were still noted 1 month after the completion of the program. No significant changes in gait speed were noted.

Another study supporting the effectiveness of exercise programs among the elderly was completed by Roberts.[75] Roberts had two groups of older adults, primarily comprised of women. One group participated in a walking program three times a week for six weeks. Each session lasted 30 minutes. Intensity was monitored via heart rate. Participants exercised at 60% - 70% of their maximum heart rate. The control group did not participate in any supervised exercise program. Subjects completed the Balance Perception Questionnaire and were tested using the Balance Scale. The Balance Scale involves maintaining eight different stances for as long as possible up to thirty seconds. After the six week walking program, the walking group scored significantly higher than did the control group (p=0.03). The pretest-posttest difference was also greater among the walking group. There were no significant differences in the balance perception scores when comparing between groups. The authors also investigated the correlation between balance measures and the perception of balance. At baseline, the correlation was found to be significant (r=0.43, p=0.001).

The effects of a walking program on postural control were also examined by

Messier et al.[76] The authors randomized 439 subjects with knee Osteoarthritis (OA) to one of three intervention groups: 1) aerobic walking, 2) health education control, or 3) weight training. The two intervention groups participated in the programs three days per week for 18 months. The health education group was created to minimize the effects of attention biases. Postural control testing (average length, average velocity, elliptical area and balance time) was conducted at baseline, 3 months, 9 months, and 18 months. Positions tested included: 1) single-leg stance, eyes open, 2) single-leg stance, eyes closed, 3) bipedal stance, eyes open and 4) bipedal stance, eyes closed. The authors reported significant improvement in bipedal stance with the eyes closed among those in the aerobic and strength training groups. They also found that the aerobic group was able to maintain single-leg stance with the eyes open longer than the education group. In conclusion, these results suggest that strength training and aerobic activity may be beneficial in improving postural control among subjects with OA.

Wolf and colleagues[77] compared the effects of tai chi chuan, education, and computerized balance training on postural stability. Seventy two older adults were randomized to one of three groups: 1) computerized training, 2) tai chi 3) educational group. The computerized training group completed a 15-week program consisting of one hour of training each week. Subjects completed a progressive balance-training program involving the maintenance of postural control during quiet stance and volitional excursions. The tai chi group met twice a week for 15 weeks. The education group met for one hour a week to discuss polypharmacy, memory loss, bereavement, sleep disturbances, falls, and other related issues. Measurements were taken before and after the training programs. The authors also completed a four month follow-up evaluation.

Evaluation included the use of the Chattecx Balance System under the following conditions: 1) quiet standing, eyes open, 2) quiet standing, eyes closed, 3) toes up, eyes open, and 4) toes up, eyes closed. The authors reported improved postural control in the computerized balance training group. In contrast, these improvements were not found in the tai chi or education groups. Interestingly, subjects that completed the tai chi program reported less fear of falling than did all other subjects following the training period.

The effects of Tai Chi Chuan on postural stability were also studied by Lin et al.[78] Twenty-eight volunteers participated in this study. One group was recruited from a tai chi club and had practiced tai chi for at least two years. The other subjects did not participate in tai chi. All subjects were community dwelling and did not have a history of falls in the 12 months preceding the study. Postural control measurements were gathered using the Smart Balance Master. Subjects were tested statically under the following conditions: 1) eyes open, fixed support, 2) eyes closed, fixed support, 3) sway-referenced vision, fixed support, 4) eyes open, sway referenced support, 5) eyes closed, sway referenced support, 6) sway-referenced vision and support. Dynamic tasks included multidirectional weight shifting. Under simple conditions, there were no differences in postural control measures between groups. The tai chi group did perform better than the control group under more challenging conditions. They also demonstrated more postural control than the control groups when performing the forward backward sway task. These results are interesting when compared to the previous study. While no differences in postural control were found in the first study, the tai chi group reported less falls. This study may help explain those results in that the benefits of tai chi seem to be more evident in challenging tasks.[78] Such tasks were not tested in the study by Wolf and colleagues.[77]

Chandler et al.[79] looked at the correlation between strength gains and functional performance following a 10 week strengthening program. The authors reported a significant correlation between strength gains and mobility skills ($p = 0.0009$). Strength gains were also associated with falls efficacy ($p = 0.05$). Interestingly, the strength gains were not significantly related to balance, endurance, or disability measures. This suggests that improvements seen in balance following training programs are unlikely due to strength gains.

Balance Training Across Age Groups

Very few studies address the effectiveness of training programs across the lifespan. Most balance intervention programs are aimed at a specific age group. Ryushi and colleagues[1] conducted a study to examine the effect of resistive knee extension training on postural control. This study was unique in that it targeted middle aged and elderly persons. Subjects were assigned to a control group or the resistance training group. Those in the training group participated in 2 exercise sessions per week for 10 weeks and trained bilateral lower extremities. The control group was told not to train their lower extremities during the 10 week training period. The investigators used the Balance Master system to measure the percentage limits of stability (% LOS) and the path length. Following the exercise protocol, subjects had increases in the % LOS and decreases in path length when subjects leaned backwards as far as possible. There was also evidence of quadriceps muscle strength gains in these subjects. The authors concluded that increases in strength may allow more effective displacement of one's center of gravity away from the midline.

Conclusions

Postural control is a complex task relying on many aspects of the neuromuscular system. Evidence suggests that postural control is developed over the life span and then begins to show decline in older adults.[3, 4, 6-8, 20-24, 30] The reason for this decline is not well understood but appears to be multifactorial.[1, 3-8, 11, 13, 20-26, 29-32, 72, 73, 79-81] Though many studies have shown declines in postural control with aging, there is little research comparing the balance performances of adults and the pediatric populations. In future studies, it would be beneficial to include a wider age range of subjects to gain a better understanding of the degree of decline in balance.

The balance deficits seen in the elderly have been associated with diminished functional mobility and greater risk for falls.[40, 41, 50, 51, 53, 82] As a result, much of the recent literature examines the efficacy of balance training programs among the elderly. From those studies we have learned that it is possible to improve balance in the elderly population.[68, 69, 71-78, 83] However, little research has been conducted to identify the most effective balance training protocol. There is evidence to suggest that static balance and dynamic balance are different entities.[56-60] Preliminary research also indicates that improvements in static balance and dynamic balance after research are not correlated.[58] Future research needs to address the efficacy of different balance training programs in order to provide the most beneficial rehabilitation and training to society.

It is also important to investigate the efficacy of these training programs in different populations. As our population continues to age, much of the research is focused on the elderly. However, the younger population is at great risk for injury, which has been shown to have detrimental effects on balance and postural control.[84-86] Therefore, it is important that we address our younger populations in future balance intervention studies.

CHAPTER 3

Age-Related Postural Control Changes in Children and Young Adults

Objective: To identify age-related differences in postural control among children and young adults.

Design and Setting: Case control study in a laboratory setting.

Subjects: Three groups of subjects participated including: 1) 19-20 year olds (N=16), 2) 9-10 year olds (N=15), and 3) 6-7 year olds (N=31).

Measurements: Subjects were scored on the following measures: 1) Functional Reach, 2) Berg Balance Test, 3) Pediatric Berg Balance Test, 4) ABC Scale, and 5) center of pressure velocity (COPV) during 10 second trials of quiet standing during unilateral and bilateral stances with eyes open and closed.

Results: Significant age-related differences were found for all measures. Post hoc testing revealed that the young adults scored significantly better than the 9-10 year old children in all dependent variables except the Berg Balance Scale and the Pediatric Balance Scale. They scored better than the 6-7 year old children in all measures. The 9-10 year old children scored better than the 6-7 year old children in all variables except left leg stance COPV and the ABC Scale.

Conclusions: These results suggest there are age-related differences in postural control among children and adults. This complements current postural control literature, as it provides information about functional measures of postural control that are just being introduced clinically in the pediatric setting. Understanding postural control across the lifespan is clinically meaningful, as postural control is necessary for human function at all

levels of performance.

INTRODUCTION

Postural control is an essential aspect of neuromuscular development in humans. From infancy we use the development of postural control as a measure of normal development. Clinicians expect to see control of one's head by two months of age. As the child continues to develop, we look for balance and head righting responses in different positions. By 6 months, a child should be able to sit independently. Cruising and independent ambulation, should be seen from 9 to 15 months.

Children and adults continue to develop postural control as they engage in higher levels of activity and begin to experience external perturbations. Beyond infancy, we begin to measure development through the acquisiton of these gross motor skills such as ball play and jumping tasks.

Several authors have demonstrated this important relationship between balance and gross motor skill. Liao and Hwang [87] found that among 5 to 12 year old's with cerebral palsy, one's postural stability (eyes open, eyes closed, and swaying visual condition) , one's ability to maintain single leg stance and one's ability to maintain tandem stance were significantly related to his/her gross motor ability. Children with cerebral palsy have also been found to demonstrate greater performance of manipulation skills with appropriate postural alignment and stability in sitting.[88,89] While postural control allows us to function and be mobile, balance deficits have also been shown to significantly limit mobility and also be associated with injury.

Postural control continues to change in the later stages of life. Much research is conducted to identify age related deficits in postural control. It is thought that clinically these changes are important, as they often result in falls and injury.

Despite the importance of postural control in childhood development, we fail to have established measures or expectations of postural control for school-aged children through adulthood. Neuromuscular development from school age into adulthood is not well understood. Therefore, it is important for us to establish realistic milestones to evaluate the development of postural control in order to allow us to identify children at risk for decreased functional mobility and/or injury. It is also important in order for us to gain a better understanding of typical human development and the acquisition of motor skill. The purpose of this study is to investigate age-related differences in static and dynamic postural control.

METHODS

Subjects

Sixty-two (33 males/29 females) active subjects volunteered to participate in this study. Subjects were classified into three age groups 1) ages 19-20 years **(**8 males/8 females**,** 2 height=171.73 ± 8.57cm, weight=70.26 ±13.68 kg), 2) ages 9-10 years **(**9 males/6females**,** height=142.65 ± 6.39cm, weight=40.33 ± 14.15kg)**,** and 3) ages 6-7 years (16 males/15 females, height=124.76 ± 4.11cm, weight=25.34 ± 4.14kg). All adult subjects read and signed informed consent forms approved by the institutional review board prior to participation. Informed consent forms approved by the institutional review board were signed by the parent or legal guardian for all minor subjects. In addition, assent was granted by all minors participating in this study. Subjects were excluded if they reported a history any of the following: 1) balance or vestibular disorders, 2) central or peripheral nervous system disorders, 3) significant lower extremity injury, or 4) symptomatic upper extremity injury

Instrumentation

Postural control was measured using an AMTI Accusway force plate (AMTI Inc., Watertown, MA) interfaced with Swaywin software (AMTI Inc., Watertown, MA). Three dimensional ground reaction forces were measured at a sampling frequency of 50 Hz. Center of pressure excursion velocities (COPV) were calculated by the Swaywin software.

Measuring Postural Control

Measures of static and dynamic postural control were taken for all subjects. Subjects completed the Berg Balance Scale, the Pediatric Balance Scale the Functional Reach Test, and the Activities-Specific Balance Confidence Scale (ABC). Center of pressure excursion velocity (COPV) data were also gathered.

The Berg Balance Scale is a 14 item performance based test (see table 2 and figures 5-6). Each item is scored between 0 and 4 with specific criteria assigned to each point value. Better performance is indicated with a greater point value. Scores for all items are summed together to get a total score for the test.

The Pediatric Balance Scale is a modification of the Berg Balance Scale found to have improved reliability. Some of the modifications include, reordering the test items, scoring criteria, and the number of trials completed.

When performing the functional reach test, subjects were instructed to stand comfortably with both feet on the floor and their preferred arm extended in front of them

(90 degrees of shoulder flexion) with an open hand (see figure 2). The placement of the distal end of the third digit was recorded as position one. Subjects then leaned forward to reach as far anteriorly as they could without losing their balance or moving their feet (see figure 3). The placement of the third digit was recorded as position two. Functional reach was calculated by subtracting position one from position two. Three trials were completed and the mean functional reach score was recorded. If subjects moved their feet during a trial, or touched the wall with their arm, the trial was discarded and repeated.

The ABC scale is a self-report measure of balance confidence (see table 1). Subjects were instructed to indicate their level of confidence in completing each activity without losing their balance or becoming unsteady by choosing a percentage between 0% and 100%. A visual scale was provided (see figure 1). If subjects do not participate in that activity they were asked to imagine how confident they would be if they did participate in the activity. The surveys were scored by summing all of the percentages (possible range – 0 to 1600) and dividing by 16. All survey items were read to the 6 and 7 year old subjects and explained as needed. The 9 and 10 year old subjects were provided assistance as needed.

In order to measure static postural control, subjects completed testing to measure COPV. Subjects were asked to stand as still as possible in bipedal stance on the force plate for 15 seconds (see figure 7). Subjects were instructed to visually focus on a stationary target placed on the wall one meter in front of them. This task was repeated three times. The trials were then repeated with the subjects eyes closed (see figure 8). The subjects arms were crossed over their chest. In the event that a subject experienced a loss of balance requiring them to step-off the plate, the trial was discarded and repeated. The task was then repeated in single leg stance with the eyes open (see figure 9). Three trials were conducted on the right leg and also on the left leg. The order of single leg stance trials was counterbalanced.

Figure 7. Bipedal Stance with Eyes Open

Figure 8. Bipedal Stance with Eyes Closed

Figure 9. Single leg stance with Eyes Open

Statistical Analysis

A one-factor analysis of variance (ANOVA) was performed to compare means at baseline among the three different age groups. Separate analyses were run for the following measures: ABC Scale, Berg Balance Scale, Functional Reach Test, bipedal stance COPV with eyes open, bipedal stance COPV with eyes closed, single leg stance COPV for the right leg with eyes open, and single leg stance COPV for the left leg with eyes open. Post hoc testing was then done using independent samples t-tests to identify differences. Significance level was set a priori at $p < 0.05$.

Effect sizes were calculated as $(mean_a – mean_b)/SD_a$ where $mean_a$ is the mean for group *a*, $mean_b$ is the mean for group b and SD_a is the standard deviation for group a. Because the standard deviation of Pediatric Balance Scales was 0.00 for group one, the standard deviation for group b was used when calculating the effect sizes for the Pediatric Balance Scale.

RESULTS

Significant group differences were found for all dependent variables (see table 3). Post hoc testing revealed that the young adults scored significantly better than the 9-10 year old children in all dependent variables except the Berg Balance Scale and the Pediatric Balance Scale (see table 4). When examining the young adults and the 6-7 year old children, the young adults were found to score better than the 6-7 year old children in all of the dependent variables (see table 5). Finally, when comparing the two groups of children, the 9-10 year olds scored better than the 6-7 year olds in all variables except: single leg stance (COPV) on the left leg and the ABC Scale (see table 6).

Table 3. 1-Way ANOVA summary Table

Measure	**F**	**p**
Functional Reach	55.88	<0.0005
COPV (bipedal, EO)	40.31	<0.0005
COPV (bipedal, EC)	38.29	<0.0005
COPV (right leg, EO)	12.08	<0.0005
COPV (left leg, EO)	13.74	<0.0005
Berg Balance Scale	9.78	<0.0005
Pediatric Balance Scale	8.74	<0.0005
ABC	4.53	<0.0005

Table 4. Post Hoc Comparisons of Young Adults and 9-10 Year Old Children.

Measure	Group	Mean	SD	t	p
Functional Reach	1	39.58	4.54	2.46	0.02
	2	33.76	8.22		
COPV (bipedal, EO)	1	.94	0.21	4.56	<0.0005
	2	1.59	0.52		
COPV (bipedal, EC)	1	1.19	0.30	5.28	<0.0005
	2	2.15	0.64		
COPV (right leg, EO)	1	3.37	0.80	4.12	0.001
	2	5.35	1.69		
COPV (left leg, EC)	1	3.25	0.86	5.16	<0.0005
	2	5.57	1.53		
Berg Balance Scale	1	55.94	0.25	1.11	0.28
	2	55.80	0.41		
Pediatric Balance Scale	1	56	0.00	1.00	0.33
	2	55.87	0.52		
ABC	1	93.87	3.56	2.44	0.03
	2	86.35	10.23		

Table 5. Post Hoc Comparison of Young Adults and 6-7 Year Old Children

Measure	**Group**	**Mean**	**SD**	**t**	**p**
Functional Reach	1	39.58	4.54	12.01	<0.0005
	3	21.67	4.99		
COPV (bipedal, EO)	1	.94	.21	11.60	<0.0005
	3	2.24	.55		
COPV (bipedal, EC)	1	1.19	.30	10.93	<0.0005
	3	3.05	.85		
COPV (right leg, EO)	1	3.37	.80	5.84	<0.0005
	3	7.83	4.02		
COPV (left leg, EO)	1	3.25	.86	6.31	<0.0005
	3	7.13	3.16		
Berg Balance Scale	1	55.94	.25	4.61	<0.0005
	3	54.67	1.47		
Pediatric Balance Scale	1	56.00	0	4.47	<0.0005
	3	54.73	1.55		
ABC	1	93.87	3.56	3.78	0.001
	3	84.03	13.44		

Table 6. Post Hoc Comparison of 9-10 and 6-7 Year Old Children.

Measure	**Group**	**Mean**	**SD**	**t**	**p**
Functional Reach	2	33.76	8.22	6.19	<0.0005
	3	21.67	4.99		
COPV (bipedal, EO)	2	1.59	.52	3.84	<0.0005
	3	2.24	.55		
COPV (bipedal, EC)	2	2.15	.64	3.62	0.001
	3	3.05	.85		
COPV (right leg, EO)	2	5.35	1.69	2.27	0.03
	3	7.83	4.02		
COPV (left leg, EO)	2	5.57	1.53	1.81	0.08
	3	7.13	3.16		
Berg Balance Scale	2	55.80	.41	3.92	<0.0005
	3	54.67	1.47		
Pediatric Balance Scale	2	55.87	.52	2.74	0.009
	3	54.73	1.55		
ABC	2	86.35	10.23	.54	0.59
	3	84.03	13.44		

Calculation of effect sizes demonstrated similar results (see table 7).

Table 7. Effect sizes of performance measures between groups

Measure	**Effect Size Adults & 9-10**	**Effect Size Adults & 6-7**	**Effect Size 9-10 & 6-7**
Functional Reach	1.28	3.94	1.47
COPV (bipedal, EO)	3.09	6.19	1.25
COPV (bipedal, EC)	3.20	6.2	1.40
COPV (right leg, EO)	2.48	5.57	1.46
COPV (left leg, EO)	2.71	4.52	1.02
Berg Balance Scale	0.56	5.08	2.76
Pediatric Balance Scale	0.25	0.82	.74
ABC	2.11	2.76	0.23

DISCUSSION

The primary finding of this study was that there were age related differences in the performance of balance measures. These findings appear to be both statistically significant ($p < 0.05$) and clinically meaningful as demonstrated by the large effect sizes. According to Cohen, an effect size of 0.8 is considered a large effect. Most of the measures had effects greater than 0.8. Moderate effects are at least a 0.5 and small effects are those greater than or equal to 0.2.[90]

The young adults scored significantly better than the 9 and 10 year old children in all dependent variables except the Berg Balance Scale and the Pediatric Balance Scale. They scored better than the 6 and 7 year old children in all measures. The 9 and 10 year old children scored better than the 6 and 7 year old children in all variables except left leg stance COPV and the ABC Scale. It appears that children in the 9 to 10 year old age group may be transitioning toward adult motor behavior. While they did not score as well as the adults in most measures, they did perform better than the 6 and 7 year old children in most measures. This may suggest that by the age of 9 or 10, significant neuromuscular development has occurred. These findings are consistent with those reported by Streepey and Angulo-Kinzler.[17] They found that ten and eleven year old children performing similar to six year olds in some moderately difficult reaching tasks and similar to adults in other moderately difficult reaching tasks.

Similar findings were reported by Hay and Redon[30]. While these authors investigated feedforward and feedback control through development, they found similar patterns to those in the current study and the study by Streepey and Angulo-Kinzler.[17] They reported that it was the 9-10 year old children that were demonstrating similar balance strategies as adults. This may help to explain why it was in the 9-10 year old children that we began to see improvements in balance that approximated the performance of adults.

It was in the Berg Balance Scale and the Pediatric Balance Scale that yielded no significant differences between the adults and the older children. The Berg Balance Scale and the Pediatric Balance Scale measure gross motor function. Scoring of most items is based on the safe completion of a task. In contrast, the other measures have more continuous scoring identifying subtle differences. This may help to explain why the children scored more similar to adults. The Berg Balance Scale and the Pediatric Balance Scale may not be sensitive enough to detect the slight differences in balance between adults and the 9 and 10 year old children. Because there are still many differences between the adults and the 9-10 year old children, one may expect that postural control and neuromuscular continue to develop into the pubescent and possibly the post-pubescent stages of development.

There are many theories developed to explain age related differences in postural control. Most of these involve the use of different balance strategies between age groups. One suggested mechanism is the difference between children and adults in the use of visual cues. A report by Riach and Hayes.[18] suggests that children utilize visual cues differently than do adults. Romberg quotients were used to estimate the influence of eye-closure on postural control. The children demonstrated low quotients compared to the adult population. These authors suggest that after the age of seven, children begin to adopt balance strategies similar to that of adults. In contrast, Slobounov and Newell[15] suggest that postural control deficits related to decreased visual input may be greater in younger children.

Other balance strategies and muscle activation patterns have been associated with postural control. Sveistrup and Woollacott[63] conducted an intervention study aimed at investigating the effects of a training program on aspects of postural control, specifically activation patterns of postural muscles. Elecromyogram data suggested that the infants in the training group had: 1) increases in probability of activating functionally appropriate muscles, 2) increased number of functionally appropriate postural muscles activated in a single trial, and 3) no significant changes in mean postural muscle onset latencies or number of trials with antagonist muscle coactivation. The authors concluded that training may affect automatic postural responses during development.

Slobounov and Newell[15] also suggest that different postural control strategies are used as we age. They reported that while three and five year old children both attempt to limit the degrees of freedom as task difficulty increases, only the five year old children demonstrate compensatory movement patterns. In adults they found that skilled subjects employed a smaller set of compensatory movement patterns as task difficulty increased.[16]

Work by Wang and Chen[91] may also provide information in regard to the mechanism behind age related changes in balance. The authors investigated the effects of several variables on balance. Interestingly, they identified significant correlations between strength and balance. This suggests that strength differences may also contribute to the age related differences in postural control.

In future research, it will be important to investigate the appropriateness of different functional balance measures in children. Examining balance performance over a greater span of development will also be beneficial. In this study, it is likely that both groups were pre-pubescent. Future research should explore the effects of puberty on postural control. A comparison between the developing child and the geriatric population that is showing declines in postural control will also provide us with more clinically important information. Further research aimed at identifying the underlying mechanisms of these age related differences is also important.

Conclusion

These results suggest there are age-related differences in postural control among children and adults. This complements current postural control literature, as it provides information about functional measures of postural control that are just being introduced clinically in the pediatric setting. In addition, these results provide preliminary data to help establish normative values for performance on these balance measures specific to the populations studied. Little work has been done to establish normative values for functional balance measures among healthy school-aged children and young adults.

Understanding postural control across the lifespan is clinically meaningful, as postural control is necessary for human function at all levels of performance. Postural control provides us independence, functional mobility and contributes to the prevention of injury.

CHAPTER 4

The Efficacy of a Six-week Balance Training Program in Improving Postural Control Among Six and Seven Year Old Childen

Objective: To examine the efficacy of a six-week balance training program in improving postural control among typically developing six and seven year old children.

Design and Setting: Test-retest design in school setting

Subjects: Twenty-six healthy, active children between the ages of six and seven completed this study. Subjects were assigned to a training group (N=12) or a control group (N=14).

Measurements: Subjects were scored on the following measures: 1) Functional Reach, 2) Berg Balance Test, 3) Pediatric Berg Balance Test, 4) ABC Scale, and 5) center of pressure velocity (COPV) during 10 second trials of quiet standing during unilateral and bilateral stances with eyes open and closed.

Results: Following the training program, no statistically significant differences were noted except for a significant main effect for time in the functional reach test. Subjects reached significantly greater distances during post-testing than they did at baseline. Despite the lack of statistically significant changes, there were moderate to strong effect sizes among the training group.

Conclusions: While no statistically significant changes were noted following the training program, the moderate to strong effect sizes seen among the training group suggesting that more research is needed to make a strong conclusion about the efficacy of balance training among healthy children.

INTRODUCTION

Postural control is an essential aspect of neuromuscular development in humans. It is essential for the performance of all levels of tasks from infancy through development into adulthood. Postural control is one component of tasks such as sitting upright, crawling, walking and high level athletic activity. While postural control allows us to function and be mobile, balance deficits have also been shown to significantly limit mobility and also be associated with injury.

Due to the intergral role postural control has in human development and function, much research has focused on improving postural control through exercise programs. However, much of this research has been in at risk populations such as the elderly or those with injury, or illness.

There is insufficient research investigating the use of balance training programs in the pediatric setting. Many of the balance intervention studies in pediatrics examine the efficacy for use with infants. The purpose of this study is to examine the efficacy of a six-week balance training program in improving postural control among typically developing six and seven year old children.

METHODS

Subjects

Twenty-nine children between the ages of six and seven (15 males/ 14 females, weight = 25.34 $\pm$ 4.14 kg, height = 124.76 $\pm$ 4.11cm) active volunteered to participate in this study. Subjects were assigned to a training group or a control group. The training group completed a six week balance training program. The control group was instructed to continue with their normal activity. With assistance from their parents, all subjects completed the International Physical Activity Questionnaire prior to participation. Informed consent forms approved by the institutional review board were signed by the parent or legal guardian for all subjects. In addition, assent was granted by all subjects participating in this study. Subjects were excluded if they reported a history of any of the following: 1) balance or vestibular disorders, 2) central or peripheral nervous system disorders, 3) significant lower extremity injury, or 4) symptomatic upper extremity injury.

Instrumentation

Postural control was measured using an AMTI Accusway force plate (AMTI Inc., Watertown, MA) interfaced with Swaywin software (AMTI Inc., Watertown, MA). Three dimensional ground reaction forces were measured at a sampling frequency of 50 Hz. Center of pressure excursion velocities (COPV) were calculated by the Swaywin software.

Measuring Postural Control

Measures of static and dynamic postural control were taken for all subjects at baseline. Upon completion of the training period, all subjects repeated the balance testing between 24 and 7 2 hours following completion of the program. Subjects completed the Berg Balance Scale, the Pediatric Balance Scale, the Functional Reach Test, and the Activities-Specific Balance Confidence Scale (ABC). Center of pressure excursion velocity (COPV) data were also gathered.

The Berg Balance Scale is a 14 item performance based test (see table 2). Each item is scored between 0 and 4 with specific criteria assigned to each point value. Better performance is indicated with a greater point value. Scores for all items are summed together to get a total score for the test.

The Pediatric Balance Scale is a modification of the Berg Balance Scale found to have improved reliability. Some of the modifications include, reordering the test items, scoring criteria, and the number of trials completed.

When performing the functional reach test, subjects were instructed to stand comfortably with both feet on the floor and their preferred arm extended in front of them (90 degrees of shoulder flexion) with an open hand (see figure 2). The placement of the distal end of the third digit was recorded as position one. Subjects then leaned forward to reach as far anteriorly as they could without losing their balance or moving their feet (see figure 3). The placement of the third digit was recorded as position two. Functional reach was calculated by subtracting position one from position two. Three trials were completed and the mean functional reach score was recorded. If subjects moved their feet during a trial, or touched the wall with their arm, the trial was discarded and repeated.

The ABC scale is a self-report measure of balance confidence (see table 1). Subjects were instructed to indicate their level of confidence in completing each activity without losing their balance or becoming unsteady by choosing a percentage between 0% and 100%. A visual scale was provided (see figure 1). If subjects do not participate in that activity they were asked to imagine how confident they would be if they did participate in the activity. The surveys were scored by summing all of the percentages (possible range – 0 to 1600) and dividing by 16. All survey items were read to the 6 and 7 year old subjects and explained as needed. The 9 and 10 year old subjects were provided assistance as needed.

In order to measure static postural control, subjects completed testing to measure COPV. Subjects were asked to stand as still as possible in bipedal stance on the force plate for 15 seconds (see figure 7). Subjects were instructed to visually focus on a stationary target placed on the wall one meter in front of them. This task was repeated three times. The trials were then repeated with the subjects eyes closed (see figure 8). The subjects arms were crossed over their chest. In the event that a subject experienced a loss of balance requiring them to step-off the plate, the trial was discarded and repeated. The task was then repeated in single leg stance with the eyes open (see figure 9). Three trials were conducted on the right leg and also on the left leg. The order of single leg stance trials was counterbalanced.

Training Protocol

Subjects assigned to the training group participated in a six week balance training program twice a week. Each session consisted of 25 minutes of group exercise. A physical therapist and an undergraduate kinesiology student supervised all sessions. All exercise sessions were completed at the children's school during recess or physical education classes. The training protocol combined static and dynamic balance activities (see table 8). Not all exercises were completed at every session. The exercises were varied to maintain interest among the subjects. However, within a session, all subjects performed the same exercises. Each child's dominant limb was determined and that limb was identified as the training limb. In order to assist the children in identifying the training limb during the training sessions, a sticker was placed on the shoe of the dominant limb (see figure 10). The training limb was referred to as the “sticker foot” throughout the training program.

Figure 10. Sticker foot

Table 8. Training Protocol

Exercise	Static or Dynamic	Figure
Single leg stance on solid surface with EO	Static	11
Single leg stance on solid surface with EC	Static	12
Single leg stance on foam mat with EO	Static	13
Single leg stance on foam mat with EC	Static	14
Single leg stance on solid surface while tossing ball/frisbee	Dynamic	
Single leg hopping in unanticipated directions	Dynamic	
Red light-green light with single leg stop (all directions)	Dynamic	15
Carioca	Dynamic	
Tandem Stance EO	Static	
Tandem Stance EC	Static	
Kickers without resistance (4 directions)	Dynamic	

Figure 11. Single Leg Stance
(solid surface, eyes open)

Figure 12. Single Leg Stance
(solid surface, eyes closed)

Figure 13. Single Leg Stance
(foam surface, eyes open)

Figure 14. Single Leg Stance
(foam surface, eyes closed)

Figure 15. Red light-Green light
Single Leg Stop

Those subjects assigned to the control group continued with their normal level of activity. The control group participated in regularly scheduled physical education classes that were conducted by their respective physical education teacher. No restrictions or specific programs were given to the control subjects during recess.

Statistical Analysis

In order to examine the effects of the training program on postural control, a repeated measures 2-way ANOVA was performed. The between subject factor was group (control, training) and the within subject factor was time (pre, post). Separate analyses were run for each of the variables listed above. All statistics were computed using SPSS software. Significance level was set a priori at $p<0.05$.

Effect sizes were calculated as $(mean_2 – mean_1)/SD_1$ where $mean_2$ is the post-test mean, $mean_1$ is the baseline mean, and SD_1 is the standard deviation at baseline. Coefficinets of variation were also calculated using the formula: coefficient of variation = SD/mean.

RESULTS

At baseline, all subjects were classified as sufficiently active or highly active using the International Physical Activity Questionnaire. Follow-up testing was completed on 26 of the 29 subjects. One subject from the training group was excluded from the study several weeks into the study due to an acute abdomen pathology. Two subjects from the control group were excluded due to absence from school at the time of post-testing.

No statistically significant differences were noted in the COPV scores under the following conditions: 1) bipedal stance with eyes open, 2) bipedal stance with eyes closed, and 3)single leg stance with eyes open, . There was a significant main effect for time in the functional reach test. Subjects reached significantly greater distances during post-testing than they did at baseline. No significant differences were noted in the Berg Balance Scale scores, the Pediatric Balance Scale scores, or the ABC scale over time (see tables 9-10).

Table 9. Group By Time Data

Measure	Group	Time	Mean	SD
Functional Reach	Training	Baseline	21.21	4.03
		Post-Test	25.21	3.53
	Control	Baseline	21.31	6.36
		Post-Test	23.43	4.29
COPV (bipedal, EO)	Training	Baseline	2.28	0.40
		Post-Test	2.27	0.72
	Control	Baseline	2.28	0.67
		Post-Test	2.78	1.43
COPV (bipedal, EC)	Training	Baseline	3.11	0.66
		Post-Test	3.17	1.00
	Control	Baseline	2.99	1.02
		Post-Test	3.62	2.28
COPV (right, EO)	Training	Baseline	7.18	1.95
		Post-Test	5.61	1.29
	Control	Baseline	8.26	5.13
		Post-Test	7.86	3.56
COPV (left, EO)	Training	Baseline	6.75	1.23
		Post-Test	5.61	1.41
	Control	Baseline	7.87	4.38
		Post-Test	8.98	5.75
Berg Balance Scale	Training	Baseline	55.17	0.83
		Post-Test	55.58	0.51
	Control	Baseline	54.57	1.22
		Post-Test	53.93	2.06
Pediatric Balance Scale	Training	Baseline	55.17	0.39
		Post-Test	55.58	0.51
	Control	Baseline	54.71	1.20
		Post-Test	54.07	2.16
ABC	Training	Baseline	80.22	15.01
		Post-Test	88.83	10.96
	Control	Baseline	86.03	12.59
		Post-Test	88.51	9.26

Table 10. ANOVA summary table

Measure	Factor	F	P value	Power
Functional Reach	Time X Group	0.83	0.37	0.86
	Time	8.80	0.01	0.19
	Group	0.29	0.59	0.92
COPV (bipedal, EO)	Time X Group	1.68	0.21	0.76
	Time	1.61	0.22	0.77
	Group	0.72	0.40	0.87
COPV (bipedal, EC)	Time X Group	0.57	0.46	0.89
	Time	0.88	0.36	0.85
	Group	0.16	0.69	0.93
COPV (single leg, EO)	Time X Side X Group	0.54	0.47	0.89
	Time X Group	1.47	0.24	0.79
	Time	0.50	0.49	0.90
	Group	2.82	0.11	0.64
Berg Balance Scale	Time X Group	0.87	0.36	0.85
	Time	0.07	0.79	0.94
	Group	10.85	0.003	0.12
Pediatric Balance Scale	Time X Group	1.93	0.18	0.73
	Time	0.09	0.77	0.94
	Group	7.61	0.01	0.25
ABC	Time X Group	1.12	0.30	0.83
	Time	3.19	0.09	0.60
	Group	0.55	0.47	0.89

Effect sizes demonstrate small, moderate, and large effects with training (see table 11). When examining coefficients of variation (COV), we see that children in the training group had a decreased COV in three measures following the training while the control group only demonstrated decreases in two of the variables. The training groups had an increase in COV for three variables, while the control group had an increased COV for five measures at follow-up (see table 12).

Table 11. Effect Sizes. All effect sizes were modified so that a positive effect size represents improvement and a negative effect sizes indicates a decline in function.

Measure	Effect Size Treatment Group	Effect Size Control Group
Functional Reach	0.99	0.33
COPV (bipedal, EO)	0.03	-0.75
COPV (bipedal, EC)	-0.09	-0.62
COPV (right leg, EO)	0.8	0.08
COPV (left leg, EO)	0.93	0.25
Berg Balance Scale	0.49	-0.52
Pediatric Balance Scale	1.05	-0.53
ABC	0.57	0.18

Table 12. Coefficients of Variation

Measure	Training Group Baseline	Training Group Post-Test	Control Group Baseline	Control Group Post-Test
Functional Reach	0.19	0.14	0.30	0.18
COPV (bipedal, EO)	0.18	0.32	0.29	0.51
COPV (bipedal, EC)	0.21	0.32	0.34	0.63
COPV (right leg, EO)	0.27	0.23	0.62	0.45
COPV (left leg, EO)	0.18	0.25	0.56	0.64
Berg Balance Scale	0.02	0.01	0.02	0.04
Pediatric Balance Scale	0.01	0.01	0.02	0.04
ABC	0.19	0.12	0.15	0.09

DISCUSSION

In this study, a six week balance intervention program did not appear to statistically improve balance in six and seven year old children. While the efficacy of balance training programs in improving adults' balance is well established, few studies have looked at balance intervention programs for children. The results of one study by Wang and Chang[61] are in contrast to the findings of this study. There are many possible reasons for this. Wang and Chang studied children with mental retardation and Down Syndrome. It is plausible that these children would respond differently to a training program than did the healthy children in this study. In addition, the training protocol was different in the Wang and Chang study. The dependent measures were also different and may be measuring a different motor skill.

Shumway-Cook et al.[62] also reported significant improvements in balance among children. Again, this was among children with impairments. This study also used a different dependent measure than the current study which may contribute to the different results. The intervention protocol was also different than that in the current study. These authors utilized the testing platform for training which may allow the subjects to practice for the follow-up testing. This study also involved a very small sample size of six children. These children were also older than the children in the current study.

When interpreting the results of the current study, it is also important to consider the trends noted following the rehabilitation program despite the lack of statistical significance. While statistically there were no significant improvements found, there are indicators that future study in this area may be warranted. Recently, effect sizes have been used to indicate clinical importance.[90] Typically effect sizes are calculated to estimate clinical importance when statistical significance is found. When examining the effect sizes seen among the training group, small effects were seen in COPV (bipedal stance, eyes open and bipedal stance, eyes closed) and the Berg Balance Scale. Moderate effects were seen in the ABC scale, and most important, large effects were seen in functional reach, COPV (right and left single leg stance, eyes open) and the Pediatric Balance Scale. All of these changes except for COPV (bipedal stance, eyes closed) demonstrated improvement. In comparison, the control group had no moderate or large effect sizes where the subjects showed improvement. In fact in five out of the eight measures, the control subjects showed declines in performance.

Examiner observation also supports the calculated effect sizes. While there was no statistical significance captured by the balance measures in this study, there was great improvement noted by the examiner. During the baseline testing, most children were not able to complete 15 second trials of single leg stance with they eyes closed. However, at follow-up the children in the training group were able to successfully complete this task. Due to the lack of successful trials at baseline, these data were not appropriate for use in this study. Similar observations were made during the single leg stance task with the eyes open. At baseline, many trials were discarded and repeated due to losses of balance. During follow-up testing, few trials were discarded among the training group. This may warrant further exploration into the sensitivity of the balance measures selected for this study. It is possible that other balance measures may be more appropriate for use among children.

Another important consideration is the meaning of the improvement seen. One component of the Berg Balance Scale is reaching forward with outstretched arm. In order to earn the maximum score for this task, the subject must reach 25 cm. The same scoring criteria is applied in the Pediatric Balance Scale. The functional reach test measures the same task. Prior to training, the training group reached an average of 21.21 cm. As a result, they were penalized in the Berg Balance Scale and the Pediatric Balance Scale. Following the intervention, the subjects were then reaching an average of 25.20cm, allowing them to earn the maximum score on that item of the Berg Balance Scale and the Pediatric Balance Scale. This may suggest that though the change was not statistically significant, it was a critical improvement.

It is also plausible that some of these measures did not capture the full treatment effect due to the nature of the tasks. The balance-training program emphasized stability in single leg stance. In contrast, most of the balance measures used in this study examined postural control in bipedal stance.

There are many possible mechanisms for the improved balance performance seen through observation and effect size calculation in this study and the previous works. One such mechanism is altered automatic postural response patterns. This mechanism is supported by the work of Sveistrup and Woollacott.[63] They reported improved automatic postural response patterns including increases in the probability of activating functionally appropriate muscles and an increase in the number of functionally appropriate muscles activated in a single trial in infants following a five day perturbation training program.

The role of antagonist muscle contractions has also been investigated. However current evidence does not support this theory. Sveistrup and Woollacott[63] did not identify differences in the number of trials with antagonist muscle coactivation following balance training. In addition, Roncesvalles et al.[14] reported no difference in antagonist co-contraction between healthy children and children with balance deficits associated with cerebral palsy.

Another mechanism was suggested by by Roncesvalles et al.[14] While studying the underlying mechanism for impaired postural control in children with cerebral palsy, the authors found that in contrast to typically developing children, children with cerebral palsy did not elicit increased postural muscle response magnitudes with larger/faster perturbations. This may suggest that improvements in postural response patterns may contribute to improved balance following balance training.

Muscle strength has also been found to be related to balance.[91] Results of a study done by Lord and Castell[72] also support this potential relationship. Following a 10 week exercise program, adults were found to have greater quadricep's strength, and postural control. Many balance intervention programs incorporate closed kinetic chain activities in a weight bearing position. It is plausible that these programs are resulting in strength gains that are contributing to improvements in balance. However, a study by Chandler[79] refutes this theory. Following intervention, he found no significant relationship between strength gains and balance measures.

The work of Wiley and Damiano[92] suggests another possible theory. Some argue that balance recovery in children with cerebral palsy may be limited by the inability of the nervous system to increase neural output to control an increased velocity of threat. This may also contribute to improvements seen following training. It is possible that training serves to improve neural output in response to postural disturbances. Future research should focus on identifying how intervention programs are improving postural control. This may provide information that will be critical in developing the most effective intervention program.

Another means of improving our effectiveness in improving postural control is to conduct more intervention studies comparing the effects of different interventions. Researchers need to use caution however, when using postural control as the outcome measure. First, scholars need to further identify the roles of postural control deficits in injury and functional mobility limitations. Future research needs to focus on more functional and long-term outcomes. Scholars need to measure the effectiveness of intervention programs in decreasing injury and improving motor skill and function. This study followed the subjects for up to 72 hours after completion of the training program. This does not provide us any information about the potential prophylactic benefits the training program may have in later childhood or adulthood. It will also be important to identify population and individual response differences to training programs.

CONCLUSION

The evidence from this study is inconclusive. While there were no statistically significant findings supporting the intervention program, there were some trends indicating that future research in this area is warranted. The findings from this study support future research in this area to gain a better understanding of the role of balance intervention programs. This study may indicate that we need to develop better balance measures for children.

CHAPTER 5

DISCUSSION

There were two primary hypotheses for this study. First, it was hypothesized that there are age related differences in the performance of postural control tasks. It was hypothesized that young adults would demonstrate greater postural control than the six and seven year old children in all performance measures. The results of this study support this finding. Adults performed better on all measures than did the six and seven year old children. These results agree with earlier findings reported by Wolff and colleagues[93] who found Improved postural control with age among subjects five to eighteen years of age.

It was also hypothesized that performance differences would be identified between 1) the nine and ten year old children when compared to the six and seven year old children in some measures and 2) the young adults children when compared to the nine and ten year old children in some measures. These too were supported by this study. Like Streepy and Angulo-Kinzler,[17] this study suggests that the nine and ten year old children may be going through a transition period. While they score similar to the youngest group on more challenging tasks, they perform similar to adults on more basic tasks. When given a moderately difficult task to complete, there are identifiable differences between all groups.

In the second study, it was hypothesized that six and seven year old children completing a six week balance training program would improve postural control more than the children that did not complete the balance intervention program. While the results of the ANOVA did not support this hypothesis, one must use caution in interpreting these results. Despite an apparent weak training effect, there were moderate and large treatment effects calculated for the treatment group post intervention. In addition, there was obvious improvement observed by the examiner. Previous studies involving children with special needs indicated that training programs may be effective in improving balance among these children. There are many potential reasons for the inconsistency in findings between this study and previous work. One potential explanation is the subject populations used in the studies. Different dependent variables and training protocols may also contribute to the disparity.

The evidence gathered in these two studies was exploratory in nature and sets the ground work for future research. There is a great need to explore the development and degradation of postural control through childhood, adulthood, and aging. It is important to examine this development in healthy individuals as well as those with injury and illness. Researchers also need to gain a better understanding of why there are age related and gender related changes in postural control.

The effects of changes in postural control must also be explored. Scholars need to further identify the roles of postural control deficits in injury and functional mobility limitations. Intervention programs also need to be investigated. Though many studies have assessed the effectiveness of intervention programs, researchers need to identify population and individual differences in response to training programs. Much research is dedicated to measuring improvements in postural control following an intervention program. Future research needs to focus on more functional and long-term outcomes. Scholars need to measure the effectiveness of intervention programs in decreasing injury and improving motor skill and function.

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Appendix A

Informed Consent Forms

Adult
9-10 year old
6-7 year old control
6-7 year old training

ORP USE ONLY:
The Pennsylvania State University
Office for Research Protections

Approval Date:
Expiration Date:

Biomedical Institutional Review Board

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY: Adult Controls
The Pennsylvania State University

Title of Project: Postural control through childhood development (IRB #17260)

Principal Investigator: Sheri Hale, PT, ATC
266 Recreation Building
University Park, PA 16802
sah193@psu.edu
814-865-7936

Other Investigator: Jay Hertel, PhD, ATC
266 Recreation Building
University Park, PA 16802
jnh3@psu.edu
814-865-8816

This is to certify that I, ______________________________, have been given the following information with respect to my participation as a volunteer in a program of investigation under the supervision of Sheri Hale. I acknowledge that I must be 18 years of age or older to consent to participate in this research study.

1. **Purpose of the study:**

The study in which you will be participating is designed to examine: 1) differences in balance related to age and 2) determine the effects of a six-week balance training program on balance while standing still and during activity.

2. **Procedures to be followed:**

If you take part in this study, you will complete one testing session. During the session you will have your height and weight measured and you will perform tests of balance, as in pictures shown below. . You will also fill out 2 surveys measuring your fear of falling and activity level.

3. **Discomforts and risks:**

In participating in this study, you may experience slight discomfort similar to that associated with light to moderate levels of exercise. There is also the possibility that you may lose your balance during balance testing. However, the likelihood of this is no greater than the likelihood of losing one's balance during activities of daily living that require single leg stance (climbing the stairs or stepping up onto a curb) or walking/standing on unsteady surfaces (grass, snow, uneven ground). In order to minimize this risk, you will be spotted by the investigators.

4. a. **Benefits to volunteer:** You will gain a better understanding of the research process.

   b. **Potential benefits to society:** Your participation in this study will benefit society by improving clinicians' understanding of the effects of age on balance, and the effectiveness of balance training programs among children.

______________________________ ______________________________
Volunteer Date Investigator Date

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY

5. Alternative procedures which could be utilized: None

6. Time duration of the procedures and study:

Your participation will take approximately 1-2 hours.

7. Statement of confidentiality:

Your participation in this research is confidential. Only the investigators will have access to your identity and to information that can be associated with your identity. In the event of publication of this research, no personally identifying information will be disclosed.

8. Right to ask questions:

You may ask any questions about the research procedures and the questions will be answered. Further questions should be directed to Sheri Hale at sah193@psu.edu or 814-865-7936 (office). You may also contact the Office for Research Protections at 814-865-1775 for questions about your rights as a research participant. You also may decline to answer any questions the researchers ask you.

9. Compensation:

There is no compensation, financial or otherwise, for participating in this study.

10. Injury Clause:

Medical care is available in the event of an injury resulting from research but neither financial compensation nor free medical treatment are provided. You are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators.

11. Voluntary participation:

Participation in this study is voluntary, and you may withdraw from this study at any time by notifying the investigator. Your withdrawal from this study or refusal to participate will in no way affect your care or access to medical services.

This is to certify that I consent to and give permission for my participation as a volunteer in this program of investigation. I have been given an opportunity to ask any questions I may have and all such questions or inquiries have been answered to my satisfaction. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

Volunteer Date

I, the undersigned, have defined and explained the studies involved to the above volunteer.

Investigator Date

ORP USE ONLY:
The Pennsylvania State University
Office for Research Protections

Approval Date:
Expiration Date:

Biomedical Institutional Review Board

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY: 9-10 y/o control
The Pennsylvania State University

Title of Project: Postural control through childhood development (IRB# 17260)

Principal Investigator: Sheri Hale, PT, ATC
266 Recreation Building
University Park, PA 16802
sah193@psu.edu
814-865-7936

Other Investigators: Jay Hertel, PhD, ATC
266 Recreation Building
University Park, PA 16802
jnh3@psu.edu
814-865-8816

This is to certify that I, ______________________, on behalf of my minor child ______________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Sheri Hale.

1. **Purpose of the study:**

The study in which your child will be participating is designed to examine: 1) differences in balance related to age and 2) determine the effects of a six-week balance training programs on balance while standing still and during activity.

2. **Procedures to be followed:**

If your child takes part in this study, he/she will complete 1 testing sessions. During the session, your child will have his/her height and weight measured and will perform tests of balance, as in pictures shown below. With your help, your child will also fill out 2 surveys measuring fear of falling and activity level.

3. **Discomforts and risks:**

In participating in this study, your child may experience slight discomfort similar to that associated with light to moderate levels of exercise. There is also the possibility that he/she may lose his/her balance during balance testing. However, the likelihood of this is no greater than the likelihood of losing one's balance during activities of daily living that require single leg stance (climbing the stairs or stepping up onto a curb) or walking/standing on unsteady surfaces (grass, snow, uneven ground). In order to minimize this risk, your child will be spotted by the investigators.

5. a. **Benefits to volunteer:** You & your child will gain a better understanding of the research process.

   b. **Potential benefits to society:** Your child's participation in this study will benefit society by improving clinicians' understanding of the effects of age on balance, and the effectiveness of balance training programs among children.

_______________________________ _______________________________
Parent/Guardian Date Investigator Date

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY

5. Alternative procedures which could be utilized: None

6. Time duration of the procedures and study:

Your child's participation will take approximately 1-2 hours.

7. Statement of confidentiality:

Your child's participation in this research is confidential. Only the investigators will have access to your child's identity and to information that can be associated with his/her identity. In the event of publication of this research, no personally identifying information will be disclosed.

8. Right to ask questions:

You may ask any questions about the research procedures and the questions will be answered. Further questions should be directed to Sheri Hale at sah193@psu.edu or 814-865-7936 (office). You may also contact the Office for Research Protections at 814-865-1775 for questions about your child's rights as a research participant. You also may decline to answer any questions the researchers ask you.

9. Compensation:

There is no compensation, financial or otherwise, for participating in this study.

11. Injury Clause:

Medical care is available in the event of an injury resulting from research but neither financial compensation nor free medical treatment is provided. You are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators.

11. Voluntary participation:

Your child's participation in this study is voluntary, and you may withdraw him/her from this study at any time by notifying the investigator. Your child's withdrawal from this study or refusal to participate will in no way affect your child's care or access to medical services.

This is to certify that I consent to and give permission for my child's participation as a volunteer in this program of investigation. I have been given an opportunity to ask any questions I may have and all such questions or inquiries have been answered to my satisfaction. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

____

Parent/Legal Guardian Date

I, the undersigned, have defined and explained the studies involved to the above volunteer.

____

Investigator Date

ORP USE ONLY:
The Pennsylvania State University
Office for Research Protections

Approval Date:
Expiration Date:

Biomedical Institutional Review Board

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY: 6-7 y/o control
The Pennsylvania State University

Title of Project: Postural control through childhood development (IRB# 17260)

Principal Investigator: Sheri Hale, PT, ATC
266 Recreation Building
University Park, PA 16802
sah193@psu.edu
814-865-7936

Other Investigator: Jay Hertel, PhD, ATC
266 Recreation Building
University Park, PA 16802
jnh3@psu.edu
814-865-8816

This is to certify that I, ___________________, on behalf of my minor child ________________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Sheri Hale.

1. **Purpose of the study:**

The study in which your child will be participating is designed to examine: 1) differences in balance related to age and 2) determine the effects of a six-week balance training programs on balance while standing still and during activity.

2. **Procedures to be followed:**

If your child takes part in this study, he/she will complete two sessions. During the first session (approximately 1 hour), he/she will have his/her height and weight measured and will perform tests of balance, as in pictures shown below. With your assistance, your child will fill out 2 surveys assessing fear of falling and activity level. He/she will repeat the same tests six weeks later.

3. **Discomforts and risks:**

In participating in this study, your child may experience slight discomfort similar to that associated with light to moderate levels of exercise. There is also the possibility that he/she may lose his/her balance during balance testing. However, the likelihood of this is no greater than the likelihood of losing one's balance during activities of daily living that require single leg stance (climbing the stairs or stepping up onto a curb) or walking/standing on unsteady surfaces (grass, snow, uneven ground). In order to minimize this risk, your child will be spotted by the investigators.

6. a. **Benefits to volunteer:** You and your child will gain a better understanding of the research process.

b. **Potential benefits to society:** Your child's participation in this study will benefit society by improving clinicians' understanding of the effects of age on balance, and the effectiveness of balance training programs among children.

_________________________________ _________________________________
Volunteer Date Investigator Date

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY

5. **Alternative procedures which could be utilized:** None

6. **Time duration of the procedures and study:**
Your child's participation will take approximately 2-3 hours over 2 sessions.

7. **Statement of confidentiality:**
Your child's participation in this research is confidential. Only the investigators will have access to your child's identity and to information that can be associated with your child's identity. In the event of publication of this research, no personally identifying information will be disclosed.

8. **Right to ask questions:**
You may ask any questions about the research procedures and the questions will be answered. Further questions should be directed to Sheri Hale at sah193@psu.edu or 814-865-7936 (office). You may also contact the Office for Research Protections at 814-865-1775 for questions about your rights as a research participant. You also may decline to answer any questions the researchers ask you.

9. **Compensation:**
There is no compensation, financial or otherwise, for participating in this study.

12. **Injury Clause:**
Medical care is available in the event of an injury resulting from research but neither financial compensation nor free medical treatment is provided. You are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators.

11. **Voluntary participation:**
Your child's participation in this study is voluntary, and you may withdraw him/her from this study at any time by notifying the investigator. Your child's withdrawal from this study or refusal to participate will in no way affect his/her care or access to medical services.

This is to certify that I consent to and give permission for my child's participation as a volunteer in this program of investigation. I have been given an opportunity to ask any questions I may have and all such questions or inquiries have been answered to my satisfaction. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

____

Parent/Legal Guardian Date

I, the undersigned, have defined and explained the studies involved to the above volunteer.

____

Investigator Date

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The Pennsylvania State University
Office for Research Protections

Approval Date:
Expiration Date:

Biomedical Institutional Review Board

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY: 6-7 y/o Exercise Group
The Pennsylvania State University

Title of Project: Postural control through childhood development (IRB #17260)

Principal Investigator: Sheri Hale, PT, ATC
266 Recreation Building
University Park, PA 16802
sah193@psu.edu
814-865-7936

Other Investigators: Jay Hertel, PhD, ATC
266 Recreation Building
University Park, PA 16802
jnh3@psu.edu
814-865-8816

This is to certify that I, ____________________, on behalf of my minor child _________________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Sheri Hale.

1. **Purpose of the study:**

The study in which your child will be participating is designed to examine: 1) differences in balance related to age and 2) the effects of a six-week balance training programs on balance among children.

2. **Procedures to be followed:**

If your child takes part in this study, he/she will participate in 14 sessions for a total of eight hours. During the first visit (approx 1 hour) your child will have his/her height and weight measured and will perform tests of balance (as seen below). With your help, he/she will also fill out 2 surveys that assess fear of falling and activity level.

_______________________________ _______________________________
Volunteer Date Investigator Date

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY

He/she will then begin a 6 week balance training program. The program includes 2 sessions per week (each approximately 30 minutes long). The balance training program will include several exercises aimed at improving balance (examples are shown below). The training program also includes hopping, jogging, and side-stepping exercises. After completing the 6 week training program, your child will repeat the testing he/she completed on the first day.








3. **Discomforts and risks:**

In participating in this study, your child may experience slight discomfort similar to that associated with light to moderate levels of exercise. There is also the possibility that he/she may lose his/her balance during balance testing or training. However, the likelihood of this is no greater than the likelihood of losing one's balance during activities of daily living that require single leg stance (climbing the stairs or stepping up onto a curb) or walking/standing on unsteady surfaces (grass, snow, uneven ground). In order to minimize this risk, all subjects will be spotted/supervised by the investigator.

4a. Benefits to you/your child: You & your child will gain a better understanding of the research process and your child will be provided with a supervised balance training program.

4b. Potential benefits to society: Your child's participation in this study will benefit society by improving clinicians' understanding of the effects of age on balance, and the effectiveness of balance training programs among children.

Volunteer Date Investigator Date

INFORMED CONSENT FORM FOR CLINICAL RESEARCH STUDY

5. **Alternative procedures which could be utilized:** None

6. **Time duration of the procedures and study:**
Your child's participation will take approximately 8 hours over approximately 6 weeks.

7. **Statement of confidentiality:**
Your child's participation in this research is confidential. Only the investigators will have access to your child's identity and to information that can be associated with your child's identity. In the event of publication of this research, no personally identifying information will be disclosed.

8. **Right to ask questions:**
You may ask any questions about the research procedures and the questions will be answered. Further questions should be directed to Sheri Hale at sah193@psu.edu or 814-865-7936 (office). You may also contact the Office for Research Protections at 814-865-1775 for questions about your rights as a research participant. You also may to decline to answer any questions the researchers ask you

9. **Compensation:**
There is no compensation, financial or otherwise, for participating in this study.

13. **Injury Clause:**
Medical care is available in the event of an injury resulting from research but neither financial compensation nor free medical treatment are provided. You are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators.

11. **Voluntary participation:**
Your child's participation in this study is voluntary, and you may withdraw him/her from this study at any time by notifying the investigator. Your child's withdrawal from this study or refusal to participate will in no way affect your child's care or access to medical services.

This is to certify that I consent to and give permission for my child's participation as a volunteer in this program of investigation. I have been given an opportunity to ask any questions I may have and all such questions or inquiries have been answered to my satisfaction. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

____
Parent/Legal Guardian Date

I, the undersigned, have defined and explained the studies involved to the above volunteer.

____
Investigator Date

Appendix B

Assent Forms

9-10 year old
6-7 year old

Assent Script and Witness Form: 9-10 y/o

Script:

Your mom/dad is allowing you to help in a project about balance. This project looks at how balance changes with age. It is also going to look at how practicing balance affects balance. If you participate in this project, you will be asked to complete one session that will last approximately 1-2 hours. You will complete 3 balance tests that include things like:

stand on one foot & on 2 feet
reach as far as you can with your hand/foot
stand up & sit down
stand with your eyes open & closed
pick up a toy from the floor
tap a stool with your foot

You will also be asked to answer a few questions about how much physical activity you do each week and how steady you feel when doing different activities.

This is to certify that I, ______________________ was present for the oral delivery of the above information to ____________________. The child appeared to understand all of the information delivered and gave clear assent to participate in this study.

____
Witness Date

I, the undersigned, have defined and explained the study to the above volunteer.

____
Investigator Date

ORP USE ONLY:
The Pennsylvania State University
Office for Research Protections

Approval Date: 02/05/04 M. Becker

Expiration Date: 11/24/04 M. Becker

Biomedical Institutional Review Board

Assent Script and Witness Form: 6-7 y/o

Script:
Your mom/dad is allowing you to help in a project about balance. Balance is what stops you from falling down when you walk, climb, and play. If you help in this project, your balance will be measured twice. You will be asked to do things like:

stand on one foot & on 2 feet
reach as far as you can with your hand/foot
stand up & sit down
stand with your eyes open & closed
pick up a toy from the floor
tap a stool with your foot

You will also be asked to answer a few questions about how much you play during the day and if you feel like you are going to fall when you play. You may also meet with me two times each week to practice balancing. If you do that, you will be asked to do things like:

play catch while standing on 1 or 2 feet
walk in different directions, at different speeds, and/or on different cushions
pretend you're kicking a ball
jumping
stepping over toys
play red light-green light

This is to certify that I, ______________________ was present for the oral delivery of the above information to ______________________. The child appeared to understand all of the information delivered and gave clear assent to participate in this study.

____
Witness Date

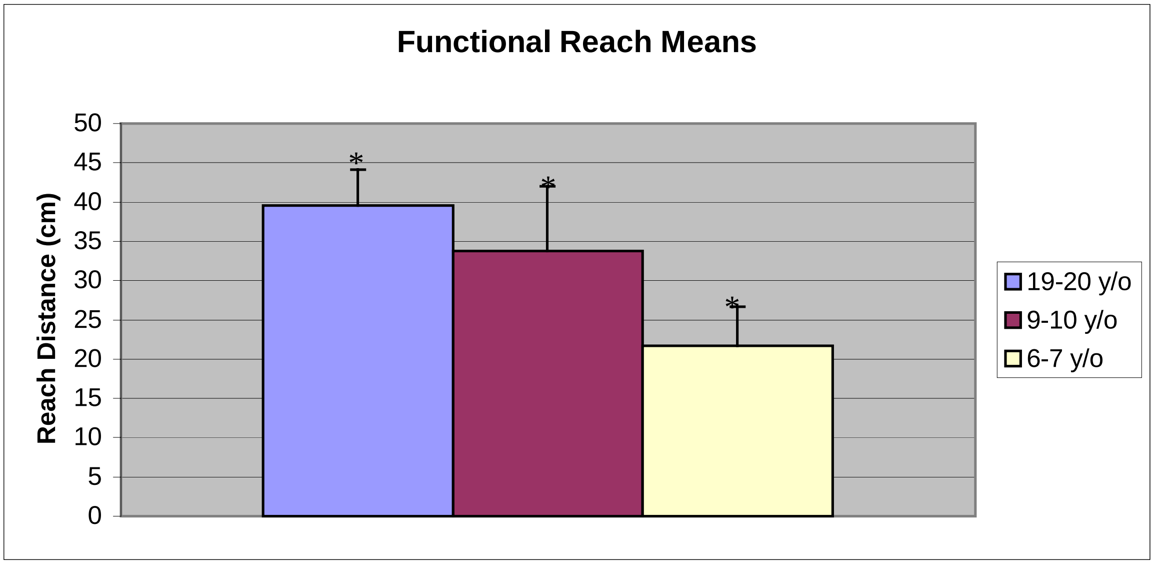
I, the undersigned, have defined and explained the study to the above volunteer.

____
Investigator Date

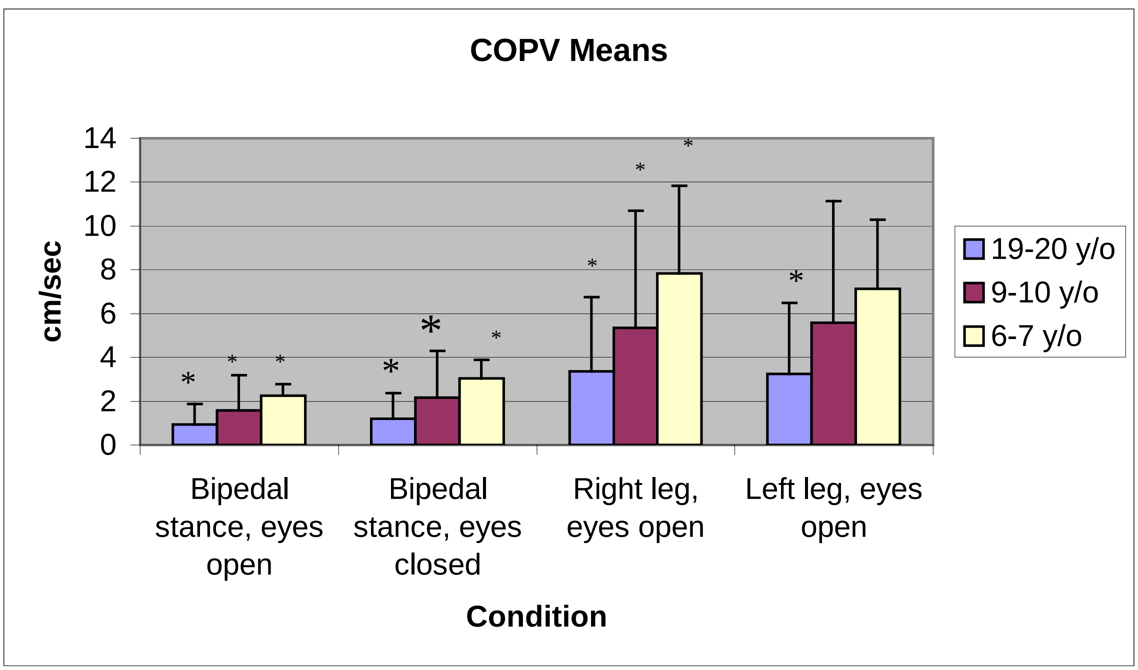
Appendix C

Results Figures from Chapter 4

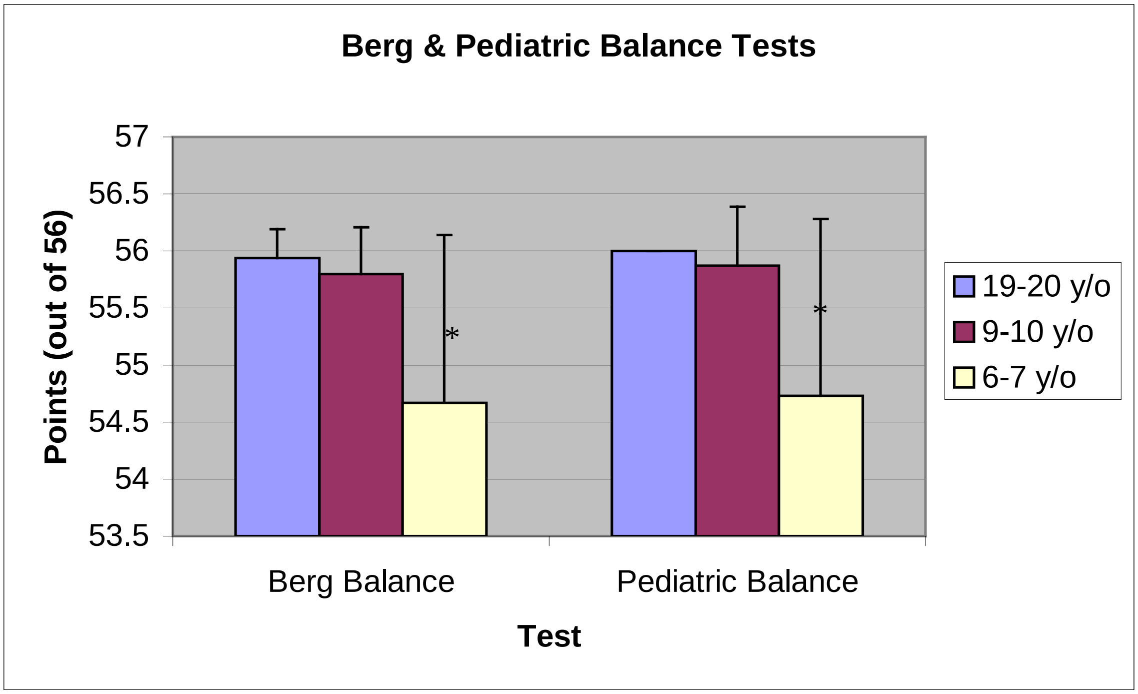
Functional Reach
COPV
Berg Balance Scale
Pediatric Balance Scale
Activities-Specific Balance Confidence Scale



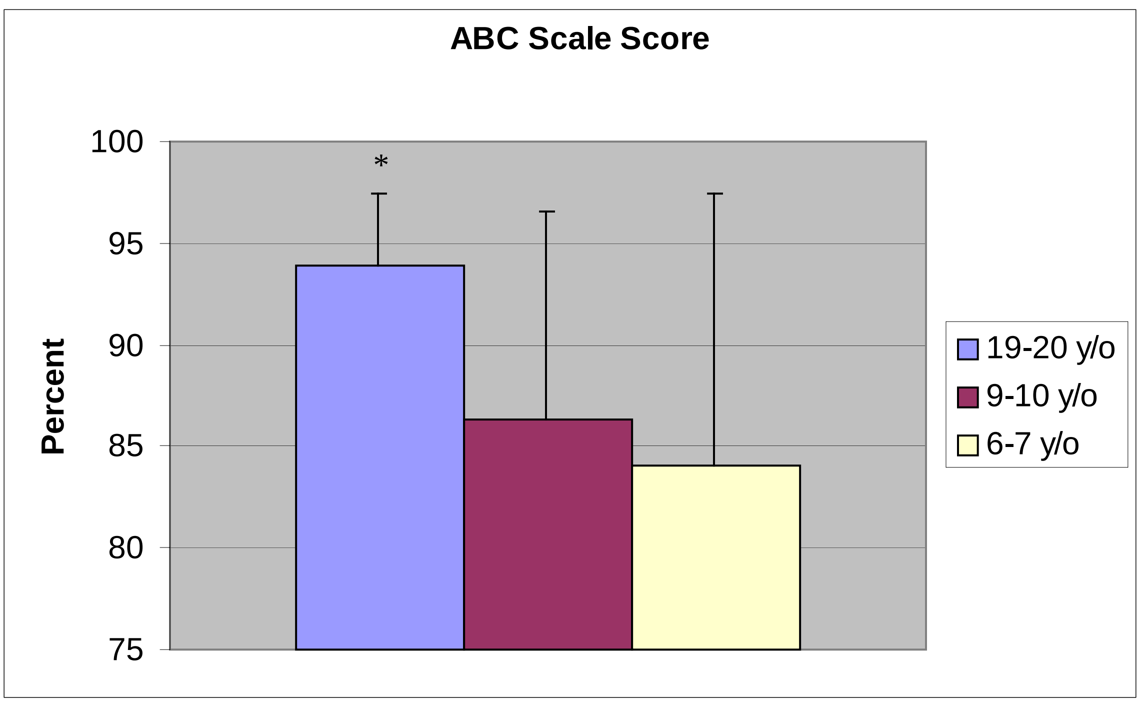
* = significantly different than all groups



* = significantly different than all groups



* = significantly different than all groups

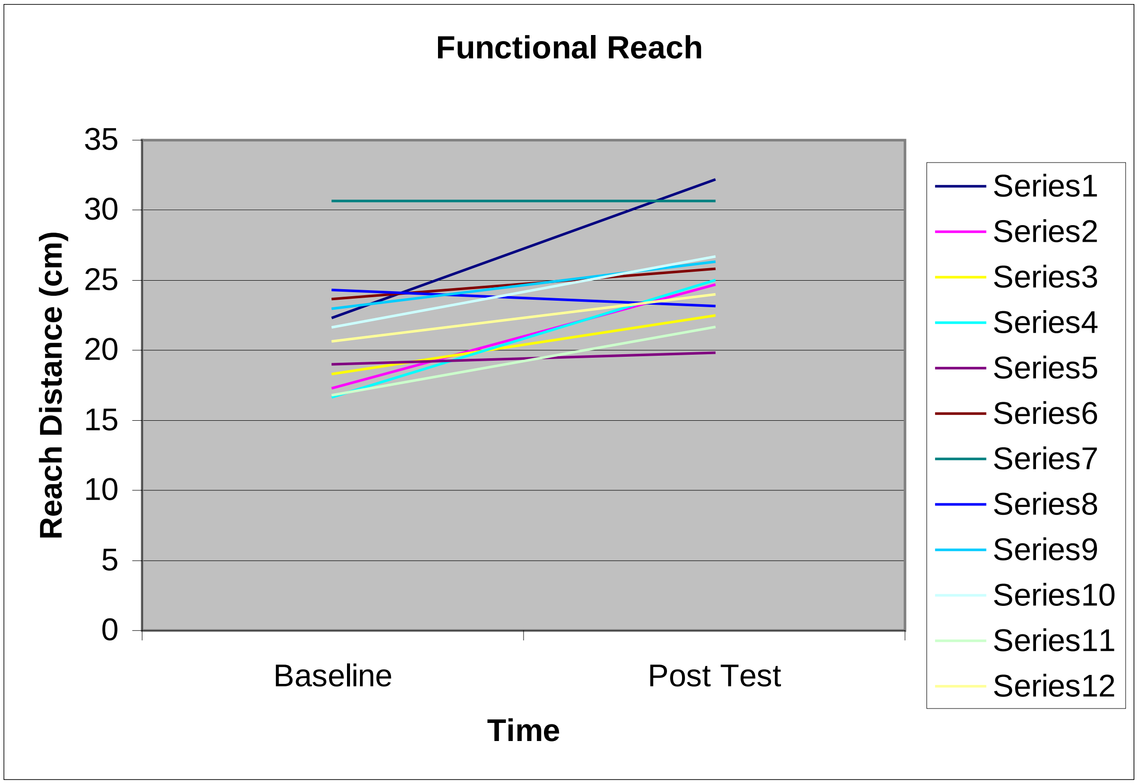


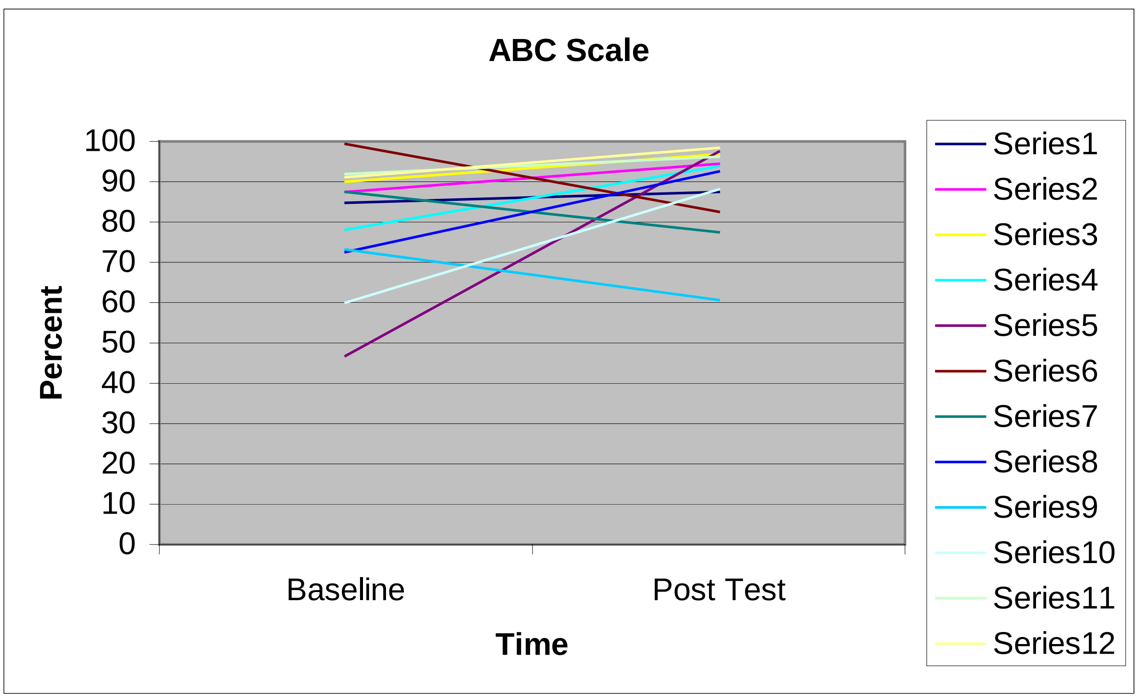
* = significantly different than all groups

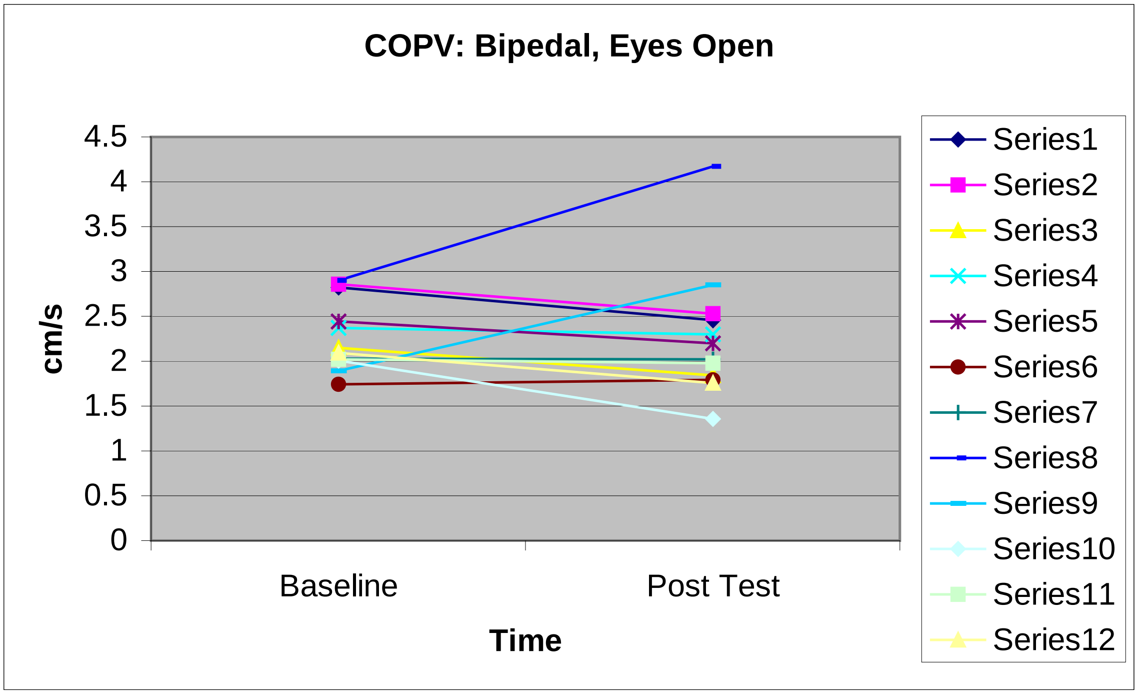
Appendix D

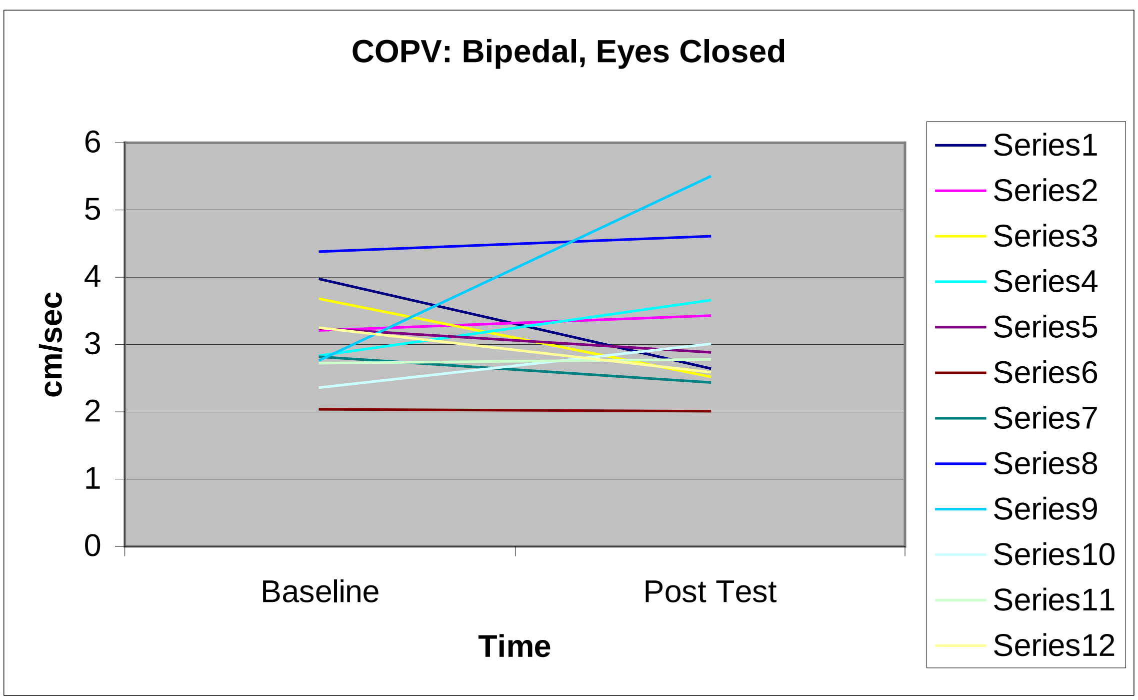
Individual Performance Changes after Training

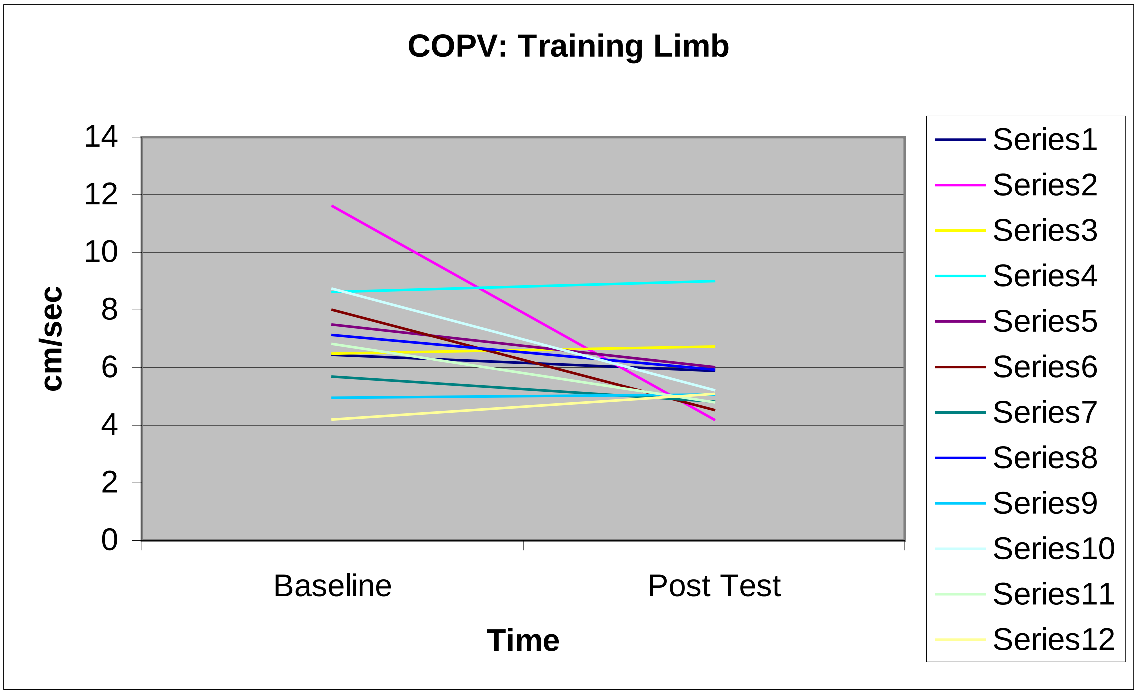
Functional Reach
Activities-Specific Balance Confidence Scale
COPV
Berg Balance Scale
Pediatric Balance Scale

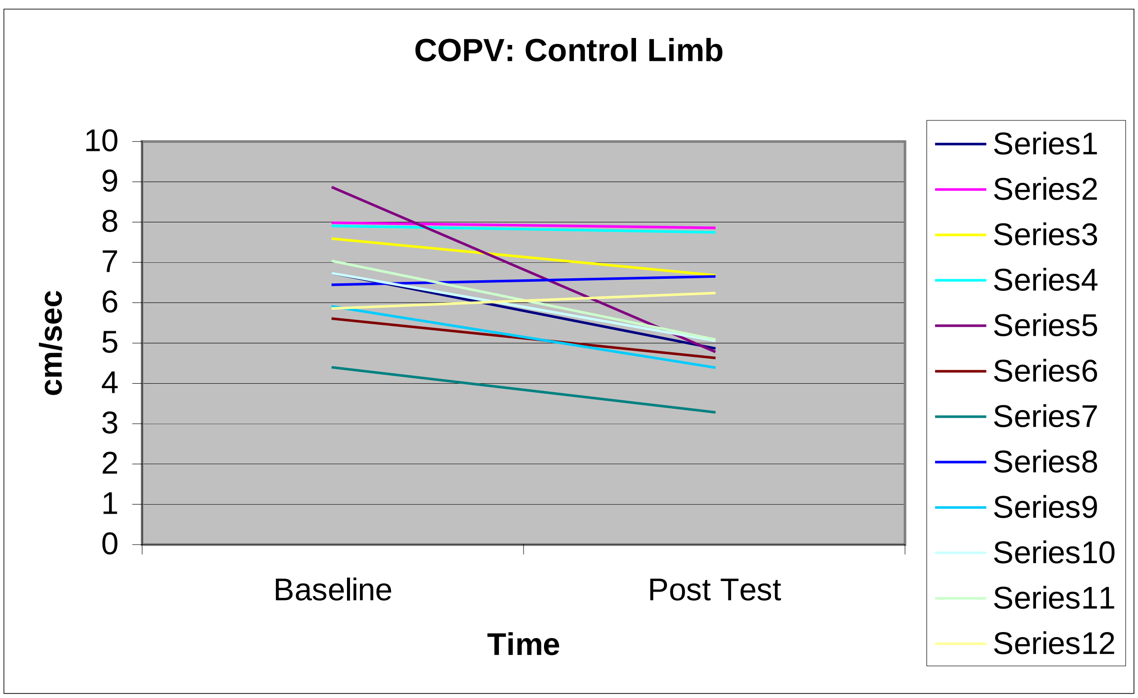

Functional Reach
Reach Distance (cm)
35
30
25
20
15
10
5
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12

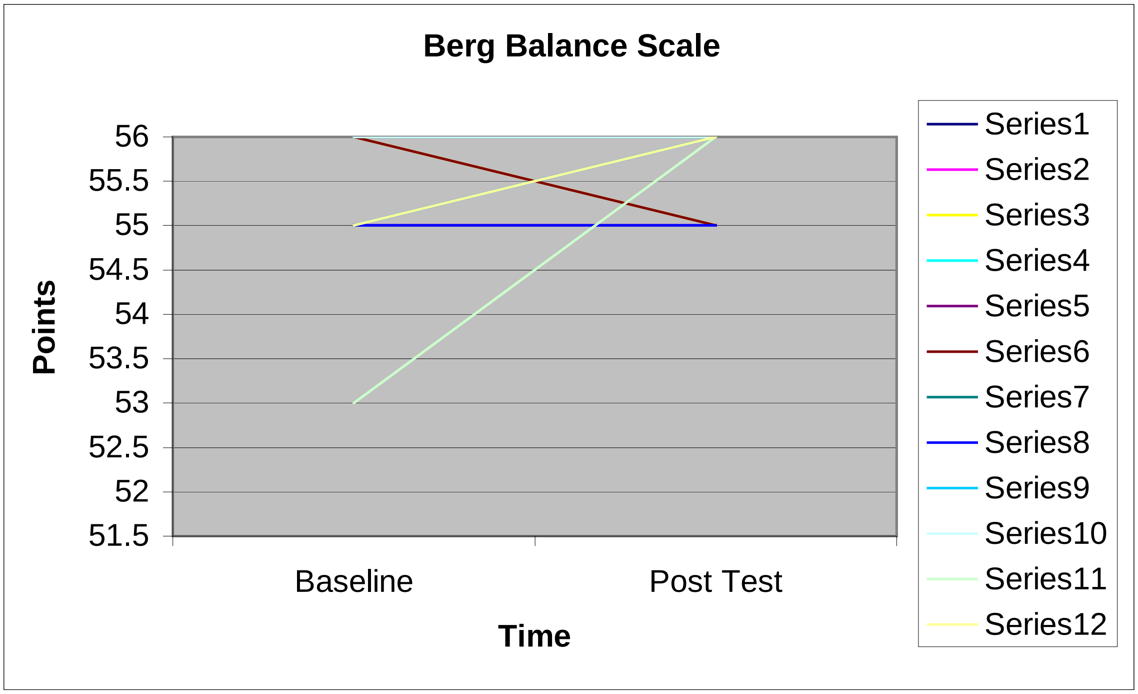

ABC Scale
Percent
100
90
80
70
60
50
40
30
20
10
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12

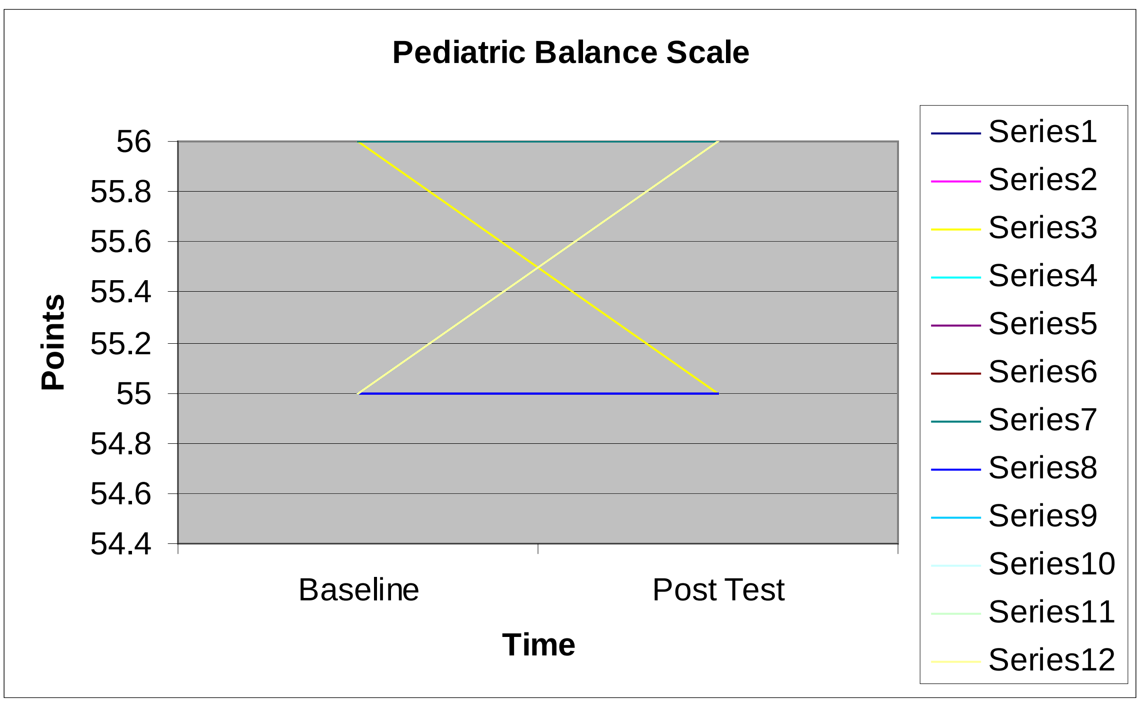

COPV: Bipedal, Eyes Open
cm/s
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12


COPV: Bipedal, Eyes Closed
cm/sec
6
5
4
3
2
1
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12


COPV: Training Limb
cm/sec
14
12
10
8
6
4
2
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12


COPV: Control Limb
cm/sec
10
9
8
7
6
5
4
3
2
1
0
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12


Berg Balance Scale
Points
56
55.5
55
54.5
54
53.5
53
52.5
52
51.5
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12


Pediatric Balance Scale
Points
56
55.8
55.6
55.4
55.2
55
54.8
54.6
54.4
Baseline
Post Test
Time
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12

Vita: Sheri Anne Hale

Education

2001-present	**The Pennsylvania State University** Doctor of Philosophy: Kinesiology, to be conferred August, 2004 Dissertation: Postural Control in Children and Young Adults	University Park, PA
1999-2001	**The University of Pittsburgh** Master of Physical Therapy, conferred June, 2001	Pittsburgh, PA
1995-1999	**The Pennsylvania State University** Schreyer Honors College Bachelor of Science: Kinesiology: Athletic Training, conferred May, 1999	University Park, PA

Professional Experience

5/03 – present	**Children's Hospital of Philadelphia** Pediatric Physical Therapist	Philadelphia, PA
9/01 – present	**Infant Evaluation Program** Early Intervention Physical Therapist	State College, PA
08/01 – 05/04	**The Pennsylvania State University** Department of Kinesiology Co-Instructor – Medical Aspects of Athletic Training Lead Instructor - Emergency Care Teaching Assistant – Administrative Aspects of Athletic Training	University Park, PA
6/01 – 08/02	**The Pennsylvania State University** Department of Athletics Athletic Trainer – Summer Camps	University Park, PA
12/99 – 4/00	**NW Rehabilitation Services, Inc.** Athletic Trainer - Amateur Penguins Youth Hockey	Pittsburgh, PA

Publications

Hertel J, Denegar CR, Johnson PD, **Hale SA**, Buckley WE. Reliability of the Cybex Reactor in the assessment of an agility task. *Journal of Sport Rehabilitation* 8(1): 24-31, 1999.

Rothermel SA, **Hale SA**, Hertel J, Denegar CR. Effect of active foot positioning on the outcome of a balance training program. *Physical Therapy in Sport*. 5(2): 98-103, 2004.

Hale SA. Etiology of patellar tendinopathy in athletes. *Journal of Sport Rehabilitation.* (in review)

Hale SA, Hertel J. Reliability and sensitivity of the Foot and Ankle Disability Index in subjects with chronic ankle instability. *Journal of Athletic Training.* (in review)