AN ABSTRACT OF THE THESIS OF

Jennifer Ann Overlock for the degree of Masters of Science in Movement Studies in Disability presented on July 30, 2004.

Title: The Relationship between Balance and Fundamental Motor Skills in Children Five to Nine Years of Age

Redacted for Privacy

Abstract approved: ______________________
Joonkoo Yun

The ability to establish and maintain balance is claimed to be an important prerequisite of movement tasks. However, despite this general belief, there is limited empirical evidence to support the contribution of balance in motor skill performance. Furthermore, psychometric properties of using a computerized force platform to assess balance ability for children have not been well examined. Therefore, the purpose of this study was two fold. First, the psychometric properties of static and dynamic balance performance measures in children using the NeuroCom SMART Balance Master® System were examined. Second, the relationship between the ability to balance and fundamental motor skill performance of locomotor and object control skills in children was assessed.

Psychometric properties were examined with a total of 57 children five to nine years old. Validity evidence was examined with correlations between balance performances and age on both static and dynamic balance and locomotor and object control skills. The results revealed a significant relationship between age and balance performance for static unilateral stance on the left foot (r = -.40, p < .01), right foot (r = -

.43, $p < .01$), and dynamic tandem walk's speed ($r = .43$, $p < .01$). There, however, was no significant relationship between age and balance performance for tandem walk's step width ($r = -.23$, $p > .05$) and end sway ($r = .05$, $p > .05$). Reliability was estimated with test-retest reliability with twenty-nine children. The reliability coefficients of these balance measures revealed that children's unilateral stance on the left and right foot were $ICC_{(2,2)} = .84$ and $ICC_{(2,2)} = .75$, respectively. Also, the results indicated that the tandem walk's step width ($ICC_{(2,2)} = .57$) and end sway ($ICC_{(2,2)} = .44$) were low.

The relationship between balance and fundamental motor skill performance was examined with 56 children. All children performed the static and dynamic test of balance, and both a qualitative and quantitative aspect of kicking and jumping skills were measured. Canonical correlations revealed a significant relationship between static balance ability and kicking ($R_c = .48$, $p < .01$) and jumping ($R_c = .45$, $p < .05$) performance. Dynamic balance was significantly related to kicking performance ($R_c = .45$, $p < .05$), however no relationship to jumping performance ($R_c = .32$, $p > .05$). These results suggest that balance performance and motor skill performance are moderately associated with each other in children five to nine years of age. The inconsistent relationship between dynamic balance and motor skill performance appears to be related to measurement issues associate with the dynamic balance assessment.

The Relationship between Balance and Fundamental Motor Skills in Children Five to Nine Years of Age

by
Jennifer Ann Overlock

A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented July 30, 2004
Commencement June 2005

Master of Science thesis of Jennifer Ann Overlock presented on July 30, 2004.

APPROVED:

Redacted for Privacy

Major Professor, representing Movement Studies in Disability

Redacted for Privacy

Chair of the Department of Exercise and Sport Science

Redacted for Privacy

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for Privacy

Jennifer Ann Overlock, Author

ACKNOWLEDGEMENTS

I would like to thank Dr. Joonkoo Yun, my major professor and thesis advisor, for his patience, guidance, commitment, writing ability, time, and the ability to follow my thought processes throughout this journey. Your dedication to this project is greatly appreciated. To Dr. Jeff McCubbin for all your encouragement and insight. To Dr. Mark Hoffman and Dr. Ron Metoyer, thank you for your assistance and guidance during this study. I extend my sincere appreciation.

I would like to thank all the professors who have taught me during my graduate study.

A hugh thanks to Kirsten Ru for being so helpful and available in all the data collection process. To Soyeun Kim for assisting in the coding of data. Thanks to all my participants and for KidSpirit in assisting me throughout my recruitment process.

Thanks to Sasha for all the phone calls and visits. To my dear Corvallis friends, Jessica and Robyn, besides two great running buddies a person can ask for, you both have kept me focused throughout this process. Thank you for making my time in Corvallis so enjoyable.

To my Father, Mother, Julie, Grandma Nelly, and Grandma Helen for supporting me throughout my time here in Oregon. I am glad I will now be home to celebrate all our special occasions together.

CONTRIBUTION OF AUTHORS

Dr. Joonkoo Yun was involved in the data collection, data analysis, and writing of this manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

THE RELATIONSHIP BETWEEN BALANCE AND FUNDAMENTAL MOTOR SKILLS IN CHILDREN FIVE TO NINE YEARS OF AGE

CHAPTER 1: INTRODUCTION

BACKGROUND

Fundamental motor skills are the foundation of complex movements for sports and recreational skills. They consist of object control and locomotor skills. Typically mastered during childhood, if children do not acquire these fundamental motor skills, they may have a difficult time enjoying physical activities that contribute to a healthy active lifestyle (DeOreo & Keogh, 1980). According to the National Association for Sport and Physical Education (2001), teaching fundamental motor skills is one of the most important foundations established for young children to lead a physically active lifestyle and enhances a child's social, cognitive, and physical development.

Balance is defined as the ability to control the body's position in space to maintain upright in a given environment (Shumway-Cook & Woollacott, 2001). There are many claims that balance is believed to be an important prerequisite for the development and acquisition of fundamental motor skills (Gabbard, 2000; Massion, 1992; Shumway-Cook & Woollacott, 1985; Sveistrup & Woollacott, 1996; Woollacott, 2002; Woollacott, Debu, & Mowatt, 1987). For example, Hoffman and Koceja (1997) argued "dynamic balance inherently relates to function, since motion and perturbation from a static stance both rely heavily on dynamic postural control mechanisms" (p. 290). From an early age, balance is a key part of the ability to move. According to Gallahue and Ozman (2002), during infancy a child must establish the relationship of his or her body to gravity to achieve an upright sitting and erect standing posture. Woollacott (2002) cited, Amiel-Tison and Grenier's (1980) work, which gave evidence to support the hypothesis that balance is critical to motor skill development. They found when stabilizing an infant's head, the infant was able to reach for an object whereas not otherwise able to perform this task without the postural control of the head and trunk. Therefore, developing an adequate level of balance is an important aspect of performing functional activities. This is observed in programs designed to facilitate motor skill performance, which commonly include balance activities. However in the literature this assumption is not strongly supported.

Despite the general belief that balance has presented itself to be a prerequisite for movement, there is limited empirical evidence to support the contribution of balance to fundamental motor skills. A few studies support the relationship between balance and motor performance (e.g., Era, Avlund, Jokela, Gause-Nilsson et al., 1997; Liao & Hwang, 2003), whereas some others do not support the relationship between these two variables (e.g., Owings, Pavol, Fole, & Grabiner, 2000; Shimada, Obuchi, Kamide, Shiba, & Okamoto, 2003). These studies contain methodological and/or interpretational limitations to examine this relationship as well.

If balance is an essential part of voluntary movement, finding ways to accurately measure children's balance ability is important to effectively assess motor performance. Common ways of assessing balance include both static and dynamic aspects found in field based motor assessment tools for children (e.g., Adapted Physical Education Assessment Scale: LAUSD, 1984; Bruininks-Oseretsky Test of Motor Proficiency:

Bruninks, 1978). For example, Bruininks-Oseretsky Test of Motor Proficiency (1978) assessment measures a child's ability to walk heel-to-toe across a straight balance beam, among other methods. However, field tests, although widely used, lack accuracy, precision, and adequate psychometric properties to describe and evaluate children's balance ability. Advances in technology have created multifaceted measurement systems that provide the ability to measure movement through ground reaction forces and center of pressure (COP) movements through force platforms and by controlled platforms, which have greatly enhanced the capability to quantify balance ability (e.g., NeuroCom, Cybex Fastex, Kistler, Biodex). These commercially available computerized force platforms are assumed to offer accurate and precise documentation of postural control.

Computerized force platforms are commonly used for adult populations, and have psychometric evidence to support their use with this population (e.g., Clark, Rose, & Fujimoto, 1997; Ford-Smith, Wyman, & Elswick, 1995; Rose & McKillop, 1998). However, reliability and validity have not been well examined for children for these apparatuses (Cambier, Cools, Danneels, & Witvrouw, 2001; Liao, Mao, & Hwang, 2001; Rose & McKillop, 1998).

There were two purposes of this present study. First, the reliability and validity of outcome measures from a computerized force platform in children were examined. Second, the relationship between balance and fundamental motor skill performance of locomotor and object control skills in children using more comprehensive assessment approaches in both balance and fundamental motor skills was assessed. Through the findings of this study, accurate estimations of the use of computerized force platforms with children were assessed and acknowledgement of the components necessary for successful fundamental motor skill performance was investigated. These outcomes are important for researchers using computerized force platforms with children and for physical education teachers who teach children fundamental motor skills, to understand the essential underlying factors of performance for successful teaching, planning, and perhaps early detection of motor deficits.

Research Questions

The following research questions were examined in this study:

1. Do children demonstrate reliability and validity for static balance assessments on a computerized force platform?
2. Do children demonstrate reliability and validity for dynamic balance assessments on a computerized force platform?
3. Is there an association between static balance and jumping performance?
4. Is there an association between dynamic balance and jumping performance?
5. Is there an association between static balance and kicking performance?
6. Is there an association between dynamic balance and kicking performance?

Assumptions

1. All participants performed to the best of their ability.
2. Fundamental motor skills are accurately measured by the total body approach.
3. NeuroCom Smart Balance Master® provides accurate balance assessments for static and dynamic balance.
4. Unilateral stance test of the NeuroCom measures static balance.

5. Tandem walk test of the NeuroCom measures dynamic balance.

Delimitations

1. Delimited to 57 participants with ages ranging from five to nine years old.
2. Delimited to residents of Corvallis, Oregon and local surrounding areas.
3. Random sampling is not possible due to the availability of participants.

DEFINITIONS

Balance: The ability to control the center of gravity over the base of support in a given environment.

Balance Master®: A computerized static and dynamic force platform system for balance assessments and retraining.

Base of Support: The surfaces of the body which experience pressure as a result of body weight and gravity, and the projected area between them.

Center of Gravity: An imaginary point in space about which the sum of the forces acting on the body equals zero; center of mass.

Center of Pressure: The point at which the sum of all the force in the x and y direction that a standing individual exerts on a force platform surface.

Dynamic Balance: The ability to move and control the center of gravity within a moving base of support.

Fundamental Motor Skills: Basic movement patterns (e.g., walk, run, jump, leap, hop, skip, kick, throw, catch, strike) that form the foundation for more advanced and specific movement activities.

Limit of Stability: The boundary or range which is the furthest distance in any direction a individual can lean from the vertical standing position without changing the original base of support by stepping, reaching, or falling.

Postural Control: The ability to control the body's position in space for the dual purposes of stability and orientation.

Postural Sway: Center of gravity sway velocity in the anterior-posterior and lateral directions.

Postural Orientation: Ability to maintain an appropriate relationship between the body segments and the environment for a task.

Stability: The maintenance of an upright posture during quiet stance.

Static Balance: The ability to limit the movement of the center of gravity within the fixed base of support.

Total Body Approach: Observational approach which breaks down fundamental motor skills into sequences of developmental stages, were the whole body progresses in each stage.

CHAPTER 2

Reliability and Validity of Static and Dynamic Balance Measurements in Children Using a Computerized Force Platform

Jennifer Ann Overlock

ABSTRACT

Purpose: To examine the psychometric properties of static and dynamic balance performance measures in children five to nine years of age using a computerized force platform.

Methods: Fifty-seven elementary-aged school children (42 girls and 15 boys) with no documented physical or mental disabilities performed one static and one dynamic test of balance. Validity evidence was examined with correlation between balance performance and age, and reliability was estimated with test-retest reliability with 29 of the children.

Results: The results of this study revealed a significant relationship between age and balance performance for static unilateral stance on the left foot ($r = -.40$, $p < .01$), right foot ($r = -.43$, $p < .01$), and dynamic tandem walk's speed ($r = .43$, $p < .01$). There, however, was no significant relationship between age and balance performance for dynamic tandem walk's step width ($r = -.23$, $p > .05$) and end sway ($r = .05$, $p > .05$). The reliability coefficients of these balance measures ranged from low to high for children's performance, where the measures for unilateral stance on the left and right foot were $ICC_{(2,2)} = .84$ and $ICC_{(2,2)} = .75$, respectively. Also, the results indicated that the tandem walk's speed ($ICC_{(2,2)} = .87$) demonstrated an adequate level of reliability, whereas tandem walk's step width ($ICC_{(2,2)} = .57$) and end sway ($ICC_{(2,2)} = .44$) were low.

Conclusions: Computerized force platform assessments were an appropriate method to measure static balance in children five to nine years of age, however were problematic for dynamic balance.

INTRODUCTION

The development of the ability to establish and maintain balance is claimed to be an important prerequisite of almost every movement task (Burton & Davis, 1992; Gabbard, 2000; Massion, 1992; Shumway-Cook & Woollacott, 1985; Sveistrup & Woollacott, 1996; Woollacott, 2002; Woollacott, Debu, & Mowatt, 1987). Balance is defined as the ability to control the body's position in space to maintain upright in a given environment (Shumway-Cook & Woollacott, 2001). All voluntary movements, even the simple tasks of standing and walking, involve an element of balance to control the body against gravitational forces (Bril & Breniere, 1993). From an early age, balance is a key part of the ability to move. Woollacott (2002) cited Amiel-Tison and Grenier's (1980) work, which gave evidence to support the hypothesis that balance is critical to motor skill development. They found when stabilizing an infant's head, the infant was able to reach for an object whereas not otherwise able to perform this task without the postural control of the head and trunk. Therefore, developing an adequate level of balance is an important aspect of performing functional activities.

Since balance is an essential part of voluntary movement, finding ways to accurately measure children's balance ability is important to effectively assess motor performance. Measuring static and dynamic aspects of balance has been used in numerous field based motor assessment tools for children (e.g., Adapted Physical Education Assessment Scale, LAUSD, 1984; Bruininks-Oseretsky Test of Motor Proficiency: Bruninks, 1978). For example, the Adapted Physical Education Assessment Scale (1984) measures the amount of time a child remains on one foot without moving the lifted foot and the Bruininks-Oseretsky Test of Motor Proficiency (1978) assessment measures a child's ability to walk heel-to-toe across a straight balance beam. These simple measurement tests, although widely used, lack accuracy, precision, and adequate psychometric properties to describe and evaluate children's balance ability. For example, the Bruininks-Oseretsky Test of Motor Proficiency has a low reliability of r = .45 for their balance measure. Advances in technology have created multifaceted measurement systems that provide the ability to measure movement through ground reaction forces and center of pressure movements through force platforms and by controlled platforms, which have greatly enhanced the capability to quantify balance ability (e.g., NeuroCom, Cybex Fastex, Kistler, Biodex). These commercially available computerized force platforms are assumed to offer accurate and precise documentation of postural control.

In recent years, computer based force platforms have been used in numerous studies for children (e.g., Effgan, 1981; Liao, Mao, & Hwang, 2001; Liao & Hwang, 2003; Foudriat, DiFabio, & Anderson, 1993), however, reliability and validity evidence has not been well examined for children (Cambier, Cools, Danneels, & Witvrouw, 2001; Liao, Mao, & Hwang; 2001, Rose & McKillop, 1998). Reliability evidences for these apparatuses are mainly available for adult populations (e.g., Clark, Rose, & Fujimoto, 1997; Ford-Smith, Wyman, & Elswick, 1995; Rose & McKillop, 1998). Although a few studies examined the psychometric properties for using these apparatuses and have made an important contribution, those studies did not provide comprehensive evidence. For example, Cambier and his colleagues (2001) conducted a study to obtain validity evidence for four and five year old children through comparing children with and without disabilities. They reported children with disabilities performed poorly on the balance tests. However, no reliability data was reported. Effgan (1981) used a computerized force platform to measure unilateral stance in children 7 to 10 years of age. The author states that test-retest reliability was relatively stable, however no coefficient was given. Therefore, it is important to systematically examine both reliability and validity evidence for children because the apparatus was originally designed for adults. Yun and Ulrich (2002) argued that validity and reliability estimation should not be generalized to all populations when the measurements are used for populations with different characteristics. Therefore, the purpose of this present study was to examine the reliability and validity of outcome measures from a computerized force platform apparatus in children five to nine years of age.

METHODS

Participants

Participants in this study were 57 children (42 girls and 15 boys) between the ages of five and nine years old (M = 7.5 years, SD = 1.4 years). Participants were recruited from a university community outreach program and the surrounding community of a small city, located in the Northwest of the United States. All participants were volunteers and no children had physical or mental disabilities. Table 2.1 summarizes the participant's demographic information. In order to estimate test-retest reliability, 29 participants were measured twice within seven days. The investigators' Institutional Review Board approved this study. Written parental consent and participant verbal consent were obtained prior to data collection.

Table 2.1 Demographic Data of Participants (N = 57; girls = 42, boys = 15)

	Participants			
Group	Min.	Max.	M	SD
Age (months)	61	119	89.16	16.42
Height (cm)	104	150	124.80	10.35
Weight (kg)	14	58	25.98	8.32

Instrumentation

The NeuroCom SMART Balance Master® (NeuroCom) System (Smart, 401) is a computer facilitated static and dynamic force platform, and also includes a five-foot long stable force platform. This commercially available apparatus is used to evaluate balance using small variations in the center of pressure obtained during anterior-posterior-lateral movements from postural sway. It uses testing protocols to isolate and measure the different components of balance. For this study, the unilateral stance test and tandem walk test were used because the performance tasks of both tests are highly similar to current field based tests, such as items in the Adapted Physical Education Assessment Scale (1984) and the Bruininks-Oseretsky Test of Motor Proficiency (1978).

Variables and Measures

Unilateral Stance Test® was used to measure static balance. The unilateral stance test involves the participant to stand on a stationary force platform on one leg with hands on his or her hips. The participant performed three 10-second trials with eyes open, on both their left and right foot. Two conditions were tested. Half of the participants started on the left foot, and the other half started on the right foot. A center of gravity (COG) sway velocity score (distance COG traveled for a 10 second trial, expressed in degrees/second) was computed for each trial. The three trial scores for each condition were averaged to compute a mean COG sway velocity (average distance traveled by the COG per the three trials). The dependent measures of this study included the left and right foot mean COG sway velocity.

Tandem Walk Test® was used to measure dynamic balance. The tandem walk test involves the participant to stand on a long force platform and when given a verbal and visual cue, walk heel-to-toe from one end to the other, and then when cued, stand still as quickly and comfortably as possible for 5 seconds. This test was repeated three times, always starting with the same foot back for all trials. Dependent measures for this study included (a) step width (average lateral distance between successive steps), (b) speed (average speed to end of platform), and (c) postural sway velocity at the endpoint (end sway; average COG sway after stopping for 5 seconds).

Procedures

All the participants were measured in a research laboratory. All participants were tested for approximately 20 minutes for both static and dynamic balance measures. The tests were randomized where half of the participants were assessed on the tandem walk test followed by the unilateral stance test. For the other half of the participants, unilateral stance test and then tandem walk test were assessed. Twenty-nine children were tested twice within seven days for test-retest reliability estimation. The testing order was reversed during the second testing session for all the participants. For the second session of the unilateral stance test, starting on the left or right foot was the same as the initial testing session.

Data was collected by the principal investigator, along with one trained research assistant. The child's height and weight were measured prior to data collection. Participants were bare-foot and were provided verbal instruction with unlimited practice time on each test prior to testing, first on the floor, then the platform. There was a three-minute rest period between each test. Testing procedures for all tests were followed as referenced in the NeuroCom Smart Balance Master® operator's manual (NeuroCom International, Inc., 1998).

Data Analysis

Reliability was examined using test-retest with 29 children. Intra-class correlation coefficients (ICC) were calculated using a two-way random analysis of variance design to determine the stability of the balance measures over two testing sessions. In general, ICC values of less than 0.5 can be referred to as indicating poor reliability, between .5 and .75, moderate reliability, and above .75, good reliability (Portney & Watkines, 1993).

To examine validity, Pearson-product movement correlation was used to correlate between age and the results of each balance test measurement. Research has shown that as children age their balance performance improves. Shumway-Cook and Woollacott (1985) found children seven to ten years of age demonstrated better balance compared to children ages four to six years old. Williams, Fisher, and Tritschler (1983) found children eight years of age maintained smoother muscle responses while their balance was disturbed than children four years of age, indicating improved balance performance with age. Data were analyzed using the SPSS 11.5 statistical software package.

RESULTS

Reliability

Reliability was examined by using intra-class correlation (ICC). The results indicated that the COG sway velocity for the left and right foot were $ICC_{(2,2)} = .84$ and $ICC_{(2,2)} = .77$, respectively. Reliability estimations from dynamic balance measurements for step width was $ICC_{(2,2)} = .57$, speed was $ICC_{(2,2)} = .87$, and end sway was $ICC_{(2,2)} = .44$. Table 2.2 summarizes the results of the two sessions.

Table 2.2 Means, Standard Deviations, and Intersession reliability of Balance Outcome Measures for Children.

	Session 1		Session 2		
Measure	M	SD	M	SD	$ICC_{(2,2)}$
Unilateral Stance:					
Left COG sway velocity (deg/sec)	1.20	.32	1.21	.31	.84
Right COG sway velocity (deg/sec)	1.23	.31	1.31	.31	.75
Tandem Walk:					
Step Width (cm)	5.99	.85	5.93	.80	.57
Speed (cm/sec)	22.06	9.16	20.84	7.90	.87
End Sway (deg/sec)	4.52	1.82	4.46	1.19	.44

Validity

Validity evidence was examined from the relationship between age and performance of the five balance measures. The results indicated a significant relationship between age and unilateral stance on the left and right foot, $r = -.40$, $p < .01$ and $r = -.43$, $p < .01$, respectively.

For the tandem walk test, the results indicated a significant relationship between age and speed, $r = .43$, $p < .01$, but the other two variables step width and end sway did not have a significant relationship with age. Table 2.3 summarizes the correlations between age and the balance measures.

Table 2.3 Correlation Matrix between Age and Balance Measures for Children.

	Age	USL	USR	TSW	TS
Unilateral Stance Left (USL)[1]	-.40**				
Unilateral Stance Right (USR)[1]	-.43**	.96**			
Tandem Walk Step Width (TSW)[2]	-.23	.58**	.52*		
Tandem Walk Speed (TS)[2]	.43**	-.15	-.16	-.07	
Tandem Walk End Sway (TES)[2]	.05	.25	.21	.25	.59*

Note: * p < .05 and ** p < .01. [1] indicates a static balance measure, [2] indicates a dynamic balance measure.

DISCUSSION

Static Balance

The results of this investigation suggest unilateral stance on the left and right foot measured by a computerized force platform was appropriate to assess static balance performance in children. The estimated reliability for static balance performance was at an adequate level. The obtained reliability coefficients were higher than previous reported reliability estimated on static balance tests from younger adults and older adults. For example, McGuine, Greene, Best, and Leverson (2000) found a moderate reliability with high school basketball athletes (R = .51) and Ford-Smith, Wyman, & Elswick (1995) reported a ICC = .57 on test-retest reliability for older adults. Based on the current study's results, children can consistently maintain postural sway while standing on one foot.

Validity evidence demonstrated by the correlation between age and static balance performance revealed a significant relationship between these two variables. The current literature in motor development suggests there is a positive relationship between age and balance performance, showing that older children perform better than younger children on balance tests (Roncesvalles, Woollacott, & Jensen, 2001; Shumway-Cook & Woollacott, 1985; Williams, Fisher, & Tritschler, 1983). For example, Shumway-Cook and Woollacott (1985) found children 1 to 2½ years old had larger postural sway than children four to six years old while their balance was perturbed ($p < .01$).

Positive relationships were also found between age and motor skill performance of children. Ulrich (2000) claimed there is a long acknowledged relationship with age and most gross motor performance. He reported correlations between age and motor performance in children three to ten years old were $r = .69$ to $.75$. Cleland and Gallahue (1993) found an improvement with age and movement performance, showing that age contributed to significant differences in movement ($r = .85$).

Balance may not have as high of a relationship to age as motor skill performance does because other factors may be involved in the performance of balance tests. Tasks that require maintaining balance depend on other contributing factors involved to carry out that particular balance task. For example, the static balance task of standing on one foot may involve other components besides age in performance, such as skill, experience, gender, or muscular strength.

Dynamic Balance

Measuring children's dynamic balance performance by the tandem walk test using a computerized force platform appears to be problematic. Only one out of three outcome measures demonstrated a good level of reliability, speed ($ICC_{(2,2)} = .87$). Whereas, reliability estimation for step width was a minimal level ($ICC_{(2,2)} = .57$) and the results of end sway demonstrated poor reliability ($ICC_{(2,2)} = .44$). A previous study estimated reliability of the tandem walk test with adults, demonstrating good reliability for speed (R = .76), step width (R = .75), but poor reliability for end sway (R = .46) (Rose & McKillop, 1998). This suggests that speed for the tandem walk test is a consistent measure of dynamic balance for both children and adults. The reliability coefficients differences between children and adults on step width may be due to the number of steps that need to be taken to complete the task. The length of force platform is 152.4 cm. Since children have a smaller foot size, they may need to take more steps to completely walk across the force platform. Precluding to the possibility of more variability with each step the children need to take may contribute to a lower level of test-retest reliability. Both the results of this study and Rose and McKillop's work suggest lower reliability for the end sway measure. For this measurement, there may be a problem with the fact there is no standardized amount of steps taken. Therefore, as an individual walks heel-to-toe and the computer signals to "hold steady," the individual's foot may be in-flight leading to the movement of the last step on the platform being included in the score the computer is registering for postural sway. This would increase the end sway score for that individual. Tasks designed to measure dynamic balance using the tandem walk test may need a more detailed standardized testing protocol to demonstrate acceptable levels of reliability, such as a specific number of steps to be taken rather than just given the length of the force platform.

Validity evidence examined for dynamic balance had similar results. Only speed from the tandem walk test was significantly related to age. The magnitude of relationship between age and speed was moderate (r = .43) and similar to the static balance performance. Step width and end sway did not significantly correlate with age. Considering the low levels of test-retest reliability of these two measures, it is not a surprise to see no significant relationship. Since reliability estimation is based on the ratio between variance of true and observed scores (Burton & Miller, 1998), obtained scores with lower reliability are more likely random numbers. Age should not be significantly related to a random number.

The results of this study also found there is no relationship between dynamic and static balance performance. Both left and right unilateral stance did not significantly correlate with the tandem walk's speed measure. This finding is similar to previous studies examining the relationship between static and dynamic balance. Drowatzky and Zuccato (1967) looked at different balance assessments with children and found a low correlation between them, ranging from .03 to .31. Hoffman and Koceja (1997) looked at static and dynamic balance using a force platform in young adults and found each test was independent of each other ($r \leq .07$). Although there was a significant relationship between static balance performance and the tandem walk's step width, it is not meaningful to interpretate these results, because step width did not demonstrate an adequate level of reliability or validity. Therefore, the computerized force platform tests were able to distinguish between the different aspects of balance.

Balance is an important part of children's ability to maintain posture and balance during everyday movement (Shumway-Cook & Woolacott, 2001). Although during recent years, numerous studies have used computerized force platforms to accurately examine children's balance performance, there was limited information on the appropriateness of using these apparatuses with children. This study supports the use of the static balance measure for children, but future studies with a more specific testing protocol designed for children are recommended for dynamic balance tests. Also, a reliable and valid test of dynamic balance for children using a computerized force platform needs to be found to assess dynamic balance ability. In addition, this study contributes to the concept that different types of balance tests cannot be looked at together to find a general category for balance control, since each test measures a different aspect of balance. Static and dynamic balance tests create different challenges to the postural control systems and do not provide redundant information. These types of balance measures are not related, therefore measure different aspects of balance function and need to be assessed separately.

REFERENCES

Bril, B., & Breniere, Y. (1993). Posture and independent locomotion in childhood: Learning to walk or learning dynamic postural control. In Savelsbergh, G.J.P. (Ed.), *The development of coordination in infancy* (pp. 337-358). Amsterdam: North-Holland.

Brouwer, B., Culham, E., Liston, R., & Grant, T. (1998). Normal variability of postural measures: Implications for the reliability of relative balance performance outcomes. *Scandinavian Journal Rehabilitation Medicine, 30,* 131-137.

Bruininks, R. (1978). *Bruininks-Oseretsky test of motor proficiency.* Circle Pines, MN: American Guidance Service.

Burton, D.W., & Davis, W.E. (1992). Assessing balance in adapted physical education: Fundamental concepts and applications. *Adapted Physical Activity Quarterly, 9,* 14-46.

Burton, A.W., & Miller, D.E. (1998). *Movement skill assessment.* Champaign, IL: Human Kinetics.

Burton, D.W., & Rodgerson, R.W. (2001). Movement skills and motor abilities. *Adapted Physical Activity Quarterly, 18*, 347-365.

Cambier, D., Cools, A., Danneels, L., & Witvrouw, E. (2001). Reference data for 4- and 5-year old children on the Balance Master: Values and clinical feasibility. *European Journal of Pediatrics, 160*, 317-322.

Clark, S., Rose, D., & Fujimoto, K. (1997). Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. *Archives of Physical Medicine and Rehabilitation, 78*, 1078-1084.

Cleland, F.E., & Gallahue, D.L. (1993). Divergent movement ability. *Perceptual and Motor Skills, 77*(2), 535-544.

Drowatzky, J.N., & Zuccato, F.C. (1967). Interrelationships between selected measures of static and dynamic balance. *Research Quarterly, 38*(3), 509-510.

Effgan, S.K. (1981). Effect of an exercise program on the static balance of deaf children. *Physical Therapy, 61*(6), 873-877.

Era, P., Avlund, K., Jokela, J., Gause-Nilsson, I., Heikkinen, E., Steen, B., & Schroll, M. (1997). Postural balance and self-reported functional ability in 75-year-old men and women: A cross-national comparative study. *Journal American Geriatrics Society, 45*, 21-29.

Ford-Smith, C.D., Wyman, J.F., & Elswick, R.K. (1995). Test-retest reliability of the sensory organization test in noninstitutionalized older adults. *Archives of Physical Medicine and Rehabilitation, 76*(1), 77-81.

Foudriat, B.A., DiFabio, R.P., & Anderson, J.H. (1993). Sensory organization of balance responses in children 3-6 years of age: A normative study with diagnostic implications. *International Journal of Pediatric Otorhinolaryngology, 27*, 255-271.

Gabbard, C.P. (2000). *Lifelong motor development* (3rd ed.). Boston: Allyn and Bacon.

Hoffman, M.A., & Koceja, D.M. (1997). Dynamic balance testing with electrically evoked perturbation: A test of reliability. *Archives of Physical Medicine and Rehabilitation, 78*, 293-293.

Liao, H.F., Mao, P.J., & Hwang, A.W. (2001). Test-retest reliability of balance tests in children with cerebral palsy. *Developmental Medicine and Child Neurology, 42*, 180-186.

Liao, H.F., & Hwang, A.W. (2003). Relations of balance function and gross motor ability for children with cerebral palsy. *Perceptual and Motor Skills, 96*, 1173-1184.

Lindmark, B., Lagerstrom, C., Naessen, T., & Larsen, H. (1999). Performance in functional balance tests during menopausal hormone replacement: A double-blind placebo-controlled study. *Physiotherapy Research International, 4*(1), 43-54.

Los Angles Unified School District. (1984). *Adapted physical education assessment scale-elementary level.* Los Angeles: Division of Special Education.

Massion, J. (1992). Postural control system. *Current Opinion in Neurobiology, 4*, 877-887.

McGuine, T.A., Greene, J.J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*, 239-244.

NeuroCom International, Inc. (1998). *Smart Balance Master operator's manual* (Version 6.1.). Clackamas, OR: NeuroCom International, Inc.

NeuroCom International (n.d.). Computerized Dynamic Posturography. Retrieved May 15, 2003, from http://www.onbalance.com

Portney, L.G., & Watkins, M.P. (1993). *Foundations of clinical research, application to practice.* East Norwalk, CT: Appleton & Lange.

Roncesvalles, M.C., Woollacott, M.H., & Jensen, J.L. (2001). Development of lover extremity kinetic for balance control in infants and young children. *Journal of Motor Behavior, 33*(2), 180-192.

Rose, D.J, & McKillop, J. (1998). Assessment of balance and mobility functions: A reference study based on the Balance Master 6.0. *NeuroCom, Inc.*

Ross, J.G., & Paste, R.R. (1987). The national children and youth fitness study: II. A summary of findings. *Journal of Physical Education, Recreation, and Dance, 59*, 51-56.

Shimada, H., Obuchi, S., Kamide, N., Shiba, Y., Okamoto, M., & Kakurai, S. (2003). Relationship with dynamic balance function during standing and walking. *American Journal of Physical Medicine and Rehabilitation, 82*, 511-516.

Shumway-Cook, A., & Woollacott, M.H. (1985). The growth of stability: Postural control from a developmental perspective. *Journal of Motor Behavior, 17*, 131-147.

Shumway-Cook, A., & Woollacott, M.H. (2001). *Motor control: Theory and practical applications* (2nd ed.). Lippincott Williams & Wilkins.

Sveistrup, H., & Woollacott, M.H. (1996). Longitudinal development of the automatic postural response in infants. *Journal of Motor Behavior, 28*, 58-70.

Ulrich, D.A. (2000). *Test of gross motor development-2* (2nd ed.). Austin, TX: Pro-Ed.

Williams, H., Fisher, J., & Tritschler, K. (1983). Descriptive analysis of static postural control in 4, 6, and 8 year old normal and motorically awkward children. *American Journal of Physical Medicine, 62*, 12-26.

Woollacott, M.H., Debu, B., & Mowatt, M. (1987). Neuromuscular control of posture in the infant and child: is vision dominant? *Development of Motor Behavior, 19*(2), 167-186.

Woollacott, M.H. (2002). Development of balance control in typically developing children and children with cerebral palsy: Contributions and constraints of musculosketetal versus nervous subsystems. In M.L. Latash (Ed.), *Progress in motor control: Structure-function relations in voluntary movements* (Vol 2). (pp. 83-101). Champaign, IL: Human Kinetics.

Yun, J., & Ulrich, D.A. (2002). Estimating measurement validity: A tutorial. *Adapted Physical Activity Quarterly, 19*, 32-47.

CHAPTER 3

The Relationship between Balance and Fundamental Motor Skills in Children

Jennifer Ann Overlock

ABSTRACT

Purpose: The purpose of this investigation was to examine the relationship between the ability to balance and fundamental motor skill performance of locomotor and object control skills in five to nine year old children.

Methods: Fifty-six children without mental or physical disabilities participated in this study. Kicking and jumping skills were measured with both qualitative and quantitative methods, and balance was tested with the NeuroCom balance tests of unilateral stance and tandem walk. Canonical correlations were examined to see the relationship between balance and fundamental motor skill performance.

Results: The results of this study revealed a significant relationship between static balance ability and kicking ($R_c = .48$, $p < .01$) and jumping ($R_c = .45$, $p < .05$) performance. Dynamic balance ability was significantly related to kicking performance ($R_c = .45$, $p < .05$), however had no relationship to jumping performance ($R_c = .32$, $p > .05$).

Conclusion: These results suggest that balance ability and motor skill performance are moderately associated with each other in children five to nine years of age. Static balance ability is shown to be associated with fundamental motor skill performance. The inconsistent relationship between dynamic balance and motor skill performance appears to be related to measurement issues associated with the dynamic balance assessment.

INTRODUCTION

Fundamental motor skills are the foundational patterns of coordination for later sport-specific skills. Typically mastered during childhood, if children do not acquire these fundamental motor skills, they may have a difficult time enjoying physical activities that contribute to healthy active lifestyles (DeOreo & Keogh, 1980; Gallahue & Ozman, 2002). According to the National Association for Sport and Physical Education ([NASPE], 2001), teaching fundamental motor skills is one of the most important foundations established for a young child to lead a physically active lifestyle and enhances a child's social, cognitive, and physical development.

Balance is defined as the ability to control the body's position in space to maintain upright in a given environment (Shumway-Cook & Woollacott, 2001). There are many claims that balance is believed to be an important part of motor skill performance. For example, Hoffman and Koceja (1997) argued "dynamic balance inherently relates to function, since motion and perturbation from a static stance both rely heavily on dynamic postural control mechanisms" (p. 290). Furthermore, motor development textbooks generally present developmental models that show the ability to balance is a prerequisite and foundation for all efficient movement (Gabbard, 2000; Gallahue & Ozman, 2002). Gallahue and Ozman (2002) argued for infants to develop the balance to sit, then stand, they first must overcome the forces of gravity with their bodies. The general belief in the field of motor development is that balance is a building block for more extensive development of fundamental movement, however this assumption is not strongly supported in the literature (DeOreo & Keogh, 1980).

Despite the general belief balance has presented itself to be a prerequisite for movement; findings from current literature are contradicting to each other. A few studies support the relationship between balance and motor performance (e.g., Era, Avlund, Jokela, Gause-Nilsson et al., 1997; Liao & Hwang, 2003), whereas some others do not support the relationship between these two variables (e.g., Butterfield & Loovis, 1994; Owings, Pavol, Fole, & Grabiner, 2000; Shimada, Obuchi, Kamide, Shiba, & Okamoto, 2003; Ulrich & Ulrich, 1985). In addition, some studies contain interpretational and/or methodological limitations. For example, Era et al. (1997) claimed balance to be a predictor of performance for activities of daily living in older adults. Despite the authors' claim, their study found balance to be a predictor of functional performance for only 2% of the total variance. Butterfield and Loovis (1994) suggested no relationship, even though some of their data suggested a significant relationship between kicking and balance for children eleven to twelve year olds, but not five to ten, or thirteen years old. Ulrich and Ulrich (1985) did not support this relationship, but their study used a balance composite score consisting of both static and dynamic scores combined together from field tests. Static and dynamic balance tests have been shown to measure separate abilities for balance control, and therefore should not be combined together (Drowatsky & Zuccatto, 1967; Hoffman & Koceja, 1997).

These empirical studies present different views of how balance relates to movement, and some limitations of them. There is no doubt that balance is important, but empirical evidence is not conclusive. Therefore the purpose of this study was to investigate the relationship between balance ability and fundamental motor skills in five to nine year old children using more comprehensive assessment approaches in both balance and fundamental motor skills. Four specific research questions were addresses in this study involving balance and motor skills. The first two questions examined if static balance was associated with kicking and jumping performance. The last two questions examined the relationships between dynamic balance and kicking and jumping performance.

METHODS

Participants

Participants in this study were 56 children (41 girls and 15 boys) between the ages of five to nine years (M = 7.5 years, SD = 1.4 years). Participants were recruited from a university community outreach program and the surrounding community of a small city, located in the Northwest of the United States. All participants were volunteers and no children had physical or mental disabilities. Table 3.1 summarizes the participant's demographic information. The investigator's Institutional Review Board approved this study. Written parental consent and participant verbal consent were obtained prior to data collection.

Table 3.1 Demographic Data of Participants (N = 56; females = 41, males = 15)

	Participants			
Group	Min.	Max.	M	SD
Age (months)	61	119	88.71	16.22
Height (cm)	104	150	124.62	10.36
Weight (kg)	14	58	25.98	8.32

Instruments and Apparatus

The NeuroCom SMART Balance Master® (NeuroCom) System (Smart, 401) is a computer facilitated static and dynamic force platform, and also includes a five-foot long stable force platform. This commercially available apparatus is used to evaluate balance using small variations in the center of pressure obtained during anterior-posterior-lateral movements from postural sway. It uses testing protocols to isolate and measure the different components of balance. NeuroCom has been used in numerous research studies (e.g., Boulgarides, McGinty, Willet, & Barnes, 2003; Clark, Rose, & Fujimoto, 1997; McGuine, Greene, Best, & Leverson, 2000; Liao & Hwang, 2003; Wallmann, 2001).

Variables and Measures

Participants were tested on four measures including kicking, jumping, as well as static and dynamic balance performance. The scoring sheet for all these measures is in Appendix H.

Kicking performance was measured quantitatively with kicking accuracy using the kicking item in the Adapted Physical Education Assessment Scale (APEAS) and qualitatively using total body approach as described by Payne and Isaacs (1999). The APEAS is a motor skill assessment that contains a test for kicking accuracy. It involves a stationary 8-inch ball kicked to a 1½ ft by 3 ft target for five attempts. Each attempt is scored with a four-point scale ranging from zero to three, with the higher score based on accuracy. The scoring includes the following: (a) zero points if the ball does not reach the wall, (b) one point if the ball hits above or to the side of target, (c) two points if the ball hits the downward extension of target, and (d) three points if the ball hits inside of target. The points are summed into one trial score from the five attempts to give a total kicking score out of a possible 15 points (i.e., 15 points means scoring inside the target for five attempts; Los Angeles Unified School District, 1984).

Total body approach is a qualitative assessment of motor skill performance based on the stages of skill pattern development (Payne & Isaacs, 1999; Seefeldt & Haubenstricker, 1982). This observational approach breaks a motor skill pattern down into stages where the whole body progresses in each stage, such as the arm, leg, and hip action all progress in the same fashion. The developmental sequence for kicking has four qualitative stages. This style of kicking is referred to as a placekick. The stages are described in Appendix E.

Standing long jump performance was measured quantitatively by distance traveled and qualitatively using the total body approach. Standing long jump measures the ability of the participant to jump as far as possible. The participant stands with their feet several inches apart with their toes just behind the take-off line. The participant attempts a two-footed take-off as he or she jumps forward as far as possible landing on both feet, measuring the distance of each jump in centimeters to the nearest centimeter. Each measurement is made from the take-off line to the heel.

The total body approach developmental sequence for the standing long jump has four stages with three phases for each stage: preparatory, takeoff and flight, and landing phase. Payne and Isaacs (1999) cited, Haubenstricker, Seefeldt, and Branta (1983) work which validated the developmental sequences of the standing long jump on a mixed longitudinal sample of 430 preschool children (2½ to 5½ years old) and 1,996 primary-grade children (6 to 9 years old). Stage one was found to be most prominent in children under 3½ years of age. Stage 2 jumping pattern was found most prevalent between four and seven years of age, where as stage 3 was dominant by eight years of age. Only 10% of 8½ to 9 year olds exhibited stage 4 patterns. Mature standing long jump process characteristics (stage 3 and 4) do not predominate until eight or nine years old. The jumping stages are described in Appendix F.

Static balance was measured using the Unilateral Stance Test®. The unilateral stance test involves the participant to stand on the stationary force platform on one leg with hands on his or her hips. The participant performed three 10-second trials with eyes open, on both their left and right foot. A total of two conditions were tested. Half of the participants started on their left foot, and the other half started on their right foot. A center of gravity (COG) sway velocity score (distance COG traveled for a 10 second trial, expressed in degrees/second) was computed for each trial. The three trial scores for each condition are averaged together to compute a mean COG sway velocity (average distance traveled by the COG per the three trials). The dependent measures include the mean COG sway velocity for the left foot and right foot.

Dynamic balance was measured using the Tandem Walk Test®. The tandem walk test involves the participant to stand on a five foot long force platform and when given a verbal and visual cue, walk heel-to-toe from one end to the other, and then when cued again, stand still as quickly and comfortably as possible for 5 seconds. This test was repeated three times, always starting with the preferred foot back for all trials. Dependent measures include (a) step width (average lateral distance between successive steps), (b) speed (average speed to end of platform), and (c) postural sway velocity at the endpoint (end sway; average COG sway after stopping for 5 seconds).

Test-retest for both static and dynamic balance abilities has been examined using 29 out of the 56 participants using intraclass correlation. Unilateral stance for the left and right foot were $ICC_{(2,2)} = .84$ and $ICC_{(2,2)} = .75$, respectively, and the tandem walk measures were speed ($ICC_{(2,2)} = .87$), step width ($ICC_{(2,2)} = .57$), and end sway ($ICC_{(2,2)} = .44$).

Procedures

All participants were measured in a research laboratory and a gymnasium. The testing time was approximately 40 minutes long. Data were collected by the principal investigator, along with one trained research assistant. The children's height and weight were measured prior to data collection. Dominant leg was defined as the leg which the participant chooses to kick a ball with. The participant information sheet included the following information: randomly assigned participant number, gender, birth date, shoe size, and sport experience. The information sheet is in Appendix G.

Order of testing for balance and motor performance tests was randomized to minimize order effect. Half of the participants were assessed on balance ability followed by the skill performance tests. For the other half of participants, skill performance and then balance ability were assessed. Within each skill and balance testing session, order of the measures was randomly assigned to each participant.

For the skill performance session, the participants were required to wear gym shoes. Each participant received a verbal and visual demonstration of each task, and then received unlimited practice trials. Procedures for quantitative kicking performance consisted of three trials of kicking an 8-inch ball off a beanbag to a target 15 feet away, for a total of fifteen kicking attempts. Quantitative jumping performance was measured using a measuring tape on the three best jumping attempts. Testing procedures for qualitative kicking performance consisted of kicking an 8-inch ball off a beanbag as hard as possible. Testing procedures for qualitative jumping performance was to perform standing horizontal jumps as far as possible. Both kicking and jumping qualitative performance were video recorded and the last three attempts were later coded into performance stages. Ten participants were selected for reliability estimations of performance stage coding for kicking and jumping. The investigator's coding results were compared with those of an experienced rater and demonstrated adequate reliability for both kicking and jumping, $ICC_{(2,2)} = .99$ and $ICC_{(2,2)} = .95$, respectively.

Static and dynamic balance were measured using two different tests on a computerized force platform. Participants were bare-foot and were provided visual and verbal instructions with unlimited practice time on each test prior to testing, first on the floor, then the platform. There was a three-minute rest period between each test. Testing procedures for all tests were followed as referenced in the NeuroCom Smart Balance Master® operator's manual (NeuroCom International, Inc., 1998).

Data Analysis

Canonical correlation was employed to examine the relationship between fundamental motor skills and balance ability. Canonical correlation is an exploratory statistical technique that creates linear combinations from the sets of variables, also called canonical variates, and examines the relationship between these two variates. In previous studies, one of the methodological issues was difficulty making conclusive decisions on the relationship between balance and fundamental motor skills using univariate statistical techniques because of inconsistent results. For example, Ulrich and Ulrich (1985) found significant correlations between balance and 4 out of the 7 motor skill comparisons;

whereas 3 out of 7 motor skills did not show significant relationships to balance ability. In this current study, both balance and motor skills were measured in a comprehensive manner and it was necessary to use a multivariate analysis rather than the traditional correlation technique. In addition, canonical correlation explains two important indices. Canonical loadings are the correlations between the original variables and the canonical variates. The redundancy indeces were examined to identify the proportion of the variance that the first set of variables is explained by the linear combinations of the second set of variables (Pedhazur, 1982).

Four separate canonical correlations, correlation between the two variates, were used because current literature has suggested that static and dynamic balance, as well as kicking and jumping skills are separate constructs. Drowatzky and Zuccato (1967) and Hoffman and Koceja (1997) found a low relationship between static and dynamic balance tests, illustrating they are different so should not be combined. For the motor skills, kicking is characterized as an object control skill, whereas jumping is a locomotor skill (Gabbard, 2000).

Each canonical correlation was checked for statistical significance using Wilk's Lambda ($p < .05$). The items having a value of .30 or greater on canonical loadings are generally viewed as significant contributors to the multivariate relationship (Tabachnick & Fidell, 2001). Data were analyzed using the SPSS 11.5 statistical software package.

RESULTS

Fifty-six participants completed each of the tests presented. Descriptive statistics results are summarized in Table 3.2. Children that participated in this study demonstrated an average of 1.5 deg/sec of sway while standing on one foot. On a five-foot long platform, walking heel-to-toe across a line, the average foot deviation was 6.2 cm, speed was 20 cm/sec, and an average end sway of 4.5 deg/sec after stopping. The average skill performances were stage 2 for jumping skills and stage 3 for kicking skills. The average kicking accuracy score was a total of 7 points, and jumping distance was 120 cm.

Table 3.2 Ranges, Means, and Standard Deviations of Balance and Skill Performance Outcome Measures for Children

	Performance Tests			
Balance Measures (N = 56)	Min.	Max.	M	SD
Unilateral Stance:				
Left COG sway velocity (deg/sec)	.63	8.80	1.46	1.28
Right COG sway velocity (deg/sec)	.67	6.60	1.50	1.08
Tandem Walk:				
Step Width (cm)	4	12.53	6.16	1.53
Speed (cm/sec)	11.37	57.43	20.49	7.92
End Sway (deg/sec)	1.97	8.50	4.38	1.68
Kicking:				
Form (performance stage)	1	4	3.04	.96
Accuracy (APEAS kicking score)	5.33	9.67	7.29	1.00
Standing Long Jump:				
Form (performance stage)	1	4	2.11	.67
Accuracy (distance jumped; cm)	68.67	176	120.45	20.02

Table 3.3 summarizes the univariate correlations between the balance and motor performance measures. The results of zero order correlation indicated that significant relationships exist among both unilateral stance on the left and right foot and kicking stage performance (left: $r = -.47, p < .01$; right: $r = -.47, p < .01$), and jumping distance (left: $r = -.30, p < .05$; right: $r = -.36, p < .01$). Tandem walk's step width was significantly correlated with kicking stage ($r = -.40, p < .01$).

Table 3.3 Correlation Matrix between Balance and Motor Performance Measures for Children

	USL	USR	TSW	TS	TES	KA	KS	JD	JS
Unilateral Stance Left (USL)[1]	1								
Unilateral Stance Right (USR)[1]	.96**	1							
Tandem Walk Step Width (TSW)[2]	.58**	.53**	1						
Tandem Walk Speed (TS)[2]	-.18	-.15	-.12	1					
Tandem Walk End Sway (TES)[2]	.25	.23	.23	.54**	1				
Kicking Accuracy (KA)[3]	-.17	-.17	-.18	.06	-.17	1			
Kicking Stage (KS)[3]	-.47**	-.47**	-.40**	.23	.07	.29*	1		
Jumping Distance (JD)[4]	-.30*	-.36**	-.15	.25	-.01	.20	.45**	1	
Jumping Stage (JS)[4]	.01	-.05	-.13	.26	.07	-.01	.32*	.65**	1

Note: * $p < .05$ and ** $p < .01$. [1] indicates a static balance measure, [2] indicates a dynamic balance measure, [3] indicates a kicking measure, [4] indicates a jumping measure.

The first canonical correlation analysis was conducted to test the link between children's static balance ability and their kicking performance. Two canonical correlation functions emerged from this analysis ($R_c = .48$ and $R_c = .01$). The results of this study revealed only the first canonical correlation was significant (Wilk's Lambda = .77, $p < .01$), indicating at least one facet of the static balance set correlated with one facet of the kicking performance set. Table 3.4 summaries the results between the static balance set and kicking performance set of the canonical correlations. Inspection of the canonical loadings indicated both variables of unilateral stance on the left and right foot highly contributed to static balance, and both kicking stage and accuracy significantly contributed to kicking performance. The redundancy index revealed that 22% of the variance in the children's static balance could be explained by the set of kicking performance variables, and 13% of the variance in the kicking performance was explained by the set of static balance test variables. According to Pedhazur (1982), a redundancy value of at least 10% is considered significant and meaningful.

Table 3.4 Standardized Canonical Coefficients, Canonical Loadings, Percents of Variance, and Redundancies Between Static Balance and Kicking Performance

	Canonical Coefficients		Canonical Loadings		Percent of Variance Explained by Own		Redundancy Explained by Opposite	
Canonical Functions	1	2	1	2	1	2	1	2
Static Balance					98%	2%	22%	0%
US Left	-.62	-3.69	-.995	-.103				
US Right	-.39	3.72	-.986	.167				
Kicking Performance					56%	44%	13%	0%
Kicking Stage	.98	-.37	.998	-.065				
Kicking Accuracy	.07	1.04	.355	.935				

Note: Only the first canonical correlation function is statistically significant ($p < .01$)

The second analysis was conducted to test the link between static balance and jumping performance. Two canonical correlation functions emerged, $R_c = .45$ and $R_c = .19$, from this analysis. However, only the first canonical correlation had a significant multivariate relationship (Wilk's Lambda = .77, $p < .01$). The results from this analysis are summarized in Table 3.5. Examination of the canonical loadings for the jumping performance set indicated that the variable of horizontal distance jumped was more highly associated than jumping stage performance to the multivariate relationship. The redundancy index revealed that 17% of the variance in the children's static balance could be explained by their jumping performance. However, only 8% of children's jumping performance was explained by the static balance ability variables.

Table 3.5 Standardized Canonical Coefficients, Canonical Loading Correlations, Percents of Variance, and Redundancies Between Static Balance and Jumping Performance

	Canonical Coefficients		Canonical Loading		Percent of Variance Explained by Own		Redundancy Explained by Opposite	
Canonical Functions	1	2	1	2	1	2	1	2
Static Balance					84%	16%	17%	1%
US Left	.94	3.62	-.866	.500				
US Right	-1.87	-3.24	-.968	.250				
Jumping Performance					41%	59%	8%	2%
Jumping Stage	-.63	1.16	.214	.977				
Distance Jumped	1.29	-.28	.880	.474				

Note: Only the first canonical correlation function is statically significant ($p < .01$)

A third canonical correlation was conducted to test the relationship between children's dynamic balance and kicking performance. Two canonical correlation functions emerged from this analysis ($R_c = .45$ and $R_c = .23$). These results revealed a significant multivariate relationship with only the first canonical correlation (Wilk's Lambda = .76, $p < .05$), indicating at least one facet of the dynamic balance set correlated with one facet of the kicking performance set. The canonical correlation analysis results between the dynamic balance set and kicking performance set are summarized in Table 3.6. Canonical loadings indicated that step width and speed were significantly contributing to the dynamic balance variant. The value representing end sway was not highly related to the set of balance variables. The results also indicated that both kicking stage and kicking accuracy meaningfully contributed to the kicking canonical variate. The redundancy index revealed that only 7% of the variance in the children's dynamic balance could be explained by their kicking performance. This value is below the minimum 10% level identified by Pedhazur (1982), indicating a non-significant and meaningless relationship between the two variable sets. However, 11% of the children's kicking performance was explained by the dynamic balance ability variables.

Table 3.6 Standardized Canonical Coefficients, Canonical Loading Correlations, Percents of Variance, and Redundancies Between Dynamic Balance and Kicking Performance

	Canonical Coefficients		Canonical Loading		Percent of Variance Explained by Own		Redundancy Explained by Opposite	
Canonical Functions	1	2	1	2	1	2	1	2
Dynamic Balance					37%	27%	7%	1%
Tandem Step Width	-.90	.18	-.900	-.176				
Tandem Speed	.34	.61	.521	-.09				
Tandem End Sway	.15	-1.35	.122	-.872				

Kicking Performance					56%	44%	11%	2%
Kicking Stage	.98	-.36	.998	-.055				
Kicking Accuracy	.06	1.04	.345	.938				

Note: Only the first canonical correlation function is statically significant ($p < .05$)

The fourth canonical correlation was conducted to test the relationship between children's dynamic balance and jumping performance. Two canonical correlations emerged, although neither was significant ($R_c = .32$ and $R_c = .11$). The results of this analysis indicated no significant relationship between dynamic balance and jumping performance ($p > .05$). Table 3.6 summarizes the canonical correlations for dynamic balance and jumping performance.

Table 3.7 Standardized Canonical Coefficients, Canonical Loading Correlations, Percents of Variance, and Redundancies Between Dynamic Balance and Jumping Performance

	Canonical Coefficients		Canonical Loading		Percent of Variance Explained by Own		Redundancy Explained by Opposite	
Canonical Functions	1	2	1	2	1	2	1	2
Dynamic Balance					32%	35%	3%	0%
Tandem Step Width	-.25	.33	-.477	.025				
Tandem Speed	1.07	.26	.848	-.405				
Tandem End Sway	-.47	-1.16	.058	-.944				
Jumping Performance					82%	18%	8%	0%
Jumping Stage	.85	-.52	.853	-.521				
Distance Jumped	.95	.31	.952	.307				

Note: None of the canonical correlations were statically significant ($p > .05$)

DISCUSSION

The results of this study suggest for children five to nine years of age, static balance plays a significant role in the performance of object control and locomotor fundamental motor skills. Specifically, the results indicate children's static balance is moderately associated with kicking performance, with a 23% variance overlap, and jumping performance, with a 22% variance overlap.

Static balance no doubt influences kicking performance, as children must maintain balance on one leg while striking a ball with the other leg. Both qualitative and quantitative measures of kicking performance were highly associated with better static balance. This is contrary to Butterfield and Loovis' (1994) results of no relationship between static balance and kicking for children under ten years old. These different results may be due to the fact that they assessed balance ability using field tests, which have a low reliability (Wilson et al., 1995) and do not provide comprehensive documentation of postural control and balance like computerized force platforms. In addition, their study only addressed one aspect of kicking skill performance, qualitative, but no quantitative aspects of kicking. This present study used comprehensive measurements on both balance and motor skill measurements addressing both qualitative and quantitative aspects of skill performance.

For jumping performance, quantitative performance was more highly associated than qualitative performance to static balance. This lack of a strong relationship may be a result of a low variability on qualitative jumping performance among the participants. The average jumping stage performance in this present study was stage 2 with a minimal standard deviation. This is similar to van Beurden, Zask, Barnett, and Dietrich's (2002) study that used a qualitative approach to assess jumping performance and found 62% of the children seven to ten years old performed at the stage 1 or 2 level. This lack of variability may also explain why jumping performance was explained by only 8% of the variance of static balance.

The results of this study provide inconsistent relationships between dynamic balance and fundamental motor skills. It appears that children's dynamic balance was related to kicking performance. There was a 20% variance overlap between these two variable sets, although the redundancy index indicated that only 7% of the amount of variance in dynamic balance could be explained by the kicking performance, indicating a meaningless relationship (Pedhazur, 1982). In addition, results revealed that dynamic balance was not related to jumping performance. There are a number of possibilities that may explain why dynamic balance did not emerge as significantly related to motor skill performance in this study. First, dynamic balance has been defined in the literature as maintaining upright within a moving base of support, such as walking (i.e., Butterfield & Loovis, 1994; Shimada at al., 2003), or the ability to maintain upright within a fixed or perturbed support surface (i.e., Gallahue & Ozman, 2002; Hoffman & Koceja, 1997). Because of the breadth of this operational definition, there is no consensus of what dynamic balance means. Therefore, measuring dynamic balance proves to be problematic.

Second, the three measures of dynamic balance used in this study did not all capture a single construct. Only two of the variables, step width and speed, highly contributed, whereas end sway minimally contributed to the dynamic balance variate. In addition, the results of test-retest reliability revealed a lack of reliability of these dynamic balance measures for children. Reliability estimations were poor for end sway ($ICC_{(2,2)}$ = .44), moderate for step width ($ICC_{(2,2)}$,= .57) , and high for speed ($ICC_{(2,2)}$ = .87). Speed was the only measure with adequate reliability ($ICC_{(2,2)}$ = .87), therefore within the dynamic balance variable set, dynamic balance may not be adequately captured. According to the computerized force platform, the two or three outcome measures of a test should be assessed in conjunction with one another to provide a fuller picture of balance; however, all three measures did not capture a single construct and demonstrated a lack of reliability. There is a need to find an acceptable measure that truly represents dynamic balance to be able to investigate relationships between dynamic balance and other motor skills. This instability of the outcome measures for dynamic balance may be the reason no significant relationships were found between dynamic balance and the fundamental motor skills of kicking and jumping.

Static balance in this study was found to be an important part of movement, explaining approximately 20% of skill performance. Although dynamic balance has been found to be important in past studies (Butterfield & Loovis, 1994), it was problematic for this study due to measurement issues. Balance, along with other factors, such as body composition, cognition, flexibility, motivation, muscular strength, and endurance are foundations of movement that contribute to motor skill performance (Burton & Miller, 1998). Burton and Rodgerson (2001) emphasized these foundations as important aspects of skill performance to consider. This current study supports the idea that balance contributes to motor skill performance. Therefore, in practical settings, improving these movement foundations will also be associated with improvements of motor skills. Ulrich and Ulrich (1984) documented children's movement foundations improved, such as balance, through practicing these foundations. Therefore, practicing balance tasks will improve balance performance, as well as skills associated with them, such as fundamental motor skills.

Through this investigation of the relationship between the ability to balance and perform fundamental motor skills, answers were sought to these questionable relationships and these findings contribute to improve teaching practices to find effective ways to increase motor performance and learning in children.

REFERENCES

Boulgarides, L.K., McGinty, S.M., Willet, J.A., & Barnes, C.W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Physical Therapy, 83*(4), 328-339.

Bruininks, R. (1978). *Bruininks-Oseretsky test of motor proficiency.* Circle Pines, MN: American Guidance Service.

Butterfield, S.A., & Loovis, M. (1994). Influence of age, sex, balance, and sport participation on development of kicking by children in grades K-8. *Perceptual and Motor Skills, 79,* 691-697.

Burton, D.W., & Rodgerson, R.W. (2001). Movement skills and motor abilities. *Adapted Physical Activity Quarterly, 18*, 347-365.

Burton, A.W., & Miller, D.E. (1998). *Movement skill assessment.* Champaign, IL: Human Kinetics.

Clark, S., Rose, D., & Fujimoto, K. (1997). Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. *Archives of Physical Medicine and Rehabilitation, 78*, 1078-1084.

DeOreo, K., & Keogh, J. (1980). Performance of fundamental motor tasks. In C. Corbin (Ed.), *A textbook of motor development* (2nd ed.). (pp. 76-91). Dubuque, IA: Brown.

Drowatzky, J.N., & Zuccato, F.C. (1967). Interrelationships between selected measures of static and dynamic balance. *Research Quarterly, 38*(3), 509-510.

Era, P., Avlund, K., Jokela, J., Gause-Nilsson, I., Heikkinen, E., Steen, B., & Schroll, M. (1997). Postural balance and self-reported functional ability in 75-year-old men and women: A cross-national comparative study. *Journal American Geriatrics Society, 45*, 21-29.

Gabbard, C.P. (2000). *Lifelong motor development* (3rd ed.). Boston: Allyn and Bacon.

Gallahue, D.L., & Ozman, J.C. (2002). *Understanding motor development: Infants, children, adolescents, adults* (5th ed.). USA: McGraw-Hill Co.

Hoffman, M.A., & Koceja, D.M. (1997). Dynamic balance testing with electrically evoked perturbation: A test of reliability. *Archives of Physical Medicine and Rehabilitation, 78*, 293-293.

Liao, H.F., & Hwang, A.W. (2003). Relations of balance function and gross motor ability for children with cerebral palsy. *Perceptual and Motor Skills, 96*, 1173-1184.

Los Angles Unified School District. (1984). *Adapted physical education assessment scale-elementary level.* Los Angeles: Division of Special Education.

McGuine, T.A., Greene, J.J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*, 239-244.

National Association for Sport and Physical Education. (2001, July).

NeuroCom International, Inc. (1998). *Smart Balance Master operator's manual* (Version 6.1.). Clackamas, OR: NeuroCom International, Inc.

NeuroCom International (n.d.). Computerized Dynamic Posturography. Retrieved May 15, 2003, from http://www.onbalance.com

Owings, T.M., Pavol, M.J., Foley, K.T., & Grabiner, M.D. (2000). Measures of postural stability are not predictors of recovery from large postural disturbances in health older adults. *Journal of American Geriatrics Society, 48*, 42-50.

Payne V.G., & Isaacs, L.D. (1999). *Human motor development: A lifespan approach* (4th ed.). Mountain View: Mayfield.

Pedhazur, E.J. (1982). *Multiple regression in behavioral research* (2nd ed.). New York: Holt, Rinchart, & Winston.

Rose, D.J, & McKillop, J. (1998). Assessment of balance and mobility functions: A reference study based on the Balance Master 6.0. *NeuroCom, Inc.*

Seefeldt, V., & Haubenstricker, J. (1982). Patterns, phases, or stages: An analytical model for the study of developmental movement. In J.A. Kelso & J.E. Clark (Eds.), *The development of movement control and coordination* (pp. 309-318). New York: Wiley.

Shimada, H., Obuchi, S., Kamide, N., Shiba, Y., Okamoto, M., & Kakurai, S. (2003). Relationship with dynamic balance function during standing and walking. *American Journal of Physical Medicine and Rehabilitation, 82*, 511-516.

Shumway-Cook, A., & Woollacott, M.H. (2001). *Motor control: Theory and practical applications* (2nd ed.). Lippincott Williams & Wilkins.

Tabachnick, B.G., & Fidell, L.S. (2001). *Using multivariate statistics* (4th ed.). New York, NY: Pearson Education Co.

Ulrich, D.A., & Ulrich, B.D. (1984). The objectives-based motor skill assessment instrument: Validation of instructional sensitivity. *Perceptual and Motor Skills, 59*, 175-179.

Ulrich, B.D., & Ulrich, D.A. (1985). The role of balancing in performance of fundamental motor skills in 3, 4, and 5 year old children. In J.E. Clark & J.H. Humphrey (Eds.), *Motor development: Current selected research* (pp. 87-97). Princeton, NJ: Princeton Books.

van Beurden, E., Zask, E., Barnett, L., & Dietrich, U. (2002). Fundamental movement skills – How do primary school children perform? The 'Move it Groove it" program in rural Australia. *Journal of Science and Medicine in Sport, 5*(3), 255-252.

Wilson, B.N., Polatajko, H.J., Kaplan, B.J., & Faris, P. (1995). Use of the Bruininiks-Oseretsky test of motor proficiency in occupational therapy. *American Journal of Occupational Therapy, 49*, 8-17.

Wallmann, H.W. (2001). Comparison of elderly nonfallers and fallers on performance measures of function reach, sensory Organization, and limits of stability. *Journal of Gerontology, 56*(9), M580-M583.

CHAPTER 4: SUMMARY

The following summary will discuss each research question presented in the introduction, and suggested future research directions.

RESEARCH CONCLUSIONS

1) Do children demonstrate reliability and validity for static balance assessments on a computerized force platform?

Reliability estimations for the static balance test of unilateral stance with children demonstrated a high level for the left and right foot, $ICC_{(2,2)} = .84$ and $ICC_{(2,2)} = .75$, respectively. Validity evidence was strong from correlations between the children's ages and static balance performance on the left and right foot, $r = -.40$, $p < .01$ and $r = -.43$, $p < .01$, respectively. Computerized force platform assessments were an appropriate method to measure static balance in children five to nine years of age, providing strong evidence of reliability and validity.

2) Do children demonstrate reliability and validity for dynamic balance assessments on a computerized force platform?

Reliability estimations from children for the dynamic balance measurement of the tandem walk's speed ($ICC_{(2,2)} = .87$) demonstrated an adequate level of reliability. However, tandem walk's step width ($ICC_{(2,2)} = .57$) and end sway ($ICC_{(2,2)} = .44$) did not demonstrated an adequate reliability. There was a significant relationship between age and balance performance for the dynamic balance tandem walk's speed measure ($r = 43$,

$p < .01$). However, the two other measures of step width and end sway did not have a significant relationship with age ($p > .05$). Only the outcome measure of speed demonstrated an adequate reliability and validity estimation for children.

3) Is there an association between static balance and kicking performance?

Canonical correlation was used to examine the relationship between static balance ability and kicking performance. The results found a significant relationship between these two variables ($R_c = .48$, $p < .01$). They showed that better static balance ability is associated with higher qualitative and quantitative kicking performance. In addition, 13% of kicking performance was explained by static balance ability.

4) Is there an association between static balance and jumping performance?

The results found static balance ability is related to jumping performance ($R_c = .45$, $p < .01$). Specifically, better static balance ability is highly associated with quantitative jumping performance, however, minimally related to qualitative jumping performance.

5) Is there an association between dynamic balance and kicking performance?

The canonical correlation results revealed a significant relationship ($R_c = .45$, $p < .05$), indicated at least one facet of the dynamic balance variable set correlated with one facet of the kicking performance set. However, the results showed only 7% of dynamic balance ability was explained by kicking performance, which shows a lack of practical significance (Pedhazur, 1982). Therefore, dynamic balance ability did not show a high association with kicking performance.

6) Is there an association between dynamic balance and jumping performance?

There was no relationship found between dynamic balance ability and jumping performance ($R_c = .32$, $p > .05$). A more reliable and valid measurement of dynamic balance ability needs to be found to accurately assess this relationship.

FUTURE RESEARCH DIRECTIONS

Suggestions for future research would begin with conducting this study with more participants, so the results could be generalizable to the general population. The inclusion of more tests of fundamental motor skill performance will see their relationship to balance ability. More tests will discern the amount of balance ability needed for optimal performance of individual motor skills.

A reliable and valid test of dynamic balance needs to be found to assess children's balance ability. Once an appropriate measure of dynamic balance has been established for children, it would be recommended that a study be conducted to determine if a relationship would be obtained between dynamic balance ability and other variables. Another future direction for research would be to investigate how much balance performance is related to motor performance in children with disabilities, such as learning disabled.

These recommendations for future studies to investigate the relationship balance ability has on motor performance in children could aid in providing insight and provide physical educators, as well as adapted physical educators, with information to develop curricula, early detection of motor deficits in young children, and increase motor performance of these individuals.

BIBLIOGRAPHY

Baker, C.P., Newstead, A.H., Mossberg, K.A., & Nicodemus, C.L. (1998). Reliability of static standing balance in nondisabled children: Comparison of two methods of measurement. *Pediatric Rehabilitation, 2*(1), 15-20.

Boulgarides, L.K., McGinty, S.M., Willet, J.A., & Barnes, C.W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Physical Therapy, 83*(4), 328-339.

Bril, B., & Breniere, Y. (1993). Posture and independent locomotion in childhood: Learning to walk or learning dynamic postural control. In Savelsbergh, G.J.P. (Ed.), *The development of coordination in infancy* (pp. 337-358). Amsterdam: North-Holland.

Brouwer, B., Culham, E., Liston, R., & Grant, T. (1998). Normal variability of postural measures: Implications for the reliability of relative balance performance outcomes. *Scandinavian Journal Rehabilitation Medicine, 30,* 131-137.

Bruininks, R. (1978). *Bruininks-Oseretsky test of motor proficiency.* Circle Pines, MN: American Guidance Service.

Butterfield, S.A., & Loovis, M. (1994). Influence of age, sex, balance, and sport participation on development of kicking by children in grades K-8. *Perceptual and Motor Skills, 79,* 691-697.

Burton, D.W., & Davis, W.E. (1992). Assessing balance in adapted physical education: Fundamental concepts and applications. *Adapted Physical Activity Quarterly, 9,* 14-46.

Burton, D.W., & Rodgerson, R.W. (2001). Movement skills and motor abilities. *Adapted Physical Activity Quarterly, 18*, 347-365.

Burton, A.W., & Miller, D.E. (1998). *Movement skill assessment.* Champaign, IL: Human Kinetics.

Cambier, D., Cools, A., Danneels, L., & Witvrouw, E. (2001). Reference data for 4- and 5-year old children on the Balance Master: Values and clinical feasibility. *European Journal of Pediatrics, 160*, 317-322.

Clark, J.E., & Watkins, D.L. (1984). Static balance in young children. *Child Development, 55*, 854-857.

Clark, S., Rose, D., & Fujimoto, K. (1997). Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. *Archives of Physical Medicine and Rehabilitation, 78*, 1078-1084.

Cleland, F. E., & Gallahue, D.L. (1993). Divergent movement ability. *Perceptual and Motor Skills, 77*(2), 535-544.

Debu, B., & Woollacott, M.H. (1988). Effects of gymnastics training on postural responses to stance perturbations. *Journal of Motor Behavior, 20*(3), 273-300.

DeOreo, K., & Keogh, J. (1980). Performance of fundamental motor tasks. In C. Corbin (Ed.), *A textbook of motor development* (2nd ed.). (pp. 76-91). Dubuque, IA: Brown.

Drowatzky, J.N., & Zuccato, F.C. (1967). Interrelationships between selected measures of static and dynamic balance. *Research Quarterly, 38*(3), 509-510.

Duger, T., Bumin, G., Uyanik, M., Aki, E., & Kayihan, H. (1999). The assessment of Bruininks-Oseretsky test of motor proficiency in children. *Pediatric Rehabilitation, 3*(3), 125-131.

Duncan, P.W., Weiner, D.K., Chandler, J., & Studenski, S. (1990). Functional reach: a new clinical measure of balance. *Journal of Gerontology, 45*, M192-M197.

Effgan, S.K. (1981). Effect of an exercise program on the static balance of deaf children. *Physical Therapy, 61*(6), 873-877.

Era, P., Avlund, K., Jokela, J., Gause-Nilsson, I., Heikkinen, E., Steen, B., & Schroll, M. (1997). Postural balance and self-reported functional ability in 75-year-old men and women: A cross-national comparative study. *Journal American Geriatrics Society, 45*, 21-29.

Ford-Smith, C.D., Wyman, J.F., & Elswick, R.K. (1995). Test-retest reliability of the sensory organization test in noninstitutionalized older adults. *Archives of Physical Medicine and Rehabilitation. 76*(1), 77-81.

Forssberg, H., & Nashner, L. (1982). Ontogenetic development of postural control in man: Adaptation to altered support and visual conditions during stance. *Journal of Neuroscience, 2*, 545-552.

Foudriat, B.A., DiFabio, R.P., & Anderson, J.H. (1993). Sensory organization of balance responses in children 3-6 years of age: A normative study with diagnostic implications. *International Journal of Pediatric Otorhinolaryngology, 27*, 255-271.

Gabbard, C.P. (2000). *Lifelong motor development* (3rd ed.). Boston: Allyn and Bacon.

Gallahue, D.L., & Ozman, J.C. (2002). *Understanding motor development: Infants, children, adolescents, adults* (5^{th} ed.). USA: McGraw-Hill Co.

Hoffman, M.A., & Koceja, D.M. (1997). Dynamic balance testing with electrically evoked perturbation: A test of reliability. *Archives of Physical Medicine and Rehabilitation, 78*, 293-293.

Horak, F.B. (1987). Clinical measures of postural control in adults. *Physical Therapy, 67*, 1881-1885.

Horak, F.B., & Shupert, C.L. (1994). The role of the vestibular system in postural control. In: S. Herdman (Ed.), *Vestibular rehabilitation* (pp. 22-46). New York: FA Davis.

Karlsson, A, & Frykberg, G. (2000). Correlations between force plate measures for assessment of balance. *Clinical Biomechanics, 15*, 365-369.

Lee, D.N., & Aronson, E. (1974). Visual Proprioceptive control of standing in human infants. *Perception and Psychophysics, 15*(3), 529-532.

Lee, D.N. (1978). On the functions of vision. In H.L. Pick Jr. & E. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 159-170). Hillsdale, NJ: Erlbaum.

Liao, H.F., Mao, P.J., & Hwang, A.W. (2001). Test-retest reliability of balance tests in children with cerebral palsy. *Developmental Medicine and Child Neurology, 42*, 180-186.

Liao, H.F., & Hwang, A.W. (2003). Relations of balance function and gross motor ability for children with cerebral palsy. *Perceptual and Motor Skills, 96*, 1173-1184.

Lindmark, B., Lagerstrom, C., Naessen, T., & Larsen, H. (1999). Performance in functional balance tests during menopausal hormone replacement: a double-blind placebo-controlled study. *Physiotherapy Research International, 4*(1), 43-54.

Liston, R.A., & Brouwer, B.J. (1996). Reliability and validity of measures obtained from stroke patients using the Balance Master. *Archives of Physical Medicine and Rehabilitation, 77*, 425-430.

Los Angles Unified School District. (1984). *Adapted physical education assessment scale-elementary level.* Los Angeles: Division of Special Education.

Macpherson, J.M., Fung, J., & Jacobs, R. (1997). Postural orientation, equilibrium, and the spinal cord. *Advances in Neurology, 72*, 227-32.

Massion, J. (1992). Postural control system. *Current Opinion in Neurobiology, 4*, 877-887.

Mathias, S.U., Nayak, U.S., & Isaacs, B. (1986). Balance in the elderly patient: The "Get up and go" test. *Archives of Physical Medicine and Rehabilitation, 67*, 387-389.

McGuine, T.A., Greene, J.J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*, 239-244.

National Association for Sport and Physical Education. (2001, July).

Nashner, L. (1989). Sensory, neuromuscular, and biomechanical contributions to human balance. In P. Duncan (Ed.), Balance: Proceedings of the APTA Forum. Alexandria, VA: APTA.

Nashner, L., & Berthoz, A. (1978). Visual contributions to rapid motor responses during postural control. *Brain Research, 150*, 403-407.

NeuroCom International, Inc. (1998). *Smart Balance Master operator's manual* (Version 6.1.). Clackamas, OR: NeuroCom International, Inc.

NeuroCom International (n.d.). Computerized Dynamic Posturography. Retrieved May 15, 2003, from http://www.onbalance.com

Owings, T.M., Pavol, M.J., Foley, K.T., & Grabiner, M.D. (2000). Measures of postural stability are not predictors of recovery from large postural disturbances in health older adults. *Journal of American Geriatrics Society, 48*, 42-50.

Payne V.G., & Isaacs, L.D. (1999). *Human motor development: A lifespan approach* (4th ed.). Mountain View: Mayfield.

Pedhazur, E.J. (1982). *Multiple regression in behavioral research* (2nd ed.). New York: Holt, Rinchart, & Winston.

Portney, L.G., & Watkins, M.P. (1993). *Foundations of clinical research, application to practice.* East Norwalk, CT: Appleton & Lange.

Roncesvalles, M.C., Woollacott, M.H., & Jensen, J.L. (2001). Development of lover extremity kinetic for balance control in infants and young children. *Journal of Motor Behavior, 33*(2), 180-192.

Rose, D.J, & McKillop, J. (1998). Assessment of balance and mobility functions: A reference study based on the Balance Master 6.0. *NeuroCom, Inc.*

Rose, J., Wolff, D.R., Jones, V.K., Bloch, D.A., Oehlert, J.W., & Gamble, J.G. (2002). Postural balance in children with cerebral palsy. *Developmental Medicine and Child Neurology, 44*(1), 58-63.

Ross, J.G., & Paste, R.R. (1987). The national children and youth fitness study: II. A summary of findings. *Journal of Physical Education, Recreation and Dance, 59*, 51-56.

Seefeldt, V., & Haubenstricker, J. (1982). Patterns, phases, or stages: An analytical model for the study of developmental movement. In J.A. Kelso & J.E. Clark (Eds.), *The development of movement control and coordination* (pp. 309-318). New York: Wiley.

Shepard, N.T. (2000). Clinical utility of the motor control test (MCT) and postural evoked responses (PER). Clackamas: NeuroCom publication.

Shimada, H., Obuchi, S., Kamide, N., Shiba, Y., Okamoto, M., & Kakurai, S. (2003). Relationship with dynamic balance function during standing and walking. *American Journal of Physical Medicine and Rehabilitation, 82*, 511-516.

Shumway-Cook, A., & Woollacott, M.H. (1985). The growth of stability: Postural control from a developmental perspective. *Journal of Motor Behavior, 17*, 131-147.

Shumway-Cook, A., & Woollacott, M.H. (2001). *Motor control: Theory and practical applications* (2nd ed.). Lippincott Williams & Wilkins.

Sveistrup, H., & Woollacott, M.H. (1996). Longitudinal development of the automatic postural response in infants. *Journal of Motor Behavior, 28*, 58-70.

Tabachnick, B.G., & Fidell, L.S. (2001). *Using multivariate statistics* (4th ed.). New York, NY: Pearson Education Co.

Ulrich, D.A., & Ulrich, B.D. (1984). The objectives-based motor skill assessment instrument: Validation of instructional sensitivity. *Perceptual and Motor Skills, 59*, 175-179.

Ulrich, B.D., & Ulrich, D.A. (1985). The role of balancing in performance of fundamental motor skills in 3, 4, and 5 year old children. In J.E. Clark & J.H. Humphrey (Eds.), *Motor development: Current selected research* (pp. 87-97). Princeton, NJ: Princeton Books.

Ulrich, D.A. (2000). *Test of gross motor development-2* (2nd ed.). Austin, TX: Pro-Ed.

U.S. Department of Health and Human Services. (2000). *2000 Surgeon General's Report.*

van Beurden, E., Zask, E., Barnett, L., & Dietrich, U. (2002). Fundamental movement skills – How do primary school children perform? The 'Move it Groove it" program in rural Australia. *Journal of Science and Medicine in Sport, 5*(3), 255-252.

Wallmann, H.W. (2001). Comparison of elderly nonfallers and fallers on performance measures of function reach, sensory Organization, and limits of stability. *Journal of Gerontology, 56*(9), M580-M583.

Wang, W.Y., & Ju, Y.H. (2002). Promoting balance and jumping skills in children with Down syndrome. *Perceptual and Motor Skills, 92*(2), 443-448.

Whitney, S.L. (1992). Dynamic balance responses in five to six year old gymnasts and swimmers. (Doctoral dissertation, University of Pittsburgh, 1992). *Dissertation Abstracts International, 53*, 09B.

Williams, H., Fisher, J., & Tritschler, K. (1983). Descriptive analysis of static postural control in 4, 6, and 8 year old normal and motorically awkward children. *American Journal of Physical Medicine, 62*, 12-26.

Williams, H.G., McCleneghan, B., & Ward, D.S. (1985). Duration of muscle activity during standing in normally and slowly developing children. *American Journal of Physical Medicine, 64*, 171-186.

Wilson, B.N., Polatajko, H.J., Kaplan, B.J., & Faris, P. (1995). Use of the Bruininks-Oseretsky test of motor proficiency in occupational therapy. *American Journal of Occupational Therapy, 49*, 8-17.

Woollacott, M.H, Debu, B., & Shumway-Cook, A. (1987). Children's development of posture and balance control: Changes in motor coordination and sensory integration. In D. Gould & M.R. Weiss (Eds.), *Advances in pediatric sport sciences* (Vol. 2). (pp. 211-233). Champaign, IL: Human Kinetics.

Woollacott, M.H., Debu, B., & Mowatt, M. (1987). Neuromuscular control of posture in the infant and child: is vision dominant? *Development of Motor Behavior, 19*, 2, 167-186.

Woollacott, M.H., Shumway-Cook, A., & Williams, H. (1990). The development of posture and balance control in children. In: M.H. Woollacott, A. Shumway-Cook (Eds.), *Development of posture and gait across the life span* (pp. 77-96). Columbia: University of South Carolina.

Woollacott, M, H., & Shumway-Cook, A. (1990). Changes in postural control across the life span – A systems approach. *Physical Therapy, 70*(12), 799-807.

Woollacott, M.H. (2002). Development of balance control in typically developing children and children with cerebral palsy: Contributions and constraints of musculosketetal versus nervous subsystems. In M.L. Latash (Ed.), *Progress in Motor Control: Structure-function relations in voluntary movements* (Vol 2). (pp. 83-101). Champaign, IL: Human Kinetics.

Yun, J., & Ulrich, D.A. (2002). Estimating measurement validity: A tutorial. *Adapted Physical Activity Quarterly, 19*, 32-47.

APPENDICES

APPENDIX A – REVIEW OF LITERATURE

The purpose of this review is to provide the readers with information on the areas of fundamental motor skills, the role of balance to reveal the importance of balance ability in fundamental motor skills, balance mechanisms, responses, and components, along with assessments of balance. This material provides a rationale for this study.

Fundamental Motor Skills

Fundamental motor skills are the foundations of complex movements for sports and recreational skills. They consist of object control (e.g., kicking, striking, throwing) and locomotor skills (e.g., jump, hop, run, leap, walk) skills. Children should ideally master these skills by ages 5 or 6 and continue to refine and be able to combine these skills to specialized sport and recreational settings by 7 or 8 years old (Duger, Bumin, Uyanik, Aki, & Kayihan, 1999; Gallahue & Ozman, 2002). If children do not acquire these fundamental motor skills, they may have a difficult time enjoying physical activities that contribute to healthy active lifestyles (DeOreo & Keogh, 1980). The U.S. Surgeon General's report on physical activity and health stated that nearly half of adolescents and young adults are not vigorously active on a regular basis. Participation in physical activity declines as children get older; 73% of 9th graders participate in regular vigorous physical activity compared to only 58% of 12th graders (U.S. Department of Health and Human Services [USDHHS], 2000). In addition, physical activity participation patterns vary within the adolescent population. For example, fewer girls than boys are physically active (USDHHS, 2000). According to the National

Association for Sport and Physical Education (NASPE), teaching fundamental motor skills is one of the most important foundations established for a young child to lead a physically active lifestyle, as well as enhance a child's social, cognitive, and physical development (2001). This phenomenon may result from young children that do not learn these fundamental movement skills will have difficulty incorporating the movement skills into a physically active lifestyle later in life.

Researchers have investigated the age children master performing fundamental motor skills, although knowing according to the motor development textbook by Gallahue and Ozman (2002) these motor skills should be mastered by ages 5 or 6 years. Current empirical research on the ages of motor skill mastery does not agree with motor development textbooks (van Beurden, Zask, Barnett, & Dietrich, 2002). By the time children reach the age of 12, many have not mastered the basic fundamental motor skills. This was demonstrated in a study by van Beurden et al. (2002) that looked at 1045 eight to ten year old children's proficiency of fundamental motor skills. These researchers investigated the mastery ages of eight fundamental motor skills in children. Rating categories were "mastery," "near mastery," or "poor" based on five to six components considered essential to each skill. Results showed only 21.3% and 25.7% achieved "master" or "near mastery," respectively, for the eight skills. Approximately 50% of the remaining children performed at the "poor" level. Seefeldt and Haubenstricker (1982) tested eight fundamental motor skills using the qualitative approach of total body sequences and found 60% of 6-year-old boys and girls performed only two out of eight skills at a mature level. Both genders performed mature running patterns, where as boys performed overarm throwing and girls performed skipping patterns at a mature level.

Therefore 40% of the 6-year-olds did not perform at a mature level. These two studies, although published twenty years apart, both show children are not mastering motor skills at young ages. In 1982, 60% of children age 6 could not perform most skills at a mature level, whereas in 2002, 50% of children age 8 to 10 could still not perform at a mature level.

This evidence of a children's lack of motor skill performance support the need to improve children's fundamental motor skills in physical education programs. Effective teaching of motor skills is an important part in the learning process for children, however one step in teaching fundamental motor skills is to find important factors associated with them. Woollacott (2002) stated, Amiel-Tison and Grenier's (1980) work gave interesting evidence to support the hypothesis that postural control is critical to motor skill development. They found when stabilizing an infant's head, the infant was able to reach for an object whereas not otherwise able to perform this task without the postural control of the head and trunk. Therefore, showing balance is a factor in motor development that may be an important aspect of motor skill performance. Children not mastering motor skills by certain projected ages may have balance concerns that are not acknowledged. Failure to master these fundamental motor skills may prohibit participation in physical activities, therefore not achieving or maintaining a healthy physically active lifestyle.

Measuring Fundamental Motor Skills

Fundamental motor skill performance has been evaluated qualitatively using developmental sequences called segmental body approach and total body approach. These approaches breakdown motor skills into sequences of stages in hierarchical order, either segments of the body or the whole body, to allow for an objective measure of an overall product score. Each higher stage in both approaches consists of biomechanically more efficient performances (Seefeldt & Haubenstricker, 1982). Both approaches show the complex nature of developmental changes in performance of fundamental motor skills.

Segmental body approach. This observational approach describes changes that are expected to occur within each body part during an action, such as the forearm, arm, leg, and hip. Changes in the movement patterns of different body segments do not necessarily occur at the same time, therefore should be analyzed separately. For instance, the arm could be at one level and the leg at another level.

There are advantages and disadvantages to this approach. The advantages are it allows the body to progress in different fashions. Instruction can be individualized to the part of the body that needs it. In addition, the varying steps within the skills have been validated by longitudinal studies. The disadvantages are it is not practical for the physical education teacher to use with classes of 30 to 40 students and it is difficult to evaluate overall progress (Payne & Isaacs, 1999).

Total body approach. This observational approach breaks skills down into stages, but the whole body in each stage, such as the arm, leg, and hip, all progress in the same fashion. This approach implies that as change occurs, the interrelationships among body segment are unified (Seefeldt & Haubenstricker, 1982). This approach looks at the progress from an immature to a mature form. In general, an immature performance at stage one is specified for individuals who do not integrate the skill components in a coordinated manner. Stage two, most of the skill components have been mastered into a smooth pattern. At stage three, the skill components movements are beginning to be performed in a well-integrated fashion, where stage four well integrated movements are performed to achieve a mature form (Seefeldt & Haubenstricker, 1982). Ulrich and Ulrich (1985) used the total body approach for 3, 4, and 5 year olds to assess six fundamental motor skills. This approach was used to assess skill proficiency to find if there is a relationship between skills, age, and balance ability.

There are advantages and disadvantages to this approach. Advantages are it is practical for physical education teachers and is useful for evaluating progress. The disadvantages are it assumes the whole body progresses as a unit, it does not allow for individualized instruction, and there is very little evidence that proposes stages actually occur (Payne & Isaacs, 1999).

Different Categories of Fundamental Motor Skills

There are two types of fundamental motor skills. They consist of locomotor and object control skills. Locomotor skills are movements that transport an individual through space from one place to another. These consist of walking, running, jumping, and hopping. Object control skills are manipulative skills that involve the control of objects primarily with the hands and feet (Gabbard, 2000). For this study, only one locomotor and object control skill will be investigated: kicking and jumping.

Kicking. Children of all ages take part in various kicking activities in and outside of school (e.g., soccer, football, kicking). Kicking is an object control fundamental motor skill in which one foot is used to strike an object. To execute a true kicking pattern, the child needs the postural control to stand momentarily on one foot while imparting force to the ball with the other foot. The age kicking develops in children has not been ascertained. However, Gabbard (2000) stated the ability to kick a stationary ball (with minimal form) appears around the age of 2 years, but it is not until 5 or 6 years that the mature pattern is achieved by most children.

Kicking performance, using placekick with a stationary ball, has been evaluated with the total body approach. Placekick, where a ball is placed stationary on the ground or a kicking tee, is usually the first achieved skill and a foundation before more advanced skills are developed, such as kicking a rolling ball, dribbling, and punting (Gabbard, 2000). In the total body approach the developmental sequence for placekicking has four qualitative stages, each consisting of three phases: preparatory phase, force production, and follow-through phase. The components of a mature placekick consist of a running start, an elongated stride immediately prior to ball contact, the kicking leg is flexed at the knee, a vigorous kick and follow through with the ball so the support leg performs a hop (Payne & Isaacs, 1999). The stages of kicking performance are described in Appendix E.

Butterfield and Loovis (1994) found kicking performance of boys and girls increased yearly up to ages 9 to 10 years old. However, by 4 to 5 years old boys and girls scored 10% and 9%, respectively, at a mature level of kicking. In addition, 6 to 7 year old boys and girls scored 42% and 30%, respectively; where are 8 to 9 year old boys and girls scored 84% and 59%, respectively at a mature level of kicking. By the time children were 6 to 7 years old, an average of 37% were able to perform mature levels of kicking.

Similar results were found by van Beurden et al.'s study of kicking-proficiency as children ran up and kicked a five-inch play ground ball as far as possible with the top of their foot (2002). The results demonstrate "poor" performance by 8 years old boys and girls who scored 45% and 80%, respectively, and by 9 years old boys and girls scored 38% and 75%, respectively. These results showed fewer than half of the children (43%) achieved "master" or "near mastery" levels by 8 to 9 years old (van Beurden et al., 2002). These studies support the need to emphasize kicking skill development for children at young ages since most of the children are not demonstrating kicking mastery by ages 5 or 6 years old (Duger et al., 1999; Gabbard, 2000; Gallahue & Ozman, 2002).

Kicking performance and gender was found as well by both Butterfield and Loovis (1994) and van Beurden et al. (2002). In Butterfield and Loovis' study a higher percentage of boys performed mature kicking patterns in ages 4 to 14 years old over girls, however with only one significant difference found in 10 to 11 year olds. In van Beurden's et al. study, kicking was one of the highest skill performance areas for the boys with 59% performing in the 'mastery' and 'near mastery' levels, yet one of the lowest for the girls with 23% performing in the 'mastery' and 'near mastery' levels. Boys outperformed girls in both studies.

Jumping. The locomotor skill of jumping is one of the most fundamental of all motor skills and most diverse. It requires the individual to project their body into the air by generated force by one or both legs and landing on one or both feet. It requires sufficient leg strength to propel the body off the ground and the ability to maintain postural control in the air and when landing.

General jumping patterns of a two-foot takeoff and landing in the form of a standing long jump and vertical jump are two common patterns jumping. Wang and Ju (2002) looked at standing long jump and vertical jump in children with and without Down syndrome, where only the children with Down syndrome received jumping lessons. The results found children with Down syndrome performed significantly better than the children without Down syndrome. Standing long jump, the standard fundamental jumping skill, looks at jumping ability in relation to maximum horizontal distance. It requires the center of gravity to be slightly ahead at about 45 degrees of the base of support at take off. This causes difficulty not to step forward due to a loss of forward balance. The vertical jump requires the body and legs to remain vertical throughout the jump for the purpose of achieving maximum height. It is usually measured by observing an individual reaching for an overhead target to elicit maximum reach. The vertical jump has been observed in two year olds, however mastery is achieved at approximately 5 years, where as mastery of standing long jump is usually observed at 6 years of age (Gabbard, 2000).

These two forms of jumping provide elements for more advanced jumping skills, such as rope jumping activities, folk dancing, running long jump, triple jump (hop-step-jump), and high jump. Standing long jump is slightly more difficult than the vertical jump due to the angle the body is projected in a forward and upwards motion and coordinated arm movements with the legs (Gabbard, 2000).

In the total body approach the developmental sequence for the standing long jump has four stages with three phases for each stage: preparatory, takeoff and flight, and landing phase. The components of a mature (stage 4) standing long jump consist of flexion of both knees with arms extended behind the body, and then extend vigorously forward and upward upon takeoff, reaching full extension above the head at liftoff. The hips and knees are extended fully, with the takeoff angle at 45° or less. Arms are thrust downward and the legs are thrust forward until the thighs are parallel to the surface when feet contact during landing.

Payne and Isaacs (1999) cited, Haubenstricker, Seefeldt, and Branta's (1983) work which validated the developmental sequence of the standing long jump on a mixed longitudinal sample of 430 preschool children (2½ to 5½ years old) and 1996 primary-grade children (6 to 9 years old). Stage one was found to be most prominent in children under 3½ years of age. Stage 2 jumping pattern was found most prevalent between 4 to 7 years of age, where as stage 3 was dominate by 8 years. Only 10% of 8 to 9 year olds exhibited stage 4 patterns. Mature standing long jump process characteristics (stage 3 and 4) do not predominate until 8 or 9 years old. The stages are of standing long jump performance are described in Appendix F.

The jumping-proficiency results from van Beurden et al.'s study looked at six components of the vertical jump as the child jumped vertically as high as possible from starting with their knees bent (2002). These results demonstrated vertical jumping proficiency was the poorest performance for boys and girls of the eight fundamental motor skills. "Mastery" was achieved in 15% and "near mastery" in 24% of the children. This shows that more than 75% of the children performed at the poor level. For individual genders, 33% of the boys and approximately 45% of the girls performed in the combined 'mastery' and 'near mastery' levels for vertical jumping.

Balance

Balance, or stability, is traditionally defined as "a state of equilibrium maintained between opposing forces" (Burton & Davis, 1992; p.14). It is believed to be an "integral part of almost every movement task" (p. 14) and is frequently called postural control. Postural control is "an ability to maintain equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support" (Horak, 1987, p.1881). Equilibrium and stability are commonly used terms to describe balance (Burton & Davis, 1992). The development of balance, or postural control, involves the nervous system and postural muscle responses contributions.

Balance and Development

Balance is defined as the ability to control the body's position in space to maintain upright in a given environment (Shumway-Cook & Woollacott, 2001). It is an important underlying factor for fundamental motor skills (Massion, 1992; Sveistrup & Woollacott, 1996; Gabbard, 2000; Woollacott, 2002; Woollacott, Debu, & Shumway-Cook, 1987; Ulrich & Ulrich, 1985). However, before the development of fundamental motor skills, certain postural reflexes occur and rudimentary abilities develop in a child.

Postural reflexes occur around birth to 1 years old. They are involuntary movements that are similar to later voluntary movements. For example, the primary stepping reflex resembles later voluntary walking (Gallahue & Ozmun, 2002). Rudimentary movements are the first forms of voluntary movements, approximately occurring around 1 to 2 years old. They involve stability movements, such as gaining control over the head, neck, and trunk muscles and establishing a relationship between the body and gravity to control the body against gravitational force to sit upright, leading to upright standing posture, and then locomotor movements as attempts to dynamically shift the body to walk, which depends on the control of the musculature in opposition to gravity (Gallahue & Ozmun, 2002).

Fundamental movements are an outgrowth of rudimentary movements that begin approximately around 2 years of age. This is a period where the child has greater control over movements and continues to explore different ways their body moves. Fundamental motor skills are characterized by mechanically efficient, coordinated, and controlled movements. These voluntary movements involve an element of stability to control the body against gravitational force, as seen in infants. Without stability, these movements could not be performed. In addition, the ability to maintain balance is included in almost all motor skill assessments, especially those focused on the movement abilities of young children (e.g., Adapted Physical Education Assessment Scale, LAUSD, 1984; Bruininks-Oseretsky Test of Motor Proficiency: Bruninks, 1978) (Gallahue & Ozmun, 1997).

Role of Balance

Balance has been demonstrated as a multifaceted approach, consisting of different types of balance. It is claimed to be an important underlying factor for the development and acquisition of fundamental motor skills (Massion, 1992; Gabbard, 2000; Sveistrup & Woollacott, 1996; Woollacott, Debu, & Shumway-Cook, 1987; Ulrich & Ulrich, 1985). It is widely believed that successful motor skill performance, even the simple tasks of standing and walking, require the ability to establish and maintain balance (Bril & Breniere, 1993; Gabbard, 2000; Macpherson, Fung, & Jacobs, 1997). For example, balance appears to be an underlying component of the fundamental motor skill of kicking. Gabbard (2000) states kicking ability requires a child to use one leg as a base of support (BOS) while rapidly moving the other in a forward direction. This task requires an individual to stand on one foot (static balance), in addition to moving and controlling their center of gravity (COG) within their BOS (dynamic balance). Researchers have attempted to answer the question of the relationship between balance and motor skills, although the results appear to be inconclusive. In addition, some of the ways used to assess balance are questionable.

Liao & Hwang (2003) investigated the relationship between balance and gross motor ability in children with cerebral palsy. The children's gross motor developmental ability and various static and dynamic balance testing using a force platform, along with static field balance tests, were assessed in fifteen 5 to 12 year old children with cerebral palsy. Static balance was tested using a stable force platform surface with eyes open, closed, and a moving visual surrounding, along with a moving surface and visual surrounding together. In addition, standing on one foot and heel-to-toe standing on the ground was tested. Dynamic balance was tested using the lateral rhythmic weight-shifting test. Their results found the five static balance tests on a stable surface showed a significant relationship to motor ability. However, none of the dynamic balance test showed a relationship to motor ability. This may in part be that lateral weight shifting does not require the balance needed to perform motor skills. In addition, their results showed 64% of motor ability was predicted by balance in children with cerebral palsy.

Butterfield and Loovis (1994) investigated the relationship between balance and kicking performance in school-aged children. They looked at contributions of age, gender, kicking performance, static and dynamic balance, and soccer participation in children 4 to 14 years of age. They tested 379 boys and 337 girls in nine grades (K-8^{th})

on place kicking performance by categorizing performers into one of four performance levels. Static and dynamic balance were measured using the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) short form consisting of one static and one dynamic balance test, along with a soccer participation survey. The results showed inconclusive evidence for kicking performance and static and dynamic balance. There were no relationship between kicking performance and static or dynamic balance in eight of the nine groups, however the group of 7th graders (11-12 year olds) showed a significant relationship between kicking performance and static balance ($t = .04$, $p < .05$) and dynamic balance ($t = -.05$, $p < .05$). This meant the 11 to 12 year olds that scored high on kicking performance performed high on static balance (one-foot stance on a beam) and low on dynamic balance (heel-to-toe walk on a beam). These findings of the opposite spectrum for the different components of balance do not show both are important for the motor skill performance of kicking. It just found good static balance ability was related to good kicking ability, and not dynamic balance. Therefore there is still an inconclusive relationship for the importance of balance ability to motor skill performance.

More inconclusive results were found by Ulrich and Ulrich (1985). They examined the relationship between the ability to balance and perform fundamental gross motor skills when age is taken out in 72 preschoolers (33 girls, 39 boys), ages 3 to 5 years old. Balance ability measures included the BOTMP balance subset resulting in a balance composite score, along with individual static and dynamic balance scores. The total body approach was used to assess the fundamental motor skill performance of throwing, kicking, striking, jumping, hopping, and skipping. Balance ability and motor skill performance showed inconclusive relationships. Using the balance composite score, hopping on preferred ($F_{1,69} = 6.37$) and non-preferred foot ($F_{1,69} = 21.72$), jumping ($F_{1,69},= 7.06$), and striking ($F_{1,69},= 5.37$) significantly related to balance ability ($p < .05$), however, balance accounted for only 5% to 17% of these skills. Skipping ($F_{1,69},= 2.22$), throwing ($F_{1,69},= 1.92$), and kicking ($F_{1,69},= 1.21$) were not significant ($p > .05$). In addition, the individual static and dynamic balance scores had no significant relationship to the performance of skipping, throwing, or kicking, but showed significance in the areas of hopping, jumping, and striking, just like the composite score. Static balance showed a significant relationship to hopping on the preferred foot ($F_{1,69} = 7.11$) and striking ($F_{1,69} = 7.42$); dynamic balance scores showed a significant relationship to jumping ($F_{1,69} = 9.73$), and both static ($F_{1,69} = 13.90$) and dynamic ($F_{1,69} = 15.30$) balance scores had a significant relationship to hopping on the nonpreferred foot ($p < .05$). These finding support that balance plays a role in the motor skills of hopping, jumping, and striking, but not for skipping, throwing, or kicking. These results Ulrich and Ulrich found conflicted with Butterfield and Loovis' (1994) study since no relationship was found between static balance and kicking performance.

Results of Butterfield and Loovis (1994) and Ulrich and Ulrich (1985) showed inconclusive relationships between balance ability and the motor skills of kicking and jumping. Butterfield and Loovis showed no relationship between balance and kicking for 4 to 10 year olds, just a relationship between static balance and kicking for 11 and 12 year olds. Ulrich and Ulrich found no relationship for balance ability or individual static and dynamic balance tests and the skill of kicking, in addition to a low practical significance for the balance ability and dynamic balance, and jumping.

It is not surprising that no conclusive results were found as a result of the tests used to assess balance. Both studies measured balance using BOTMP sub-test, which is a field test that may be unable to measure the type of balance control necessary for kicking or jumping. In addition, the BOTMP sub-tests have been found to have a low reliability (Wilson et al., 1995). This lack of relationship among balance ability and motor skills may be due to the insensitivity of the field tests used. The obtained scores may reflect the ability to perform that discrete task, such as the ability to stand stationary on one foot, but not the ability to control the body movements during kicking and jumping. Butterfield and Loovis (1994) supported this point by stating that the field test of balance beam walking, which was used to measure dynamic balance, was insensitive to the balance strategy used for kicking performance.

A complete evaluation of balance ability needs to be warranted to demonstrate true balance ability. van Beurden et al.'s (2002) study showed a lack of assessing true balance ability. Their children performed well on a static balance test, but poor for other motor skill performances. From these results, one may think the children had good balance, but poor motor skills. However, the other motor skills, such as kicking and jumping, involve dynamic and functional balance that were not looked at. You cannot say a child has good balance ability just because he or she has good static balance to stand on one foot. The other components of balance need to be looked at. Therefore a complete evaluation of balance ability needs to be investigated.

In addition to motor skills, studies have looked at balance and their relationship to functional activities, such as activities of daily living (ADL) in adults (Era et al., 1997; Owings, Pavol, Foley, & Grabiner, 2000; Shimada, Obuchi, Kamide, Shiba, Okamoto, &

Kakurai et al. 2003). Era et al. (1997) conducted a study to find associations between balance and performing ADL in 75-years olds. Standing balance on a force platform with eyes open and closed, along with self-reported physical activity sheet, were conducted on 1392 men and women. The results showed a statistically significant relationship between balance and ADL ($r = .13$, $p < .01$), but balance was a weak predictor of ADL performance ($R^2 = 2\%$). When physical activity, health, and gender were added to the relationship to ADL performance, balance was not significant ($r = .06$, $p > .05$), however physical activity ($r = -.35$), health ($r = .15$), and gender ($r = .15$) were all highly significant predictors of ADL performance ($p < .01$). Therefore these three factors largely influenced ADL performance ($R^2 = 22\%$) and balance did not.

Owings et al. (2000) conducted a study that showed balance was not related to functional tasks. They looked at 79 older adult's (50 female and 29 male) static and dynamic balance measures to see if these would predict maintaining balance after a disturbance. Static balance was measured with a two-footed stance on a force platform. Dynamic balance was measured with the Limits of Stability test and rhythmic swaying on a force platform. In addition, three postural disturbances were provided (tripping, treadmill, or maximal lean test) that elicited a stepping response to regain their balance. The results of this study showed no relationships between the subjects static or dynamic balance measures with either successful or failed balance recoveries from a disturbance. This study found performance of static and dynamic balance tests were statistically independent of motor skills and that balance ability is not related to the functional tasks of a stepping response while walking.

Shimada et al. (2003) conducted a study and found that static balance shows no relation to the motor skill of walking. These researchers looked at the relationship between static, dynamic, and functional balance in young and older adults and found static balance did not relate to the functional skill of walking ($r = -.55$, $P = .02$), therefore standing and walking balance are independent of each other in young adults. In contrast to these findings, Era et al. (1997) separated individuals into two groups as those who need and did not need help with functional abilities, such as walking, stairs, and bicycling. The individuals who did not need help performed better on static balance tests. This shows that those with better static balance were able to perform more activities independently, illustrating that balance is important for physical activity. These two studies show contradicting evidence to the importance of balance to performing motor skills.

Studies have shown there is a relationship (Butterfield & Loovis, 1994; Era et al., 1997; Ulrich & Ulrich, 1985) and is not a relationship (Era et al., 1997; Owings et al., 2000; Shimada et al., 2003) between balance ability and functional skill performance in both children and adults. There is no doubt that balance is important, however empirical evidence is inconclusive on this issue relating to motor skill performance.

Mechanisms for Balance

The ability to maintain balance depends on the integrative functioning of many factors. One way this is accomplished is through sensory systems providing the central nervous system (CNS) with specific information about the position and motion of the body. The information to control balance is provided by the visual, vestibular, and somatosensory systems. Each system provides a different frame of reference, with respect to gravity, support surfaces, and the surrounding environment, for postural control, which is then decoded and organized by the CNS to know where the body is in space (Shumway-Cook & Woollacott, 2001). This process results in a state of balance. Missing or inaccurate information from one of these systems may result in a loss of balance (Shumway-Cook & Woollacott, 2001).

The somatosensory system provides information through the muscle spindles, Golgi tendon organs (sensitive to muscle length and tension), and joint receptors (sensitive to joint movement and stress) to the CNS regarding the position and motion of the body with reference to the support services (environment), in addition to the relationship of the body segments to one another (Burton & Davis, 1992; Lee, 1978). This system provides a vertical orientation, so in circumstances where the support surface is not flat or stable, somatosensory inputs are not helpful to establish a vertical orientation (Shumway-Cook & Woollacott, 2001).

The vestibular system provides information to the CNS about the position and motion of the head with respect to gravity. It consists of two types of receptors: semicircular canals and otoliths. The semicircular canals sense fast angular movements of the head, such as during walking or stumbling. The otoliths detect linear head position and movements with respect to gravity. They detect slow head movements, such as postural sway. A limitation of the vestibular system is it cannot detect the true picture of the body moving in space. These receptors alone cannot distinguish between just the head moving or both the body and head moving together (Horak & Schupert, 1994).

The visual system provides important information for postural stability. The optic flow field can distinguish between all forms of body movement. It provides information regarding position and motion of head movements in relation to surrounding objects (environment). If one moves their head forward, their optical view moves backward, indicating forward motion (Nashner & Berthoz, 1978). Reference points for movement are directed vertically since most surrounding are aligned vertically—doorways and windows. Visual inputs are not a necessity to balance since an individual can remain balanced on one foot with their eyes closed. However, it does actively contribute to balance control during quiet standing. In addition, the brain may misinterpret visual inputs as well. For example, if an object in sight moves backwards, the brain initially interprets the information as self-motion. A limitation to this sense is the brain has difficultly distinguishing between object motion and self-motion (Shumway-Cook & Woollacott, 2001). These three sensory systems provide the CNS with specific information regarding body orientation.

Sensory Systems Dominance

Through the development of balance control in children, the dominance of one sensory system over another changes. Visual inputs appear to be dominant in the control of posture before the ages of 6 to 7 years, then shifts to all systems to lead up to better balance (Lee & Aronson, 1974; Shumway-Cook & Woollacott, 1985).

The influence of vision appears to be particularly important in postural control for children. It is known that postural responses begin to develop in a cephalocaudal direction: a child first gains control of the head and neck, followed by the truck and subsequently the legs

(Woollacott, Shumway-Cook, & Williams, 1990). Therefore as control over the head and neck develops, vision will play an important role. Visual, along with contributions of somatosensory and vestibular sensory systems were investigated in children and adults by Lee and Aronson (1974), Shumway-Cook and Woollacott (1985), and Woollacott, Debu, and Mowatt (1987).

Lee and Aronson (1974) investigated to what extent vision is an integral part of postural control in the early stages of development. They wanted to see the responses to conflicting visual and somatosensory input in children 13 to 16 months old learning to stand. They designed a "moving room," consisting of a stable floor with the walls moving forward to simulate postural sway or a loss of balance in the backwards direction. They found the children would sway in the direction of the moving room, resulting in 82% of the trials children swayed, staggered, or fell in the forward direction. The children ignored their ankles somatosensory inputs telling them they were falling forward. This shows the children relied on visual information for postural control and were insensitive to their somatosensory system inputs (Lee & Aronson, 1974). Shumway-Cook and Woollacott (1985) found children 1 to 3 years old showed vision dominates as well. However, adults and older children with conflicting visual and somatosensory input were sensitive to misleading visual information, although they did not loose their balance (Woollacott, Debu, & Mowatt, 1987). This shows visual information is important in adults as well, but other sensory systems are involved in correcting misleading information received.

Shumway-Cook and Woollacott (1985) found the shift from visual dominance to somatosensory integration occurs between the ages of 4 to 6 years old. Greater threats to stability were found caused by reorganizing sensory inputs and resolving conflict during postural control. Leading to older children between 7 and 10 years old learning to adapt their postural responses during sensory conflict, although still taking longer to adapt than adults.

Woollacott, Debu, and Mowatt (1987) found for young children and adults that visual input is not required to control stability, however it is still dominant. They conducted horizontal perturbations on children 2 to 6 years old and adults, with their visual input removed, while recording muscle response latencies. The results showed with vision removed children 2 to 3 year olds had reduced or the same muscle response latencies as with vision. Where as children 4 to 6 years old showed greater variability in muscles latencies. The adults had no significant difference in the muscle responses latency. Although there was reduced or variability in muscle latencies in young children, postural responses still occurred without visual cues. These results show visual cues are not required to activate postural responses to remain balanced and removing vision will increase the sensitivity of the somatosensory and vestibular systems (Woollacott, Debu, & Mowatt, 1987). However in conditions where vestibular cues only remain to control stability, children were unable to depend on the vestibular system alone to balance efficiently. Research has shown the visual system is dominant in postural control. However, it still remains children are most unstable with sensory conflict, especially when the visual, somatosensory, and vestibular information do not agree (Shumway-Cook & Woollacott, 1985).

Postural Muscle Responses

In addition to the sensory systems providing the CNS with specific information about position and detecting a loss of balance, the postural muscle responses for controlling balance are an important contributor to the development of independent balance control in children.

Research has shown children without disabilities as young as 15 months of age can produce consistent postural response patterns similar to young adults as seen as distal muscles are activated prior to proximal muscles, but the responses are of longer latency and duration and have larger amplitude bursts of activity (Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985). Williams, McCleneghan, and Ward (1985) looked at muscular activity of the gastrocnemius, tibialis anterior, and erector spinae muscles while standing in children 4 to 10 years old for 30 seconds. These muscles provide the greatest muscular support for postural control by having an even distribution of muscular effort between the truck and leg muscles. The results showed 4 year old children's gastrocnemius and erector spinae muscles were active the largest percentage of the time, while the tibialis anterior was generally not active. The same response were seen in 8 and 10 year olds as well, showing appropriate muscle activity to control balance, however at the age of 6 years, all three muscles were active and showed co-contraction a larger percentage of the time. Therefore a transition period was found to occur in balance control between ages 4 to 6 years old.

This transition period was also seen in a study by Shumway-Cook and Woollacott (1985). They found a delay of leg muscle activation when balance was perturbed at these ages, where as there is no delay for children younger than 4 and older than 6 years. At approximately 6 years of age 95% of the neuromotor maturation is complete. In addition, they found by the age of 7 years, constant patterns of muscle response under sensory conflicts are comparable to adults (Shumway-Cook & Woollacott, 1985). As well as, Williams et al. (1985) study showed 8 to 10 year olds demonstrated appropriate muscular activity to control balance.

In addition, Williams, Fisher, and Tritschler (1983) conducted a study that showed muscle activity during balance tasks of 4, 6, and 8 year olds. They found that muscle EMG amplitude decreased systematically between the ages of 4 to 8 years of age. The 4 year olds had the most erratic profile, where as the 8 year olds had smoother EMG profiles. This shows that the younger children used excessive amounts of muscular activity to perform tasks, whereas older children appear to be better able to produce the appropriate amount of muscular activity for maximum efficiency. Therefore, this supports that around the age of 6 years old is where the somatosensory, vestibular, and visual systems are working together and the neuromotor system is refining itself. However, intervening factors, such as experience, have been shown to increase sensory systems and muscle responses in children (Debu & Woollacott, 1988; Whitney, 1992).

Experience with Balance

As children age their balance improves through the development and refinement of their sensory systems and muscle responses. With age comes physical maturation, along with life experiences and opportunities to perform activities that involve balance, as demonstrated by better balance of older children when compared to younger children. Physical maturation cannot be controlled, where as experiences with balance activities can. Therefore, balance experience makes a difference in balance performance among young children (Debu & Woollacott, 1988; Whitney, 1992). Studies have demonstrated this point by looking at balance ability of children participating in balancing activities through gymnastics and comparing them to children participating in other activities, such as swimming, as well as comparing more and less experienced children in gymnastics.

Whitney (1992) compared female gymnasts with balance experience and swimmers 5 years of age on postural sway, muscle response latencies, and kinematics during walking on a balance beam. The results indicated that gymnasts showed a tendency to have less sway, faster muscle response latencies, and less range of motion during walking than swimmers. Therefore, showing younger children with balance experience responded faster and demonstrated less postural sway when perturbed than children with no balance experience. This study supports that at an early age, children can improve balance performance by engaging in balance activities.

Debu and Woollacott (1988) supported this claim as well by testing both experienced and non-experienced children gymnasts. Their results found children with more experience tended to present more adult-like muscle responses, than the non-experienced group. For example, the experienced gymnasts showed efficient postural responses by not engaging muscles that were not involved and shorter muscle response latencies than the inexperienced group who tended to co-contract muscles and have longer response latencies. Therefore, it appears experience acquired through practicing gymnastics and training increased the postural responses at an early age.

Research has shown that significant differences exist between experienced and inexperienced in children involved in balance activities. Young children participating in balance show differences related to muscle involvement and response latencies than those not participating in balance activities (Debu & Woollacott, 1988; Shumway-Cook & Woollacott, 1985; Whitney, 1992; Woollacott et al. 1990). This shows practicing balance activities at a young age can increase balance ability and postural responses used to control balance during motor skills.

Components of Balance

Tests of balance are set up to measure the different aspects of balance. Tasks that involve standing on one or two feet, standing on two feet while moving the upper body around, and task that involve locomotion are ways to test balance, also categorized as static, dynamic, and functional balance. Empirical evidence has shown that static, dynamic, and functional balance are different aspects of balance and therefore should be assessed and addressed separately (Brouwer, Culham, Liston, & Grant, 1998; Drowatzky & Zuccato, 1967; Hoffman & Koceja, 1997; Lindmark, Lagerstrom, Naessen, & Larsen, 1999; Shimada et al. 2003).

Different aspects of balance were addressed in an early study by Drowatzky and Zuccato (1967). They investigated the relationship between selected static and dynamic assessments and found a low correlation between them. The authors examined six static and dynamic balance tests typically found in the physical education literature. Fifty girls ranging from 11 to 13 years old were given six tests: stork stand (both legs), diver's stand, stick test, sideward leap, bass stepping stone test, and balance beam test. The correlations between each pair of tests were computed (15 pairs in all). The results showed the highest correlation was between the bass stand and the sideward stand ($r = .31$), meaning these two tests had 9.6% in common. All of the other correlations were lower than this, ranging from .03 to .26. These results support that each balance test measured some separate ability for balance control.

Different types of balance tests cannot be looked at together to find a general category for balance control. This point was supported by Hoffman and Koceja (1997) that different types of balance tests are not related to how an individual actually controls their balance. These researchers conducted a study on static and dynamic balance measures while on a force platform in ten young adults. Static balance consisted of a standing postural sway measure and a newly developed dynamic balance measure of the time duration to return to a stable standing balance after an electrically induced perturbation to both leg's tibial nerves. They found that static balance did not correlate with dynamic balance measures ($r \leq .07$), showing they are independent of each other.

This concept was seen in a study by Shimada et al. (2003) as well. They investigated the relationship between static, dynamic, and functional balance in young and older adults. Eighteen young adults ranging from 20 to 32 years old and 18 older adults ranging from 65 to 79 years old performed three measures: static (standing balance), dynamic (standing on a rotating and translating force platform) , and functional balance (walking while perturbed on a bilateral separated treadmill that measured changes in anterior and posterior trunk accelerations). Their results found no relationship between the static, dynamic, and functional balance tests. Static balance did not correlate with either the dynamic ($r = .19$; $P = .43$) or functional balance ($r = .39$; $P = .10$). In addition, dynamic balance did not correlate to functional balance ($r = -.55$, $P = .02$).

The following studies show that balance is multifaceted. Therefore supporting there is a type of balance needed to remain upright, being able to control the movement of the body while the feet are stationary and while moving. Static, dynamic, and functional balance tests create different challenges to the postural control systems and do not provide redundant information. These three types of balance are not related therefore measure different aspects of balance function and need to be assessed separately. Therefore balance has been subdivided and defined as three separate components.

Measurement of Balance

The measurement of balance can be subdivided and measured into three components: static, dynamic, and functional. There are clinical and field tests available to measure each component of balance. Clinical tests are administered in laboratory settings on apparatuses (NeuroCom, 1998). Field tests are used in the field, and are generally part of motor assessments and do not require high technical equipment (Bruininks, 1978; Ulrich, 2000).

Static Balance. The definition of static balance is the ability to limit the movement of the COG within the fixed BOS (Gallahue & Ozmun, 2002). This is also known as stability or standing balance. Clinical tests for static balance use a force platform. A force platform will measure subjects postural sway as they control their posture while standing on a stationary platform on either one or two feet (Clark & Watkins, 1984; DeOreo, 1976; Owings et al., 2000). Karlsson and Frykberg (2000) stated that postural sway is believed to contain valid information about balance. The center of pressure (COP) and horizontal plane forces exerted on a force platform while standing stationary is able to quantify the continuous movement of the body. Common objective measures for static balance include average sway velocity (average degrees of sway per second) (McGuine, Greene, Best, & Leverson, 2000), sway index (average amount for movement from the COG, measured in centimeters) (Baker, Newstead, Mossberg, & Nicodemus, 1998; Brouwer et al. 1998), and sway path length (the average distance traveled per second during the time period, measured in velocity) (Hoffman & Koceja, 1997; Rose, Wolff, Jones, Bloch, Oehlert, & Gamble, 2002).

Static balance field tests involve the length of time a subject can maintain a particular balancing position on a stable surface, such as standing on one foot or on a balance beam (APEAS, 1984; Bruininks, 1978). Field test are most used with standardized assessments, such as the Adapted Physical Education Assessment Scale and Bruininks-Oseretsky Test of Motor Proficiency.

Dynamic Balance. Dynamic balance is defined as the ability to move and control the COG within a fixed BOS (Gallahue & Ozmun, 2002), also known as dynamic balance ability (NeuroCom, 1998). The area the body is able to move in is called the limits of stability. A subject's limits of stability is pictured as a cone with its apex projecting from the feet in the standing position. This area within the cone represents the range the COG should be able to lean from their standing position without altering the original BOS by losing balance by stepping, reaching, or falling.

Clinical assessment devices have attempted to measure dynamic balance ability, using a force platform by having subjects voluntary move their COG from the stationary BOS in different directions. Common objective measures for dynamic balance include sway velocity (Shimada et al., 2003), end point and maximum excursion (Boulgarides, McGinty, Willett, & Barnes, 2003; Wallmann, 2001), and directional control (Liston & Brouwer, 1996; NeuroCom, 1998). Dynamic field test involve measuring an subjects reaching distance in front of the BOS on a stable surface (e.g., functional reach; Duncan, Weiner, Chandler, & Studenski, 1990).

Functional Balance. Functional balance is defined as the ability to move and control the COG within a moving BOS. This term refers to measuring the COG during locomotor movements, although stated as dynamic balance in most of the literature (Butterfield & Loovis, 1994; Shimada et al., 2003). This term will refer to the shape of the BOS changing over time, such as in walking or other activities where the feet do not remain fixed. Clinical assessments use measurements of time, such as speed, and end point sway velocity and step width (NeuroCom, 1998), but no assessment of the quality of movement performed. These tests are usually preformed on a long force platform. Functional field tests involve performing some sort of dynamic BOS, such as balance beam walking (Butterfield & Loovis, 1994), counting the number of steps off a line (Bruininks, 1978), hopping on one foot (APEAS, 1984), or basic functional tasks (e.g., get up and go; Mathias, Nayak, & Isaacs, 1986).

Computerized Force Platform Balance Assessments: NeuroCom Balance Systems

The NeuroCom Smart Balance Master® system is a commercially available computerized force platform that offers comprehensive documentation of postural control. The Balance Master a clinical assessment used to evaluate static, dynamic, and functional balance using COP measures obtained during anterior-posterior and medial-lateral movements. The computer calculates the COP, the vertical component of the COG, and the theoretical 100% limits of stability using the subject's height. The stable or dynamic force platform system continuously monitors the position and movement of the estimated COG in any direction by sampling the vertical forces, filtering out high-frequency oscillations and calculating the deviation from the vertical center to obtain objective and quantifiable measurements (Clark, Rose, & Fujimoto, 1997; NeuroCom, 1998). In addition, it is the only comprehensive device available for real-time movement analysis on a long force platform (Cambier, Cools, Danneels, & Witvrouw, 2001). The force platform contains four lead cells that transmit force information to the computer 100 times per second.

NeuroCom offers a broad range of systems to assess postural control. Each system contains specific tests for balance assessments on either a stable, moving (rotates or slides), or long force platform. Each test produces three or more outcome measures that should be assessed in conjunction with one another to provide a fuller picture of balance.

Reliability evidence for this apparatus are mainly available for the adult population (e.g., Rose & McKillop, 1998), however there is limited empirical data on the Balance Master for children (Cambier et al., 2001). Cambier et al. (2001) conducted a study to obtain reference data for 4 and 5 year old children. Seventy children without disabilities and three children with disabilities performed three tests on the Balance Master: Modified Clinical Test for the Sensory Interaction on Balance, Unilateral Stance test, and the Tandem Walk test. The test results of the 70 children without disabilities were compared to 3 children with disabilties in order to merit this system for children and assist in the assessment of postural control in different conditions for children. Liao & Hwang (2003) used the Balance Master to test static and dynamic balance in 5 to 12 year old children with cerebral palsy. Static and dynamic balance was tested using parts of the sensory integration test and the lateral rhythmic weight-shifting test. They found moderate (.60 - .67) to high (.86 - 1.0) reliability on the seven measures used.

There are many tests available using the NeuroCom Balance Master, however a few of the commonly used tests are describe below (NeuroCom, 1998).

Unilateral Stance Test®.

The Unilateral Stance Test is a static balance test that measures postural sway of a subject standing on a force platform on one leg, with the raised leg not touching the weight bearing leg. The subject performs three 10-second trials with eyes open and three with eyes closed, for each foot, a total of twelve trials in four different conditions. A COG sway velocity score is computed for each trial. The three trials are averaged together for each condition to find the mean COG sway velocity. A high mean COG sway velocity value indicates increased postural sway, i.e., poor ability to balance, while a low mean sway score indicates a relatively better ability to maintain balance. The results are averaged into three measures: sway velocities for each trial, mean sway velocity for each condition, and a composite mean sway velocity. The composite scores are an indication of the overall ability to balance for this test. Table 1 summarizes these three measures.

Table A.1. Outcome Measures, Descriptions, and Unit of Unilateral Stance Test

Test	Outcome Measures	Description	Units
Unilateral Stance	Sway Velocity	Distance traveled by the COG per a trial	Degrees per second
	Mean Sway Velocity	Average of the sway velocity scores from any one condition	Degrees per second
	Mean Sway Velocity (Composite)	Average of the mean COG sway velocity for all conditions	Degrees per second

McGuine et al. (2000) measured balance using the unilateral stance test for high school basketball players during preseason to categories players with poor, average, or good balance. They wanted to see if measures of postural sway would predict ankle sprains during the season. The results showed that players with better balance, those with less postural sway, had less ankle sprains than those with poor balance ($x^2 = 10.35$; $p = .001$). In addition, the researchers reported a high reliability of the composite score (R = .88) and moderate for eyes open and closed (R = .51 and R = .64) for high school students. Test-retest for the unilateral stance test has been reported for adults 20 to 79 years old by Rose and McKillop (1998) to be poor for eyes open and closed (R=.35 and R = .50) and moderate for the composite score (R = .76).

Tandem Walk Test®.

The Tandem Walk Test is a functional balance test used to measure several characteristics of gait. It involves a subject to stand on a long force platform with one foot in front of the other and when given a visual cue, start walking heel-to-toe from one end of the long force platform to the other as quickly as possible, and then stand still as quickly and comfortably as possible. This test is repeated three times. The results are averaged into three measures: step width, speed, and postural end sway velocity at the endpoint. Step width looks at the COG control of being able to maintain the COG over a narrow BOS. The speed looks at how fast the subject can move and end sway measures look at controlling the COG after a forward momentum. Table 2 summarizes these three measures. Test-retest for the tandem walk test has been reported by Rose and McKillop (1998) to be moderate for step width (R=.77) and speed (R=.76), and poor for end sway (R=.43).

Table A.2. Outcome Measures, Descriptions, and Units of Tandem Walk Test

Test	Outcome Measures	Description	Units
Tandem Walk Test	End Sway	Average COG sway velocity after stopping at end of walk for 5 sec.	Degrees per second
	Speed	Average speed to the end of the force platform	Centimeter per second
	Step Width	Average lateral distance between successive steps	Centimeters

Incorporating balance tests that look at each component of balance—static, dynamic, and functional tests—will provide a complete analyze of balance performance. This was seen in van Beurden et al. (2002) as 75% of the 8 to 10 year old children performed well on the static balance test of standing on one foot, but a less than 40% of these children performed well on kicking and vertical jumping. These motor skills incorporated components of dynamic and functional balance as well that were not evaluated, only a static balance test. If the researchers looked at all three components of balance—static, dynamic, and functional—possibly not as many children would have performed as well as they did for the balance component. All the components of a skill need to be assessed to find a true evaluation of performance.

This review of literature provides readers with information on fundamental motor skills, along with the importance and role of balance to fundamental motor skills. In addition, this review includes the balance mechanisms and ages children develop proper postural responses and the effect experience has on these responses has been provided. Lastly, the components of balance and how they are measured was reviewed. From this literature, there is inconclusive evidence of the importance of balance to motor skills performance.

APPENDIX B – INFORMED CONSENT DOCUMENT

INFORMED CONSENT DOCUMENT

Project Title: The Relationship between Balance and Fundamental Motor Skills

Principal Investigator: Joonkoo Yun, Ph.D., Exercise and Sport Science

Research Staff: Jennifer Overlock, Graduate Student

PURPOSE

Your child is invited to participate in a research study conducted in the Exercise and Sport Science department. The purpose of this study is to investigate relationship between balance ability and fundamental motor skill performance of locomotor and object control skills in children 5 to 9 years old. Through the findings of this study, the components necessary for successful motor skill performance can be acknowledged. This outcome is important for teachers who teach children fundamental motor skills to understand the essential underlying factors of performance for successful teaching and planning physical education. The purpose of this consent form is to give you the information you will need to help you decide whether to be in the study or not. Please read this form carefully. You may ask any questions about the research, what your child will be asked to do, the possible risks and benefits, your child's rights as a volunteer, and anything else about the research or this form that is unclear. You are welcome to stay with your child during the testing sessions. When all of your questions have been answered, you can decide if you want your child to be in this study or not. This process is called "informed consent". You will be given a copy of this form for your records.

We are inviting your child to participate in this research study because your child is between 5 to 9 years old and has no documented physical or mental disabilities. Fifty participants are expected to participate in this study; 15 of the 50 children will return to perform the balance portion of this study within 7 days from their initial testing date. You are welcome to be present during your child's testing sessions.

PROCEDURES

If you agree to participate in this study, your child's participation will require one testing session that will last approximately 40 minutes. Fifteen children will be asked to return within 7 days to repeat only the balance portion of the test, lasting approximately 20 minutes. These 15 children will have up to a total of 60 minutes of expected participation time. You will be asked on an information sheet if your child will be able to return to repeat the balance portion of the test. The following procedures are involved in this study:

Information will be collected for gender, height, weight, date of birth, preferred kicking leg, shoe size, and history of kicking or balancing experience (i.e., years of soccer or gymnastics experience). This information creates a profile for your child.

Kicking: Your child will kick a 8 inch ball off a beanbag as hard as he or she can, which will be video recorded, and attempt to kick a 8 inch ball into a target 15 feet away in a gymnasium.

Jumping: Your child will perform a standing long jump on a mat in a gymnasium, which will be video recorded.

Balance tests: Your child's balance will be tested on two balance tests. During this session, your child will stand on a piece of equipment that is used to measure balance. The first test involves standing on 1 foot with his or her hands on his or her hips for 10 seconds on a 18" x 18" platform for three trials. He or she will be measured on his or her right and left foot. The second test involves your child to walk heel-to-toe on a 5-foot platform and stand at the end for 5 seconds in the heel to toe position. Fifteen children will return approximately 7 days later to repeat the balance portion of this study.

RISKS

The possible risks associated with participating in this research project are minimal. The risks of getting hurt will be low, but there is always a possibility. Your child will stand and perform the standing long jump on a mat. During the standing long jump there may be a minimal risk of getting hurt during the impact of landing, or falling forwards, backwards, or to the side upon landing from a loss of balance. To prevent this potential risk of impact or falling during the jump, your child will jump onto a mat. Your child will be asked to stand on one foot, both the right and left, for 10 seconds. An examiner will be close by when performing all balance tests. He or she may get tired or weak when doing these activities. He or she can tell me at any time if he or she does not want to continue.

BENEFITS

There will be no direct benefits to the participants of this study. The results of this study are important for physical education teachers who teach children fundamental motor skills to understand the essential underlying factors of performance for successful teaching and planning physical education.

COSTS AND COMPENSATION

You will not have any costs for your child's participation in this research project. Your child will receive a pencil at the completion of his or her participation for this study.

CONFIDENTIALITY

Records of your child's participation in this research project will be kept confidential to the extent permitted by law. However, Oregon State University Institutional Review Board (a committee that reviews and approves research studies involving human subjects) may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies your child. After completing the informed consent process, your child will be assigned an identification number. In the event of any report or publication from this study, your child's identity will not be disclosed. Results will be reported in a summarized manner in such a way that your son/daughter cannot be identified.

VISUAL RECORDING
By initialing in the space provided, you verify that you have been told that visual recording will be generated during the motor skill performance of your child. Your child's performance during these testing sessions is needed to check the consistency of the researcher's coding of the developmental levels of your child's performance. The video tapes will be stored in a secure location. Only research staff can access and view your child's records. At the completion of this study, the tape of your child's performance will be erased.

______Parent/Guardian's initials

RESEARCH RELATED INJURY
In the event of research related injury, compensation and medical treatment is not provided by Oregon State University.

VOLUNTARY PARTICIPATION
Having your child take part in this research study is voluntary. You may choose not to have your child take part at all. If you agree to have your child participate in this study, you may stop your child's participation at any time. If you decide not to have your child take part, or if you stop having your child participate at any time, your decision will not result in any penalty or loss of benefits to which he/she may otherwise be entitled. Such as your child's participation in KidSpirit will not be affected if he or she chooses not to participate in this study. If any data is collected from your child prior to withdrawal it will not be included in the study's results.

QUESTIONS
Questions are encouraged. If you have any questions about this research project, please contact: Jennifer Overlock at (541) 737-5927, email: overlocj@onid.orst.edu or Joonkoo Yun at (541) 737-8584, email: jk.yun@oregonstate.edu. If you have questions about your child's rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________________ ______________________

(Signature of Parent/Guardian or Legally Authorized Representative) (Date)

RESEARCHER STATEMENT
I have discussed the above points with the participant or, where appropriate, with the participant's legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

______________________________ ______________________

(Signature of Researcher) (Date)

APPENDIX C – ASSENT DOCUMENT

ASSENT DOCUMENT

Project Title: The Relationship between Balance and Fundamental Motor Skills
Principal Investigator: Joonkoo Yun, Ph.D.
Research Staff: Jennifer Overlock, Graduate Student

We are doing a research study. A research study is a special way to find out about something. We are trying to find out if there is a relationship between the ability to balance, kick, and jump. This form is about the study, so you can learn more about it. You can ask any questions. After all of your questions have been answered, you can decide if you want to be in this study or not.

If you decide that you want to be in this study, we will ask you to do several things. Your parent can stay with you the entire time. We will first measure your height and weight. In one session you will kick an ball as hard as you can off a bean bag while being video recorded, kick the ball into a rectangular target 15' away, and jump as far as you can onto a mat from behind a line, which will be video recorded. In the balance session, you will stand on a piece of equipment that is used to measure balance. There will be two different balance tests. The first one you will stand on one foot for ten seconds three times. You will do this on your right and left foot. The second test you will stand on a line and walk heel-to-toe across a line and stand in the heel-to-toe position at the end for 5 seconds.

We want to tell you about some things that might happen to you in this study. The risks of hurting yourself will be low, but there is always a possibility. You will be standing on one foot and jump onto a mat to keep you from hurting yourself when you land or in case you for forwards, backwards, or to the side when you land the jump. If you get tired or weak when doing these activities you can stop at any time. Just tell Jennifer any time you feel any discomfort. The testing time will last about 40 minutes.

If you decide to be in this study, you will know the results from the tests. When we are done with the study, we will write a report about what we found out. We won't use your name in the report or tell anyone else your scores.

You don't have to be in this study. It's up to you. If you say okay now, but you want to stop later, that's okay too. All you have to do is tell us.

If you want to be in this study, please sign your name.

I, ______________________________, want to be in this research study.
(Print your name here)

______________________________ ____________________
(Sign your name here) (Date)

APPENDIX D – INSTITUTIONAL REVIEW BOARD APPROVAL

INSTITUTIONAL REVIEW BOARD

OREGON STATE UNIVERSITY

Office of Sponsored Programs and Research Compliance
312 Kerr Administration Bldg.
Corvallis, Oregon
97331-2140

Telephone
541-737-3437

FAX
541-737-3093

Email
IRB@oregonstate.edu

TO: Joonkoo Yun,
Exercise and Sport Science

RE: The Relationship between Balance and Fundamental Motor Skills
(Student Researcher: Jennifer Overlock)

IRB Protocol No. 2498

The referenced project was reviewed under the guidelines of Oregon State University's Institutional Review Board (IRB). The IRB has **approved** the application. This approval will expire on **4/16/2005**. This new request was reviewed at the Expedited level. A copy of this information will be provided to the full IRB committee.

Enclosed with this letter please find the approved informed consent document for this project, which has received the IRB stamp. This information has been stamped to ensure that only current, approved informed consent forms are used to enroll participants in this study. All participants must receive the IRB-stamped informed consent document.

- Any proposed change to the approved protocol, informed consent form(s), or testing instrument(s) must be submitted using the MODIFICATION REQUEST FORM. Allow sufficient time for review and approval by the committee before any changes are implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB.
- In the event that a human participant in this study experiences an outcome that is not expected and routine and that results in bodily injury and/or psychological, emotional, or physical harm or stress, it must be reported to the IRB Human Protections Administrator within three days of the occurrence using the ADVERSE EVENT FORM.
- If a complaint from a participant is received, you will be contacted for further information.
- Please go to the IRB web site at: http://osu.orst.edu/research/RegulatoryCompliance/HumanSubjects.html to access the MODIFICATION REQUEST FORM and the ADVERSE EVENT FORM as needed.

Before the expiration date noted above, a Status Report will be sent to either close or renew this project. It is imperative that the Status Report is completed and submitted by the due date indicated or the project must be suspended to be compliant with federal policies.

If you have any questions, please contact the IRB Human Protections Administrator at IRB@oregonstate.edu or by phone at (541) 737-3437.

Redacted for privacy

4/17/04

pc: 2498 file

APPENDIX E – STAGES OF KICKING PERFORMANCE

STAGE 1	Performer is stationary and positioned near the ball. If moves prior to kicking, the steps are short and concerned with spatial relationships rather than attaining momentum for the kick. Thigh of the kicking leg moves forward with the knee flexed and is nearly parallel to the surface by the time the foot contacts the ball. Knee-joint extension occurs after contact, resulting in a pushing rather than a striking action. Upper extremity action is usually bilateral but may show some opposition in older performers. (If the performer is too far from the ball as the extremity moves to meet the ball, the knee flexes only slightly and the leg swings forward from the hip in a pushing action.) The knee of the kicking leg continues to extend until it approaches 180°. If the trunk is inclined forward following contact with the ball, the performer will step forward to regain balance. If the truck is leaning backward, the kicking leg will move backward after ball contact to achieve body balance.
STAGE 2	Performer is stationary. Initial action involves hyperextension at the hips and flexion at the knee so that the thigh of the kicking leg is behind the body. The arms may move into a position of opposition in situations of extreme hyperextension. The kicking leg moves forward with the knee joint in a flexed position. Knee-joint extension begins just prior to foot contact with the ball. Arms-leg opposition occurs during the kick. Knee extension continues after the ball leaves the foot, but the force of the kick usually is not sufficient to move the body forward. Instead, the performer usually steps sideward or backward.
STAGE 3	Performer takes one or more deliberate steps to approach the ball. The support leg is placed near the ball and slightly to the side of it. The kicking foot stays near the surface as it approaches the ball, resulting in less flexion than in stage 2. The trunk remains nearly upright, thereby preventing maximum force production. The knee begins to extend prior to contact. Arm-leg opposition is evident. The force of the kick may carry the performer past the point of contact if the approach was vigorous. Otherwise, the performer may remain near the point of contact.
STAGE 4	Approach involves one or more steps with the final "step" being on airborne run or leap. This permits hyperextension of the hip and flexion of the knee as in stage 2. The shoulders are retracted and the trunk is inclined backward as the supporting leg makes contact with the surface and the kicking leg begins to move forward. The movement of the thigh nearly stops as the knee begins to extend rapidly just prior to ball contact. Arm-leg opposition is present. If the forward momentum of the kick is sufficient, the performer either hops on the support leg or scissors the legs while airborne in order merely step in the direction of the kick.

Payne & Isaacs, 1999

APPENDIX F – STAGES OF JUMPING PERFORMANCE

STAGE 1	Vertical component of force may be greater than horizontal; resulting jump is then upward rather than forward. Arms move backward, acting as brakes to stop the momentum of the trunk as the legs extend in front of the center of mass.
STAGE 2	In preparatory phase, arms move forward and back, but during flight phase they move sideward. The knees and hips flex and extend more fully than in stage 1. Angle of takeoff above 45°. Landing is made with the center of gravity above the base of support, with the thighs perpendicular to the surface.
STAGE 3	In preparatory phase, arms swing backward then forward. The knees and hips flex fully prior to take-off as arms extend and move forward. Knees extension may be complete, but the takeoff angle is still above 45°. Upon landing, the thigh is still less than parallel to the surface and the center of gravity is near the base of support.
STAGE 4	Arms extend vigorously forward and upward upon takeoff, reaching full extension above the head at "liftoff." The hips and knees are extended fully, with the takeoff angle at 45° or less. In preparation for landing, the arms are brought downward and the legs are thrust forward until the thigh is parallel to the surface when feet contact for landing The center of gravity is far behind base of support upon foot contact, but at the moment of contact the knees are flexed and the arms are thrust forward in order to maintain the momentum to carry the center of gravity beyond the feet.

Payne & Isaacs, 1999

APPENDIX G – INFORMATION SHEET

The Relationship between Balance and Fundamental Motor Skills
Oregon State University

Thank you for participating in this study. Please complete the following information as accurately as possible about your child.

Demographic Information:

Name: ______________________________ Date of Birth: _____________

Age (yrs/months): _______________ Male or Female (circle)

Height (feet/in.): _____________ Weight (lbs.): ___________

Foot Size: _______________

Dominant Leg: _______________

Does your child currently participate in any sports? Yes No

If yes, please list which sports (i.e. soccer, gymnastics) and for how long they have participated in them?

____

____

Has your child participate in any sports in the past? Yes No

If yes, please list which sports and for how long: __________________________

____

____

Would you be interested in returning within 7 days for your child to repeat the

two balance tests? Yes No

Subject Number: ________

APPENDIX H – SCORING SHEET

Id.	Name	Height	Weight	Balance Master 1st	Balance Master 2nd	Jump 1	Jump 2	Jump 3	Kick 1	Kick 2	Kick 3	Kick 4	Kick 5	Foot
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											
		cm in	lbs											