BILATERAL ASYMMETRIES IN FLEXIBILITY, STABILITY, POWER, STRENGTH, AND MUSCLE ENDURANCE ASSOCIATED WITH PREFERRED AND NONPREFERRED LEG

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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TABLE OF CONTENTS

LIST OF TABLES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Exercise and Sport Sciences

BILATERAL ASYMMETRIES IN FLEXIBILITY, STABILITY, POWER, STRENGTH, AND MUSCLE ENDURANCE ASSOCIATED WITH PREFERRED AND NONPREFERRED LEGS

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The uninjured limb is commonly used as a pre-injury model because of the assumption that the limbs are symmetrical. Unfortunately, this may not be true in all athletes. One-legged athletes (1LA) (e.g., jumpers/kickers) may develop bilateral asymmetries as a result of specific training. The purpose of this study was to determine whether asymmetries in flexibility, stability, power, strength, and muscular endurance existed in the preferred and nonpreferred legs of 1LA athletes. Five characteristics were measured in three groups of subjects: nonathletes (NAS) (n=8, age 21.0 $\pm$ 1.2 y, height 170.1 $\pm$ 6.9 cm, weight 68.5 $\pm$ 13.1 kg); two-legged athletes (2LA) (n=8, age 20.8 $\pm$ 1.3 y, height 169.9 $\pm$ 8.6 cm, weight 66.3 $\pm$ 10.0 kg), and one-legged athletes (n=8, age 20.3 $\pm$ 1.4 y, height 179.7 $\pm$ 11.0, weight 72.9 $\pm$ 13.9 kg). Quadricep and hamstring flexibility were measured using an inclinometer during a passive prone knee-flexion test and a supine passive straight-leg raise, respectively. Stability was assessed by having subjects jump onto a forceplate and stand on one leg. One-legged hop distance (OLH) represented power. Quadricep and hamstring strength at 60°/sec and muscle endurance at 180°/sec were measured isokinetically. Leg preference was determined using three tasks: kicking a soccer ball, stepping on an object, and smoothing out sand. Twelve 2x3 ANOVAs were used to determine if differences existed in the legs (preferred, nonpreferred) by group (NAS, 1LA, 2LA) for flexibility, stability, OLH, strength, and muscle endurance. Tukey's HSD post hoc test was performed to locate any significant differences. Results revealed no significant interactions in leg preference by group (NAS, 2LA, 1LA) for flexibility, stability, OLH, strength, or muscle endurance. However, main effects among groups were revealed when the means of both legs were combined. Tukey's post hoc test revealed that 1LAs were significantly stronger isokinetically (quadricep and hamstring) and jumped significantly farther compared to the NASs and 2LAs. Observed differences among groups could be a result of training level differences (i.e., varsity vs. recreational) affecting exercise volumes and intensities. The lack of significant asymmetries between preferred and nonpreferred legs suggests that an inadequacy in training elicited asymmetrical adaptations. In conclusion, asymmetries in the preferred and nonpreferred legs do not exist; hence, leg preference could not be associated with asymmetries in flexibility, stability, power, strength, or muscle endurance.

CHAPTER 1
INTRODUCTION

An athlete's safe, swift injury rehabilitation process and return-to-play leads to success for that athlete or team. For professional athletes, it may mean financial prosperity; for nonprofessional athletes (i.e., high school, amateur, or recreational), rewards include league championships or best personal performances. Health care professionals working with athletes need to ensure a safe and speedy return-to-play with minimal risk of re-injury. Deficiencies in a limb's physical traits (i.e., range of motion, flexibility, strength, power, endurance, or sport-specific functionality) as a result of injury should be quickly and safely reduced to levels almost identical to those of the uninjured limb.[46,47,52-54,68] Using the uninjured limb as a pre-injury model is very common because of the assumption that the limbs are physically and functionally symmetrical.

Statement of the Problem

Unfortunately, the limbs may not be perfectly symmetrical when observing left and right physical characteristics.[68,75,90,91] This is apparent in the upper extremity, where the dominant arm is usually stronger and more versatile.[28,75,80] In the lower extremity, the differences may not be as obvious in two-legged athletes[14,20,63] (e.g., sprinters and swimmers) and nonathletes[60,101] (e.g., sedentary population). However, one-legged athletes (e.g., long jumpers and high jumpers) may develop a significant bilateral asymmetry due to a constant training overload on the jumping leg.[38,75] The ability to determine any training or injury-induced asymmetries would be valuable to the clinician and researcher.

Clinically, a bilateral comparison is performed between limbs with the assumption that the limbs are symmetrical. However, pre-injury asymmetries between the limbs may invalidate this bilateral comparison and complicate the rehabilitation process. Assuming pre-injury symmetry or asymmetry when the opposite exists, sets erroneous functional progression criteria. Establishing incorrect functional rehabilitation progression criteria may delay an athlete's progress through the rehabilitation process. In research, assuming bilateral symmetry offers a simpler methodological approach, but possible data misinterpretation if asymmetry exists. If asymmetry does exist, then lower extremity research methodology needs to be stringent and consistent among subjects and among studies to prevent misinterpretations. If symmetry between the limbs existed, one leg could be tested and representative of both. Also, subjects would not have to be grouped based on athlete type. The test leg would be randomly chosen. If limb asymmetry is wrongly assumed, the naive researcher might waste valuable time on a tedious methodology to account for false asymmetries.

For both the clinician and researcher, problems of misinterpretation arise when incorrect assumptions are made. Depending on the type of activity, level of participation, or training regimen, the limbs may or may not be symmetrical. As a result, rehabilitating athletes and experimental validity are affected. Therefore, this study attempted to answer the following questions:

- Are there physical and or functional asymmetries between the right and left legs of one-legged athletes?
- Are there physical and or functional asymmetries between the right and left legs of two-legged athletes?
- Are these asymmetries associated with the preferred leg?

Hypotheses

Three hypotheses were developed from the review of literature.

H1: There will be asymmetries between the lower limbs of one-legged athletes as measured by the following tests.

- One-legged hop (OLH)) for distance
- Time to stabilization (TTS)
- Quadricep and hamstring strength
- Quadricep and hamstring flexibility
- Quadricep and hamstring muscle endurance

H2: There will be no differences between the lower limbs of two-legged athletes as measured by the following tests.

- OLH for distance
- TTS
- Quadricep and hamstring strength
- Quadricep and hamstring flexibility
- Quadricep and hamstring muscle endurance

H3: It is hypothesized that the preferred legs of one-legged athletes will be associated with greater hamstring flexibility, and quadricep strength. Additionally, it is hypothesized that the nonpreferred leg will be associated with greater quadricep flexibility, better stabilization times, longer hop distances, greater hamstring strength and time to fatigue.

Definition of Terms

The following terms have been defined for the present study

- **Asymmetry:** imbalance, unequal and non-proportionate.[1]

- **Dominance:** the central nervous system (CNS) phenomenon in which one side of the brain plays a major role in a specific function.[97]

- **Lateral dominance:** the preferred use and superior performance of one side of the body as compared to the other side.[35]

- **Laterality:** a phenomenon that occurs in an organism with paired faculties (hands, ears, feet, eyes), whereby the performance of certain tasks is better on one side.[97]

- **Nonpreferred leg:** the leg that is used to support the activities of the preferred leg by lending postural support and stability.[75]

- **One-legged athlete:** an athlete that trains and competes in a skill that mainly focuses on one leg (e.g. long jumpers, high jumpers, football kickers, etc.).

- **Preference:** one's subjective choice of limb use that is a result of laterality.[97]

- **Preferred leg:** the leg used to manipulate an object or to lead out during a jump;[75] determined by using the following tasks: kicking a ball, stepping on an object and smoothing out sand. The leg that consistently performs 2 out of the 3 tasks will be designated as the preferred leg.[15]

- **Two-legged athlete:** traditional athletes that train and compete in an activity that does not focus on one leg (e.g. sprinters, swimmers, long-distance runners).

Assumptions

This study was conducted with several assumptions.

- All subjects will answer all questions pertaining to their personal history truthfully.

- Habitually, the lower extremities have been used equally and without voluntary preference during activities of daily living.

- Subjects will perform the tests with maximal physical effort.

- Subjects will interpret the questions on the leg preference inventory identically and answer the leg preference questionnaire truthfully.

- All athletes tested have trained in their respective sports using specific volumes and intensities, but have all completed work adequate enough to elicit a training response.

- Physical or performance changes or lack thereof in subjects' bodies were a result of their respective training programs.

- Performance on the battery of tests will not affect their subjective preference.

Limitations

Three limitations to the study have been identified.

- There will be difficulty in selecting one-legged athletes (e.g., long-jumpers, high-jumpers, hurdlers) due to a relatively small population; therefore, the sample will be obtained from a population of convenience.
- Since there will be difficulty calculating total amount of work done by each leg during training and through activities of daily living, subjects will be classified into athlete type according to the amount of time attributed to sport participation.
- Variability in training methods (e.g., periodization) and level of participation (e.g., high school versus collegiate) contributes to variability in potential asymmetrical development; therefore, to allow adequate time for specific sport adaptation subjects participating in their respective activities for at least 1 year will be classified as a two-legged or one-legged athlete. Those that do not meet these criteria will be considered nonathletes/sedentary.

Significance

Realizing whether or not there is asymmetry between the limbs is critical to the clinician and researcher. Researchers using the lower limbs in their studies need to clarify their methodology if significant physical differences between limbs exist. For example, athletes participating in any study need to be screened as to whether or not they are one-legged in their sport and need to be grouped separately from those who are not. If the preferred and nonpreferred leg were associated with these asymmetries, leg preference would have to be determined and these asymmetries considered. In addition, the method of assessing the preferred and nonpreferred leg needs to be reliable, and consistent among different studies. If asymmetry in the physical qualities between the limbs is not taken into account, data interpretation may be affected. In contrast, if significant differences were not noted between the limbs, then the need to establish a preferred and nonpreferred leg using a leg preference assessment tool would be unnecessary. Researchers would not need to group athletes according to athlete type (e.g., one-legged or two-legged) and or leg preference. Randomly assigning a leg to be tested would suffice.

Similarly, the results of a clinical bilateral comparison between an injured limb and the non-injured limb may be misinterpreted if bilateral symmetry or asymmetry is assumed when the opposite actually exists. Any misinterpretations will vary functional rehabilitation progression criteria and eventually return-to-play decisions. If the clinician has discerned the preferred and nonpreferred leg and asymmetry between them exists, functional progression criteria should be set accordingly. If the proper assumption regarding the existence of leg symmetry is made, the rehabilitation time to return to full participation should not differ whether the injury was to the preferred or nonpreferred.

Unlike the lower extremity, discerning upper extremity preference is a relatively simple task that can be quickly and easily determined using a valid and reliable questionnaire. As a result, certain attributes about the preferred and nonpreferred side may be described. For example, the preferred hand, which is based on which hand one prefers to use to perform a certain task, may also be assumed to be the stronger and more skilled than the nonpreferred hand. Similarly, the clinician or researcher can obtain information on the physical attributes of each leg by using a reliable tool leg preference assessment tool. It is this information that will be valuable for the clinician in establishing exercise progression and return-to-play criteria; and for the researcher, it will be important in validating future research methodology.

CHAPTER 2
REVIEW OF LITERATURE

Symmetry

Upper limb symmetry has been reported frequently in the literature. Falsone et al.[28] researched the test-retest reliability of the one-arm hop test in 13 male collegiate wrestlers and 13 male collegiate football players. They suggested that the difference in hopping performance between dominant arm and nondominant arm was insignificant.

Studies suggesting lower limb symmetry are also common. Lucca and Kline[60] isokinetically tested knee extensor and flexor torque production in 54 college students and suggested no significant strength differences between the lower limbs. Harrison et al.[36] investigated single-leg standing balance in 78 uninjured recreationally active males and females and 17 patients that were 10 to 18 months post-anterior cruciate ligament surgery between the ages of 17 and 45 years of age. They suggested no significant differences in balance performance between the lower limbs of both groups. Yang et al.[101] suggested the existence of structural symmetries when they evaluated proximal femur bone mineral densities of 266 healthy Chinese women between the ages of 18 and 88 y. They concluded that side dominance had no significant effect on femoral bone density. These studies suggested the existence of functional and structural symmetry between the lower limbs.

Symmetry suggested in these studies was attributed to the simultaneous usage of the lower limbs in activities of daily living, such as locomotion. Consequently, a bilateral comparison of injured and noninjured limbs can be valid and useful in establishing accurate exercise progression goals and return-to-play (RTP) criteria if symmetry truly exists.

Since sport injury rehabilitation centers on restoring functional abilities to normal, optimal, or a pre-injury state of health,[54] it would be useful to know how that level was defined. Unfortunately, it is rare to know an injured limb's normal or pre-injury state of health. Using a bilateral comparison, clinicians assume limb symmetry and use the uninjured limb as a comparison model for the injured limb. Armstrong et al.[4] compared the hand strength in the dominant and nondominant hand in 83 right and left handed healthy participants between the ages of 18 and 72 years of age for the purpose of validating the '10% rule' suggesting that the dominant hand is 10% stronger than the nondominant hand. They suggested insignificant strength differences between the hands and advised to be cautious when comparing the hands using the '10% rule'. Linton and Indelicato[59] suggested a need for players to exhibit 80% isokinetic strength of their injured leg compared to their uninjured leg before progressing activity level. Reider et al.[83] suggested allowing players to return to practice if they exhibit 90% normal strength of the injured knee compared to the uninjured knee. Both RTP criteria were based on the assumption that both limbs are symmetrical in a pre-injured state. Other authors have made the same assumption when establishing bilateral comparison guidelines for rehabilitation exercise progression and RTP criteria.[46,47,52-54]

Athletes aiming to return to full participation should have their injuries adequately rehabilitated to ensure optimal performance and minimal risk of re-injury. Mahar and MacLeod[62] studied the effect of simulated leg length discrepancies on mean center of pressure position and postural sway in 8 male and 6 female volunteers and reported that leg length asymmetries as little as 1 cm significantly shifts mean center of pressure position to the longer leg side and increases postural sway. They suggested that asymmetries might be biomechanically significant and result in injury. Whether or not the leg length discrepancy was structural or functional was not addressed.

For professional athletes with millions of dollars in bonuses and endorsements at stake, developing accurate rehabilitation goals and RTP criteria are imperative. For nonprofessionals, self-fulfillment and personal goal achievement through injury-free participation can be just as enriching. Clinically, the validity and reliability of a bilateral comparison is valuable.

In the literature, studies utilizing one leg as an adequate representation of both limbs have been documented. Pincevero et al.[76] examined muscle activation of the quadricep and hamstring muscles during a prolonged closed kinetic chain exercise (e.g., lunge) in the dominant leg of 8 males and 2 females. The dominant leg, determined by asking subjects which leg they would prefer to kick a ball with, performed the lunge. Increased muscle activation during the exercise was reported and the authors concluded that the muscles fatigue as a unit, supporting the idea of coactivation. Blackburn et al.[8] examined proprioception and muscular strength to determine the dominant factor in balance and joint stability in 32 physically active college-aged students. The dominant leg used was established as the leg that subjects chose to kick a ball. The authors concluded that enhancing proprioception and muscular strength are equally effective in promoting joint stability and balance. Nyland et al.[69] assessed the effects of eccentric work-induced hamstring fatigue on knee and ankle biodynamics and kinetics during a functional pivot shift in 20 athletic college-aged females with a left stance leg preference.

The left stance leg was deemed the lower extremity subjects chose for stance when attempting a soccer kick. The authors suggested knee control deficits increase during hamstring fatigue. In all three studies, the leg tested was established by asking subjects a reliable leg dominance question. Although the authors only tested one leg their conclusions possibly encompassed both limbs based on the assumption that the lower limbs are symmetrical. Whether or not these conclusions applied to the test leg or both legs was not indicated.

Asymmetry

Although there is extensive literature suggesting upper and lower limb symmetry, asymmetry has been noted throughout the literature as well. Functional asymmetry was noted when Hartsell et al.[37] examined the effect of arm dominance, acceptable muscle balance between the wrist pronators and supinators and isokinetic testing reliability in 10 healthy males and 10 healthy females between the ages of 18 and 30 years old. They suggested the presence of significant strength differences between the dominant and nondominant wrist pronators and supinators. Structural asymmetry was noted when Krahl et al.[55] examined whether unilateral sports-specific strain affects the skeletal system of athletes by radiologically examining the bones of the forearms and hands of 12 male and 8 female professional tennis players. Their findings suggested that the increased bone density and diameter as well as bone length in the stroke arm was a result of mechanical stimulation and hyperemia of the constantly stressed side.

Asymmetry between lower limbs has also been suggested in the literature. Daly and Cavanaugh[21] examined the effects of workload, pedaling rate, and dominance (based on ball-kicking task) on pedaling asymmetry in 20 male recreational cyclists and suggested that work output was asymmetrical in the lower limbs. Sadeghi et al.[87]

discussed symmetrical behavior during able-bodied gait and the effect of limb dominance on symmetrical behavior of the lower limbs. The authors suggested symmetrical behavior in the lower limbs during gait has always been assumed for simplicity; however, the gait asymmetry observed seemed to reflect a natural functional difference between the limbs that is influenced by laterality. Rosene and Fogarty[84] examined differences in anterior tibial translation among sports (volleyball, soccer, basketball, and softball), sex, and leg dominance in 22 male and 38 female intercollegiate athletes and suggested that significant differences in anterior tibial translation between the right and left legs were present. Singh[91] tested 94 right-handed healthy medical students between 17 and 19 years of age and 30 children less than 5 years of age during a walking test, foot pressure test, ball kicking task and a lifting task. Observations were also made on the upper and lower extremity long bones of 20 skeletons and the shoe wear of all subjects tested. The author suggested that the right and left lower limbs are not used equally. Femoral weight, foot pressure performance and shoe wear patterns were asymmetrical.

The existence of functional and structural lower limb asymmetry has been suggested. To validate the bilateral comparison, these pre-injury asymmetries must be accounted for.

Inconsistencies in the literature regarding the existence of bilateral symmetry or asymmetry in functional and physical characteristics have been suggested. In the study that examined bilateral differences in anterior tibial translation, Rosene and Fogarty[84] advised that clinicians performing subjective bilateral comparisons must be aware that differences (in laxity) may exist in the absence of injury. Clinically, rehabilitation exercise progression and RTP decisions may be affected; experimentally, procedures and interpretations may be affected if one leg is tested.

Terminology

In some studies previously mentioned, the terms dominant and nondominant or preferred and nonpreferred legs were assessed using similar assessment methods. The terms dominant and preferred are used interchangeably throughout the literature. In addition, terms such as laterality and asymmetry have also been used in similar contexts. In order to discuss the relationship between asymmetries and the preferred and nonpreferred leg, a distinction between these terms is necessary to clearly comprehend the literature. Therefore, the first step is to define the following terms: lateral dominance, laterality, dominance, preference and asymmetry. The next step is to establish certain assumptions about the preferred and nonpreferred leg based on the definition of choice used for this study.

Harris,[35] in developing a test to determine lateral dominance, defined lateral dominance as the preferred use and superior performance of one side of the body as compared to the other side. Since then, other reviews have traced the preferential use of one side of the body, to the brain.[18,75] Touwen[97] wrote a review that defined laterality as a phenomenon that occurs in an organism with paired faculties (hands, ears, feet, eyes), whereby the performance of certain tasks is better on one side. One's subjective choice of limb use that is a result of laterality was referred to as preference. He also stated that laterality is an asymmetrical function[97] where asymmetry is defined as imbalance, unequal and non-proportionate.[1] He defined dominance as the central nervous system (CNS) phenomenon in which one side of the brain plays a major role in a specific function.[97] In a study by Sadeghi et al.,[87] symmetry and limb dominance in able-bodied gait was reviewed. Limb dominance was related to the notion that the brain is functionally asymmetrical, whereas limb preference and laterality were defined as the preferential use of one limb in voluntary motor acts. Hence, the terms laterality and asymmetry could be used synonymously. Preference is the inclination to use one side instead of the other and should not be confused with the previous terms. The reasons why one prefers to use one side instead the other are still controversial; however, dominance and laterality may influence one's choice. Dominance should not be used synonymously with laterality because the former refers to a CNS phenomenon and the latter refers to a peripheral phenomenon.

Unfortunately, the majority of the research uses the term dominance when inferring that a person is more inclined to use one limb to perform certain tasks versus the other. Hoffman et al.[41] deemed functional leg dominance as the leg that performed 3 tasks 2 out of 3 times with the same leg: ball kick, step-up, and balance recovery. Blackburn et al.[8] defined leg dominance as the leg each subject would use to kick a ball. Pincivero et al.[76] determined dominant leg by asking the subjects which leg they would preferentially use to kick a ball. These studies demonstrate that researchers have used the term dominance differently in context than what has been defined.

Other studies have used the term preference with similar ideas in mind. Hartsell et al.[37] established hand preference as the hand subjects preferred to use when tossing a ball. Nyland et al.[69] deemed leg preference as the leg subjects chose to use in kicking a ball. Interestingly, tasks used to determine preference have also been used to determine dominance, even though the terms have been distinctly defined. In reviewing the literature, it was assumed that authors used these terms without considering the definitions established earlier. The terms dominance and preference in the review of literature were interpreted similarly.

The word dominance sometimes is accompanied by connotations of superiority. In the area of leg dominance and preference, physical and functional superiority come to mind. However, according to the above definitions, this is incorrect. Touwen's definitions insinuate unilateral cerebral dominance predisposing the use of the right hand or foot over the left or vice versa.[97] Whether task performance is superior or not is unclear. Dominance, derived from the CNS, may result in laterality that is defined as task performance superiority by one side versus the other. Preference, or one's choice of performing tasks with one side versus the other, is a function of laterality.[97] Although preference is a function of laterality, an association between superior performance and limb preference has not been established. The term dominance should only be used when superior peripheral function is linked to cerebral dominance and should not be confused with preference or laterality. Hence, the term preference, instead of dominance and laterality should be used when referring to the limb one is more inclined to use when performing certain tasks. The characteristics of the preferred limb, specifically the lower limb, will be studied here.

Theoretical Origins of Asymmetries

Innate/Invariant Model

The definitions described evolved as a result of different theories explaining limb dominance. Theories regarding the origins of limb dominance and asymmetry have been researched in the literature. Several authors proposed an innate origin of preference leading to asymmetry. Kinsbourne[50] described the Invariant Model suggesting functional brain asymmetries in place at birth and remaining constant throughout one's lifespan.

Gentry and Gabbard[31] tested this model by studying foot preference behavior in 956 participants grouped according to the following age groups: 4, 8, 11, 13, 16, and 20 y old. In contrast to the Invariant Model, results suggested foot preference behaviors vary as a function of age or other factors and are not permanently set. In a review by Dimond[25] on cerebral dominance or lateral preference in motor control, the idea that one hemisphere is dominant over the other was discussed. The author discussed the role of the asymmetrical motor output systems between hemispheres and suggested limb preference based on the side that performs skills better. However, whether this asymmetry was instilled in the prenatal brain and remains constant or developed over time remains unanswered.

Previc's Theory of Postural Control relating cerebral lateralization to asymmetric prenatal development of the ear and labyrinth may provide an answer. The theory traces aural lateralization from an asymmetrical craniofacial development and right side vestibular dominance to fetal position during the final trimester where the fetus is positioned cephalic-leftward-right ear facing out. As a result, a left-otolithic advantage becomes instilled creating a dependence on the left side of the body for postural control, allowing the right side to perfect voluntary or mobilizing motor functions.[79] In support, Pompeiano[78] stated that although the labyrinths exert bilateral control over the antigravity reflexes, their excitatory influence is greatest for the ipsilateral muscle groups. Hence, left labyrinth stimulation results in left postural muscle excitation and reduced right musculature excitation suggesting postural reflexes on the left side emerging before voluntary motor control on the right side. They also stated the left side postural superiority reflects greater strength of vestibulospinal reflexes as a result of early fetal maturation.

Gabbard and Hart[30] tested Previc's theory on 45 male and 49 female undergraduate kinesiology students between the ages of 19 and 22 years of age. Subjects completed a footedness questionnaire and performed a one-leg static balance task under simple and complex conditions. Results suggested inconsistency in Previc's theory since there were no statistically significant differences between the right and left limbs in simple postural control performance. Interestingly, as complexity increased, performance on the right (preferred) surpassed the left. The same leg should have performed simple and complex tasks if Previc's theory were solid.

Maupas et al.[65] examined asymmetric leg activity during walking in 13 male and 18 female healthy subjects and observed some functional asymmetry during walking called angular preponderance of flexion. The authors were unable to link the asymmetry to footedness or anatomical asymmetries and instead suggested that the origin of the asymmetry could be a spinal stepping generator, similar to those found in other animals. They suggested that babies exhibit locomotory activity that disappears after 6 months indicating developmental myelination of descending pathways that eventually inhibit the activity of the generator. For this to be true, an innate generator has to be present. The presence of a generator would contribute to the thought that asymmetries are innate. The influence of this generator on leg preference and skill performance was not discussed.

MacNeilage's[61] Postural Origins Theory of primate neurobiological asymmetries describes an evolutionary influence. The theory described how instinctive traits are passed down from early primates. Early primates used one leg for operations on the environment and the other for support suggesting the predisposition of today's primates to use one limb for fine manipulation and the other for support.

Support in the literature that limb preference stems from innate sources was observed in studies that examined similar lateralization patterns between the sexes. The literature is inconsistent in suggesting a significant relationship between sex and limb asymmetry. Levy and Levy [57] measured bilateral foot length of right and left-handed 15 year-old boys and girls based on the premise that fetal sex steroids may play a critical role in determining relative maturational rates of the brain and body regions. They compared the left and right feet of 98 females, 18 of which were under the age of 6, and 52 males of whom 17 were under the age of 6. They suggested a strong influence of sex on cerebral and pedal asymmetrical development due to mechanisms that are unclear. Mascie-Taylor et al.[64] analyzed 146 graduates to see if their data supported the conclusions of Levy and Levy's study. Fifty-six percent of this sample was male. The distribution of handedness by sex did not differ between this study and Levy and Levy's. However, the direction of laterality was opposite to that determined in the previous study. Similarly, they both suggested that sex contributed to laterality.

Means and Walters[67] compared hand and feet length at birth to determine the relationship between sex and handedness, and whether asymmetry is present at birth or develops with age. Hand and foot length of 77 male and 79 female children aged 4 to 9 y was measured. The authors suggested no significant differences existed between the sexes. In support, Dargent-Pare et al.[22] examined the relationship between foot and eye preferences with handedness, sex and age in 2639 males and 2560 females between the ages of 15 and 35 y. They found no systematic differences between men and women.

Some studies suggested that differences between males and females are nonexistent, supporting the notion that limb preference and asymmetries are innate. In contrast, other studies suggested differences contributing to the idea that limb preference may not be innate.

Limb preference in activities of daily living and athletics may be influenced by innate origins involving prenatal posture, evolution, and neurospinal architecture. Laterality or limb preference can then be manifested as physical or functional asymmetry, regardless of environmental influences. However, other ideas surrounding developmental or maturational, and cultural or environmental perspectives have been proposed in the literature.

Maturational/Equipotentiality Theory

Innate origins of asymmetry have not been consistently supported in the literature. Other studies suggested a developmental or maturational perspective on the origin or asymmetry.

A review by Corbaillis and Morgan[18] described the Equipotentiality Hypothesis suggesting maturational development of cerebral hemispheres after birth on a gradient from the left side to the right as an origin of asymmetry. Lenneberg[56] described the Equipotentiality Hypothesis suggesting the importance of maturational processes between infancy and adulthood and stated that the cerebral hemispheres are not specialized in newborns but become progressively specialized with age. Gentry and Gabbard[31] tested the hypothesis and studied foot preference behavior in 956 participants grouped according to the following age groups: 4, 8, 11, 13, 16, and 20 years old. In support, the authors suggested that foot preference behaviors are not innate but vary as a function of age and other factors.

Thelen et al.[95] observed patterns of bilateral coordination and lateral dominance in the leg movements of 8 normal infants, biweekly from 2 to 26 weeks of age. The authors noted a decrease in interlimb latencies between week 2 and 26. Results suggested that the chronological variability observed in kicking patterns was developmental. The authors stated that infants are born with a lower limb oscillatory mechanism containing locomotor precursors analogous to mature walking that begins to work in-phase or in strict alternation to the contralateral leg during the maturation process. These mechanisms support the idea of specialized motor behavior maturation between the legs. Similarly, Salmaso and Longoni[89] suggested a maturational process leading to lateral preference. They divided 1694 people into two age groups: 10-18 years old and 19-80 years old, determined hand preference, and reported more right-handers in the older group. Both studies support the Equipotentiality Hypothesis; however, whether this maturational process leads to symmetry or asymmetry was not discussed.

The theories supporting a maturational process of asymmetry are adequate in explaining observed differences; however, Previc's Theory of Postural Control and the Postural Origins Theory of primate neurobiological asymmetries insufficiently support mechanisms initiating this process. Annett and Alexander[3] described Annett's Right-Shift Theory of Handedness and Cerebral Dominance suggesting a genetic starting point. The theory was developed as a result of observing a normal (Gaussian) distribution of cerebral asymmetry based on a hand skill performance and its shift towards right-handedness. The authors suggested that the normal distribution is attributed to chance, and accredited the shift towards one side to a genetic influence for left cerebral advantage. The theory sufficiently explained the right-sided motor preference in the majority of the population, but also sufficiently accounted for inconsistencies in left-handers and those with mixed preference. The theory considered social, environmental and technological influences on the shift, but consistently supported the idea that the mechanisms initiating lateralization are genetic.

Developmental Model

The theories described earlier suggested that limb preference resulted from involuntary mechanisms. However, other studies suggested limb preference resulting from a developmental perspective. That is, one's preferred limb is based on superior skill performance. Sainburg and Kalakanis[88] tested 2 females and 4 males between the ages of 24 and 36 years old to investigate dominant and nondominant arm differences during reaching movements. No significant differences were noted in arm dynamics during the initiation of the reaching movement; however, differences were noted in final limb position dynamics. To help explain the results of the previous study, Gottlieb[33] suggested a three-element model where task execution is based on three factors: task realization, feedback-mediated skill execution, and modulation of the feedback elements. As skills are repeated and perfected, less feedback modulation is needed. The central nervous system develops internal models that predict musculoskeletal and environmental influences; thus, helping plan subsequent movements more efficiently. In a review of handedness and motor skill, Provins[80] suggested that new voluntary motor skills are undoubtedly learned. With repetition, these skills would eventually require less spatio-temporal organization. The author suggested efficient motor skill performance as a result of repeated behavior. Both studies suggested automatic skill execution after enough repetition to where skill performance seems natural. Superior skill performance may be a factor that determines leg preference. Unfortunately, studies directly suggesting limb preference rooting from skill perfection have not been found in the literature.

Theories proposed in the literature insist that asymmetries are present. Leg preference may be genetically predetermined, a result of a maturational process, influenced by superior skill performance, or all three; regardless, factors such as athletics and activities of daily living may enhance these asymmetries.

Overload Principle

In athletes, asymmetry is amplified as athletes devote countless hours perfecting motor skills primarily utilizing their preferred limb. The Overload Principle suggesting the occurrence of physical changes in tissue if the stresses imposed are greater than what the tissue is accustomed explained the physical adaptations arising in the overly used limb.[38] Hellebrandt and Houtz [38] demonstrated this principle by observing strength changes in 8 male and 9 females using 7 different training procedures over a 4-year period. The authors observed strength increases resulting from the training methods. Delorme's[23] training method used in this study consisted of day-to-day increases in load to the maximum load selected for that week. Hellebrandt and Houtz[38] suggested the occurrence of adaptations if the body is unaccustomedly stressed, regardless of the method used.

Peters[75] observed upper limb bilateral asymmetry in athletes like tennis players, pitchers, quarterbacks and bowlers, who repeatedly use one arm more than the other. Krahl et al.[55] radiologically examined the upper extremities in 20 male and female professional tennis players and 12 control subjects between 13 and 26 years of age. Increased bone density substance, bone diameter, and bone length in the stroke (dominant) arm compared to the contralateral arm was observed. Perrin et al.[74] examined bilateral strength differences isokinetically in 15 right-handed male baseball pitchers, 15 right-handed male swimmers and 15 right-handed male nonathletic students, all between the ages of 18 and 27 y. They suggested right strength superiority in shoulder extension in all groups and right side superiority in shoulder internal rotation in pitchers only. The occurrence of upper extremity asymmetries in physical characteristics of athletes is well documented in the literature. Studies examining these differences in the lower extremity are rare. Logically, superior physical characteristics should be seen in the jumping leg of one-legged athletes like long jumpers, high jumpers, and football kickers. Unfortunately, no studies have been found that examine interlimb differences in physical characteristics in these types of athletes.

Limb Preference Assessment

Many authors have developed lists of tasks for the upper limb, lower limb, eyes, and ears to determine lateral preference. Observing trends in lateral preferences obtained using these assessment tools have contributed to the development of theories that explain the evolution of cerebral dominance and lateralization.

One of the first test protocols for lateral dominance, The Harris Tests of Lateral Dominance,[35] was developed in 1958. Hand, eye and foot dominance were subdivided into specific categories of tasks. Tasks used to assess foot dominance included: the foot used to kick a ball and the foot used to stomp on an object. Subjects were instructed to circle a particular letter depending on how often they used the foot to perform the task. **R** or **L** was circled if the right or left foot was exclusively used, respectively. *R* or *L* was circled if the right or left foot was used most of the time, respectively. M was circled if both feet were used equally. Instructions regarding the determination of dominance from the two tasks were lacking.

In 1971, Oldfield[71] developed The Edinburgh Inventory as a method of determining dominance using a set of inventory items and a scoring and computational convention. The ball-kicking task was the only foot dominance task used. Twenty handedness and 1 eyedness items were included in the inventory. Subjects were instructed to place a '+' sign in the appropriate boxes. Subjects put '++' in the appropriate box if their preference to use one side were so strong that they would never try to use the other hand unless absolutely forced. If subjects were indifferent, they marked a '+' in both boxes. The author tested the inventory on 1,128 male and female undergraduate students. Subjects completed the inventory and their laterality quotient calculated by subtracting the total left +'s from the total right +'s, dividing the difference by the total left and right +'s, and multiplying the quotient by 100. After analyzing the data, an item-analysis was calculated and the 20-item handedness list was shaved down to 10. In both, the one footedness and eyedness tasks were included. The researcher eliminated 10 items that seemed less apt due to socio-economic and cultural influences.

Handedness inventories are common in the literature. However, due to social, environmental and technological influences, determining handedness may not be accurate in describing cerebral dominance and true lateralization. Footedness items are less affected by these same influences.[15,27,31,71] Chapman et al.[15] developed a foot preference inventory to investigate the relationship of foot preference to lateralization of cerebral functions. Five reliable foot behaviors were selected from previous inventories and the other 8 were added because they appeared analogous to items used in hand-preference inventories. Two hundred and twenty psychology students were asked which foot would perform each behavior better. Items were given a score of '1' for using the right foot, a

'2' for using the one foot and then the other, and a '3' for using the left foot. Following reliability testing of the 13 items, the author dropped the items with the lowest values. The final inventory items included: kicking a ball, stamping a tin, rolling a golf ball through a maze, writing in the sand, smoothing out sand, arranging pebbles, balancing on a rod, rolling a golf ball around a circle, kicking, foot tapping, and hopping on one foot.

Elias et al.[27] developed an inventory to test the hypothesis that preferred footedness may serve as better predictor of functional laterality than handedness. The Waterloo Footedness Questionnaire – Revised (WFQ-R) included 5 tasks that assessed foot preference for the manipulating foot. These tasks were: kicking a ball, smoothing sand, stomping on a bug, picking up marbles, and pushing a shovel in the ground. Five other tasks assessing foot preference were included for the foot that provides support during an activity. These tasks were: standing on one foot, stepping up onto a chair, balancing on a railway track with one foot, hopping on one foot, and the weight-bearing foot during relaxed standing. Subjects circled one of five choices: Right always (Ra) or Left always (La), Right usually (Ru) or Left usually (Lu), or both feet equally often (Eq). Responses were scored on a scale from –2 or left always to 2 or right always. Higher scores denoted right side laterality and lower or negative scores denoted left side laterality. A score of '0' denoted ambidexterity.

Many studies determining leg preference as part of their methodology have utilized sport-specific tasks appearing on previous inventories such as kicking a ball. Other researchers have used this task extensively to establish leg preference.[8,19,21,71,84] Tasks related to activities of daily living (ADL) have been used combination with the ball-kicking task such as a step-up, stepping on an object, and balance recovery. Some nonsport-specific tasks and tasks not related to ADL have also been used such as writing with the toes and picking up objects. Hoffman et al.[41] used a step-up test and a balance recovery test to determine leg dominance in their investigation of lower limb performance in anterior cruciate ligament (ACL) reconstructed patients. Demura et al.[24] examined lateral dominance in maximal muscular power, muscular endurance, isokinetic muscular strength, and grading ability of the lower extremities. They designated the dominant leg as the leg that performed 2 out of the 3 following tasks: kicking a ball, stepping first in order to pick up an object off the floor, and drawing a line or circle on the floor with the toes. Neither study reported reliability of the leg preference tools used.

Other researchers have tested the validity and reliability of leg preference assessment tools. Chapman et al.[15] assembled a list of tasks to measure foot preference and tested the reliability of the list and the individual items. Test-retest reliability was examined when 36 subjects were tested twice 3 weeks apart, resulting in a Personian correlation of 0.94 between the two occasions. Items having point-biserial correlations of 0.60 or higher included kicking a ball, writing in sand with the foot, smoothing out sand, moving a golf ball in a circle, and kicking. Coren and Porac[19] determined the validity and reliability of self-report items for the measurement of lateral preference. After testing 95 undergraduates on behavioral measure of footedness, they were administered the questionnaire. A correlation coefficient of $r = 0.81$ between self-reported leg preference and actual task performance was calculated. Ninety-six percent of the original self-report agreed with self-reported preference one year later. The authors suggested that kicking a ball task and stepping onto a stool were valid and reliable tasks. Raczkowski and Kalat[82] also studied the validity and reliability of questionnaire items.

Using tasks from previous questionnaires, the authors administered a 23-item questionnaire to 47 psychology students. After 1 month after completing the original questionnaire, subjects were given performance tests and asked to complete the original questionnaire a second time. For the ball-kicking task there was 86% agreement between taking the questionnaire the first time and performance. There was 89% agreement between taking the questionnaire the first and second time. For the second task, subjects were asked which foot do they put their shoe on first? There was 83% agreement between the first questionnaire and performance and 93% agreement between the first questionnaire and the second.

Dodrill and Thoreson[26] evaluated lateral dominance assessment reliability over a 5-year period in 162 normal and neurologically impaired adults between the ages of 16 and 69 years old. Two leg preference items, kicking a ball and stepping on a bug, along with other hand preference and eye preference items, were administered to all subjects at the beginning of the study and approximately five years later. The authors suggested greater consistency with the hand preference items. Although foot and eye preference reliability measures were less compared to handedness, the authors argued that foot preference item reliabilities were satisfactory. Throughout the literature, assessment tools utilizing multiple tasks, especially tasks such as kicking a ball, initial stepping and stomping/stamping, have been shown to be reliable.

Once the preferred leg has been labeled with a reliable assessment tool, the legs themselves still need to be defined. In a review by Peters[75] the preferred leg was defined as the leg used to manipulate an object or to lead out during a jump. The nonpreferred was defined as the leg used to support the activities of the preferred leg by lending postural support and stability. Demura et al.[24] distinguished the dominant leg in 20 female athletes in order to determine lateral dominance of the legs in maximal muscle power, muscular endurance and grading ability. After establishing the dominant leg using 3 tasks, the dominant leg for power exertion was defined as the stance leg in kicking the ball, taking off for a powerful jump, or hopping on one foot. The dominant leg for functional use was defined as the leg that kicked the ball, stepped first when picking an object up, or drew the circle or line on the floor. Both authors defined functional characteristics associated with both legs after establishing the preferred leg. Questions regarding the origin of one's preference and the accompanying characteristics remain uncertain.

In the literature, methods of assessing the preferred and nonpreferred leg are widespread. Once assessed, both legs have been defined based on their role during a task. Unfortunately, research attributing possible asymmetrical physical and functional qualities with preferred and nonpreferred legs has been lacking. Hence, the relationship between leg preference and asymmetrical performance in flexibility, stability, strength, power, and endurance needs to be studied. Also, asymmetries in the lower extremities of different types of athletes, specifically one-legged and two-legged, as a result of the developmental and overload principle ideas, need to be studied. No studies have attributed specific physical or functional characteristics to the preferred and nonpreferred leg of different athletes.

Physical and Functional Characteristics

Flexibility

Flexibility of the soft tissues around a joint is a characteristic frequently assessed during the initial injury assessment and throughout the rehabilitation process. Few studies analyzed flexibility differences between the preferred and nonpreferred legs of different athletes. Agre et al.[2] determined flexibility and strength differences between the dominant and nondominant legs in 25 male collegiate soccer players. Flexibility measures for hip flexion via a straight-leg raise were not significantly different between the dominant and nondominant leg. Knapik et al.[51] observed the relationship between preseason strength and flexibility measures with athletic injuries in 138 female college students between the ages of 16 and 21 y that participated in one or two of the following activities: soccer, volleyball, field hockey, tennis, fencing, basketball, squash, and lacrosse. The authors did not observe significant differences in hamstring flexibility measured using an active straight-leg raise or quadricep flexibility measured using active knee flexion. In this study, preferred and nonpreferred legs were not established. Kearns et al.[45] examined the architectural characteristics of muscles that are associated with dominant leg use in 20 untrained and moderately active male college freshmen and 26 junior male soccer players. Flexibility was not directly measured; however, authors suggested significantly longer dominant leg muscle fascicles compared to the nondominant leg. The authors added that training and using one leg preferentially over the other resulted in increased muscle thickness and fascicle length. Whether or not these differences can relate to differences in measured flexibility remains unclear.

Agre et al.[2] and Knapik et al.[51] measured hamstring flexibility via passive straight-leg raise and an active straight-leg raise, respectively. Knapik et al.[51] measured quadricep flexibility with active knee flexion.

Several methods of measuring hamstring flexibility have been described in the literature. Webright et al.[99] measured hamstring flexibility using a supine active knee extension test with the hip flexed at 90º in 40 undergraduate males and females to compare the effect of repetitive knee extension movements in a slump position with a static stretching technique on hamstring flexibility. Ninety-degree hip flexion with the subject supine was established using a goniometer. Keeping the ankle relaxed, subjects actively extended the knee while maintaining thigh contact with the crossbar. Hamstring flexibility was measured using a goniometer at the knee. Similarly, Brandy et al.[12] measured hamstring flexibility using a knee extension test with the hip flexed at 90º; however, the knee extension movement was passive instead of active. One hundred subjects between the ages of 20 and 40 years old were used to determine the optimal time and frequency of static stretching to increase hamstring flexibility. The hip and knee were both passively flexed to 90º using a goniometer. One tester maintained 90º of hip flexion while the other passively extended the knee to the point at which the subject complained of discomfort or tightness. The goniometric measurement at the knee was recorded with full extension set at 0º. Hamstring flexibility was measured using the active knee extension test; however, differences in quadricep strength may influence subject performance during this test. In addition, these studies did not look at subjects that have hyperflexible hamstring, thus the validity of this method is questionable for hyperflexible the population.

Hsieh et al.[42] examined the reliability of three instruments used when measuring hamstring flexibility during a passive straight let raise in 4 men and 6 women between the ages of 26 to 36 y. Supine subjects were instructed to remain relaxed while the tester raised the leg with the knee fully extended to the point in the range when the tester palpated a small amount of pelvic movement. Hamstring flexibility was measured using a goniometer, flexometer and tape measure. The results suggested high intrasession reliability at 0.99, 0.97, and 0.99, for the goniometer, flexometer and tape measure, respectively. Intersession reliability was lower at 0.88 for the goniometer and flexometer, and 0.74 for the tape measure. Henricson et al.[39] also measured hamstring flexibility using a passive straight-leg raise. The hamstring flexibility of 30 healthy students and athletes between the ages of 25 and 39 years old was measured in order to examine the effect of heat, stretching, and heat and stretching combined on hip range of motion. Hip flexion was measured in the supine position with the contralateral hip flexed at 45º and the knee flexed at 90º. Passive hip flexion was achieved by pulling the leg with a 5-kilogram force via a dynamometer and measured using a goniometer at the hip. Similarly, Bohannon[9] measured hamstring flexibility using a passive straight-leg raise. Nine women and 2 men from 20 to 32 years old were used in this study cinematographically comparing the angle of straight leg raising in relation to the horizontal with the same angle in relation to the pelvis. In this method, pelvic stabilization was accomplished by strapping down the contralateral leg and anterior pelvis. Knee extension was maintained using a three-point splint. The subject's leg was pulled into hip flexion with a loaded pulley attached to the ankle via a stirrup. The load on pulley was initially less than 10% of the subject's stated weight and was reduced according to the subject's discomfort tolerance. The authors noted the importance of pelvic stabilization during a passive straight-leg raise test when measuring true hamstring flexibility reliably. Pelvic rotation adds to hip flexion range of motion giving the false impression of increased hamstring flexibility. The last 3 methods of measuring hamstring flexibility utilized a passive straight-leg raise. Although these methods were suggested to be reliable and are able to measure hamstring hyperflexibility, complications with each method were addressed. All three studies noted pelvic movement influencing hip flexion necessitating contralateral leg or pelvic stabilization during the test. Henricson et al.[39] fixed the contralateral hip at 45º, potentially rotating the tested hip posterior before the test was even performed. The last two studies used a constant force to passively move the leg into hip flexion, while the study by Bohannon[9] considered limb weight and subject tolerance and discomfort. Hsieh et al.[42] used pelvic movement instead of subject's discomfort or force applied to the limb, to determine hamstring flexibility and reported intrasession and intersession reliability values of 0.97 and 0.88, respectively.

Violan et al.[98] examined the effect of karate training on flexibility, muscle strength and balance in 14 males between the ages of 8 and 13 y. Ten males were also asked to volunteer for the study and served as the control group. Flexibility, static balance, handgrip strength, and leg muscle strength were assessed before and after 6 months of biweekly karate training. Hamstring flexibility was measured with the hip and knee initially positioned at 90º of flexion, and then passively moving the knee into extension until muscle resistance was felt. Quadricep flexibility was measured by flexing the prone subject's knee until muscle resistance was felt or until the hip flexed indicated by the rising of the buttocks. In this study, preferred leg was not determined and the side tested was not mentioned. Regardless, the authors suggested significant increased quadricep and hamstring flexibility after the 6 months of training.

Numerous studies have mentioned measuring hamstring flexibility in a variety of ways and quadricep flexibility was only measured one way. One study discussed hamstring flexibility differences related to the dominant and nondominant legs and subjects tested were collegiate soccer players. Studies that compare hamstring and quadricep flexibility between the preferred and nonpreferred legs and among different types of athletes, especially athletes that predominantly use one leg, are needed.

Stability

Joint stability is a characteristic frequently measured during injury rehabilitation that can be divided into three types: static, dynamic, and semidynamic dynamic. Static joint stability refers to the ability of a joint's dynamic stabilizers (muscles) to brace the joint in a static position with the foot on a stable surface.[8] Semidynamic stability refers to the ability of joint's dynamic stabilizers to brace the joint in a static position with the foot on an unstable surface.[8] Dynamic stability refers to the ability of a joint's dynamic stabilizers to brace a joint during movement.[8] Rozzi et al.[86] studied the effects of fatigue on knee joint laxity, proprioception, balance, and electrical muscle activity in 17 male and 17 female basketball and soccer players. Decreased kinesthetic awareness and increased muscle latency around the knee joint suggested decreased dynamic joint stability with fatigue. A joint's dynamic stability can be affected by injury or premature fatigue making the joint less stable during movement. Therefore, it is crucial to ensure sufficient joint dynamic stability to protect the joint during movement. Insufficient joint stability may lead to re-injury

Harrison et al.[36] examined differences in single-leg standing balance between a person's ACL-reconstructed leg and their uninjured leg using an observational method of balance evaluation. They also examined the reliability of the observational method by comparing postural sway performance measured by the Balance System consisting of a force-plate and software. Seventy-eight recreationally active subjects were recruited for the control group and 17 patients were recruited for the treatment group. Subjects' ages ranged from 17 to 45 y. In both groups, dominant leg was determined using the ball-kicking task. For the balance test, subjects stood on one leg on the force plate, flexed the contralateral leg to 90°, crossed their arms over their chest and placed their hands on the opposite shoulders, and fixed their eyes on a stationary mark on the wall in front of them. Their performance was assessed using a three-point ordinal scale. A score of 1 represented poor performance where the subject demonstrated 3 or more compensatory movements or where their postural sway fell outside their base of support. Two (2) represented fair performance where the subject demonstrated less than 3 compensatory movements and their sway remained contained within their base of support. Good performance was represented by a score of 3 where the subject was able to balance without difficulty, no compensatory movements and no postural sway. While subjects stood on one leg for the 10-second test, postural sway measures were recorded through the force plate and Balance System software. The authors suggested insignificant differences between the dominant and nondominant leg in single-leg standing performance measured by postural sway and observed standing balance evaluation. The authors also suggested a significant correlation between postural sway and observed standing balance tests. The modest correlations ranged from 0.38 to 0.45. Intertester and intratester reliability was not directly determined for the observational method; however, it was significantly correlated with the reliable Balance System measures.

Blackburn et al.[8] determined whether strength or proprioception was the dominant factor in controlling balance and joint stability in 19 women and 13 men aged 18 to 25 years old and who were physically active. The dominant leg was assessed using the ball-kicking task. Having subjects stand on their dominant leg with their eyes closed and hands on hips for 10 seconds on the NeuroCom Smart Balance Master long-forceplate system assessed static stability. The software calculated subject sway-velocity by dividing the distance between ground reaction force variations relative to the center of balance, by a specified time interval. Semidynamic stability was assessed using the Biodex Stability System where the subjects stood on their dominant leg with hands on hips and eyes closed for 10 seconds on the unstable platform at a stability level of 6. Balance performance was scored as a stability index calculated by the Biodex Stability System. Dynamic stability was assessed using the Bass Test where subjects jumped and landed on 10 markers while holding a single-leg stance on each one for 5 seconds. Performance was scored using a point system that rewarded successful landing and stability. Subjects were pretested, placed on a training program that focused on strength or proprioception training or both, and post-tested. Results suggested significant semidynamic and dynamic stability improvement in all groups. Likewise, Rozzi et al.[86] used the Biodex Stability System when they evaluated lower extremity balance by having subjects single-leg stand for 20 seconds with hip flexion at 0º, knee flexion at 90º, arms folded across the chest and hands on opposite shoulders. The platform was set at level 2. The software generated a stability index score and the mean of 3 scores was used in their analysis. In both studies, the Biodex Stability System was used and the dominant leg was used to represent both legs. Contrastingly, researchers of both studies piloted their methods; however, they used different levels of platform instability. Since the Biodex's program calculated stability indexes, the factors and calculations that were used remain unknown.

Goldie et al.[32] assessed the reliability of a newly developed stability testing protocol in 24 subjects between the ages of 18 and 24 years of age. The protocol provided force-platform data from a one-legged stance. Unlike the previous studies, asking subjects which leg was habitually used for hopping assessed leg preference. Subjects stood on one leg with the contralateral hip and knee slightly flexed as to raise the foot 10 centimeters off the ground. They were instructed to keep their hands on their hips and keep their eyes on a fixed target 5 meters away. The Kistler six-component force-platform system measured the following: 3 orthogonal ground reaction force components (vertical force, medial-lateral force, and anterior-posterior force) and two horizontal plane coordinates of center of pressure for 5 seconds. Trials where the unsupported leg touched down on the force platform were saved for analysis. The authors suggested better reliability using ground reaction force measures compared to center of pressure measures. Differences in measures were significant between the two stances: eyes open and eyes closed. They also suggested a lack of systematic effects for leg preference on steadiness in a one-legged stance with the eyes open or closed.

Colby et al.[17] assessed functional stability test reliability of a step down and hop tests by measuring time to stabilization (TTS) via a force platform in three groups: a non-impaired group consisting of 14 men and 11 women aged 31 $\pm$ 9.1 y; an ACL-deficient group consisting of 5 men and 8 women aged 40.4 $\pm$ 12.6 y; and an ACL-reconstructed group consisting of 9 men and 2 women aged 26.3 $\pm$ 10.4 y. Subjects were instructed to step down (from a 19 cm high step) or hop (from a distance equivalent to length measured between the greater trochanter and medial malleolus over a height of 7.5 cm) onto a force platform. They were told to stabilize on the one leg as quickly as possible and TTS of the anterior-posterior (Mx) and medial-lateral (My) center of pressure, anterior-posterior (Fx) and medial-lateral (Fy) force, and vertical force (Fz) were measured. Mx and My stabilization were defined as the point where the sequential series of cumulative averages of all data points remained within ¼ standard deviation of the overall series mean. Fz stabilization was defined as the point where the data points remained within 5% of the subject's body weight. Mx, My, and Fz for the step-down test were found to be reliable (R> 0.82 - 0.93). For the hop test, Fx, Fy, and Fz were found to be reliable (R>0.87 – 0.97). As a result, the authors suggested better reliability with the hop test in measuring TTS for Fx, Fy, and Fz. The authors also noted significant differences in TTS measures when they compared dominant and nondominant leg performance. Performance denoted by Fx and Fy during the nondominant leg's step-down test was higher. Similarly, Ross et al.[85] examined TTS differences between functionally stable and unstable ankles. Subjects jump off two legs at 50% maximum vertical jump height onto a force platform 70 cm away. They were instructed to land on an undefined test leg and to stabilize as quickly as possible. TTS was defined as the time needed to reduce the variation of a given ground reaction force (GRF) component to the range of variation of the corresponding GRF component in a stabilized position. This range of variation of the corresponding GRF component in a stabilized position was determined in a 5-second window at the end of a 20-second data collection period. Although the methods were validated for the purpose of their study, reliability was not determined. Examining stability using a landing from a functional movement (jump) onto a stable surface mimics the body's ability to stabilize in a sport-specific manner. Using relative performance criteria (e.g., 50% maximum vertical jump from 70 centimeters away) to determine jump height versus relative structural criteria (e.g., leg length distance over a 7.5 cm barrier) to determine jump distance considers functional ability not body proportions. Colby et al.[17] revealed differences in the preferred and nonpreferred legs while Harrison et al.[36] and Goldie et al.[32] did not. Blackburn et al.,[8] Rozzi et al.,[86] and Ross et al.[85] did not examine differences in the preferred and nonpreferred legs at all. The existence of asymmetrical dynamic stability remains inconsistent in previous studies using nonathletes. Studies examining asymmetrical dynamic stability in the legs of one-legged and two-legged athletes are lacking.

Power

Functional power is a physical quality that is essential to an athlete's performance. Combining muscular strength and speed of contraction, power is vulnerable to becoming deficient as a result of injury-related inactivity. Problems arise in the assessment of functional power. Symmetrical bilateral performance of power on an isokinetic dynamometer may be quantitatively accurate and reliable; however, it does not necessarily insinuate adequate functionality during activity. In order to accurately test functional power, the movement itself or a hybrid of it, is the best tool. Allowing an athlete with inadequate functional power to return to full competition too hastily predisposes them to re-injury or submaximal performance. Therefore, it is essential to restore an athlete's functional power to near pre-injury levels prior to returning to full competition.

Several studies have examined the validity and reliability of the one-legged hop for distance as a measure of functional power and performance. Jarvela et al.[43] evaluated the validity of the one-legged hop test (OLH) for distance by comparing OLH performance to isokinetic knee flexion and extension strength at 60 (5 repetitions), 180 (5 repetitions), and 240°/sec (25 repetitions) using a Cybex 6000 Dynamometer in 65 males aged 30.6 $\pm$ 8.6 and 21 females aged 30.0 $\pm$ 11.1 who have undergone ACL reconstruction. Isokinetic knee extension and flexion mean torque and the mean of 3 OLH trials were obtained in both legs. Five to 9 y after undergoing ACL reconstruction, no significant differences in isokinetic knee flexion and extension strength were found between the limbs. Significant differences in OLH performance between the limbs were also absent. Comparing isokinetic strength performance and OLH performance, subjects that performed normally (bilateral performance ratio greater than 90%) during the OLH also performed well during the isokinetic testing. Those that performed the OLH below what was defined as normal significantly performed worse during the isokinetic strength tests. The authors suggested good correlation between the OLH and isokinetic knee extension. Reliability of isokinetic strength testing and the OLH have been established in the literature.

Reliability studies on the OLH reinforce its importance. Booher et al.[11] assessed the reliability of three types of single-leg hops: single-leg hop for distance, the 6-meter timed hop, and the timed 30-meter agility hop. Four males and 14 females ranging in age from 18 to 29 y performed each of the 3 tests on the dominant and nondominant leg on 2 occasions at least 24 hours apart. Leg dominance was established using the ball-kicking task. Results showed a great ICC at 0.99 for the single-leg hop between the 2 days. In addition, an independent t-test illustrated the inexistence of significant differences between the nondominant and dominant leg. Likewise, Bolga et al.[10] assessed the reliability of the single-leg hop, 6 meter timed hop, but also examined the triple hop for distance and the crossover hop for distance. Five males and 15 females aged 24.5 $\pm$ 4.2 y performed each test 3 times following 3 practice trials on 2 separate occasions 48 hours apart. Leg dominance was determined using the ball-kicking task and was the only limb tested. Mean performance scores were calculated and revealed higher reliability values for the single-leg hop for distance and the crossover hop for distance (r = 0.96 and 0.96, respectively) compared to the triple hop for distance. Although validity and reliability for using functional tests like the OLH have been established, research examining preferred and nonpreferred leg performance in different types of athletes require investigation.

Mangine et al.[63] used the OLH to assess functional performance as part of a physiological profile of elite soccer athletes. Eighty-three American male National Team soccer players were tested on flexibility, knee ligament laxity, anaerobic endurance, body fat, isokinetic strength, and functional testing. Both legs were assessed; however, the dominant leg was not established. Results of the OLH suggested normal limb symmetry defined in the study as a symmetry index of 85 to 100%, one leg versus the other. Other studies comparing the performance differences of the preferred and nonpreferred legs during functional tests between soccer players and other athletes are lacking.

Strength

Strength is an important quality that deserves close monitoring during injury rehabilitation. The strength of the musculature surrounding a joint is important in contributing to a joint's dynamic stability and overall maximal performance. An injury that sidelines an athlete for a considerable amount of time inhibits strength development of the affected area. Prolonged inactivity may result in muscle inhibition and possibly muscular atrophy. Decreasing strength deficits contributes to dynamic stability and sound performance.

Symmetrical isokinetic strength in athletes and nonathletes has been frequently suggested in the literature. Spry et al.[93] examined quadricep and hamstring isokinetic strength bilaterally in 43 male and 33 female nonathletes using the Cybex II Isokinetic Dynamometer at 60°/sec. Leg dominance was established using Chapman's et al.[15] 11-item inventory for foot preference. Peak torque was noted as the highest value of 3 trials for knee flexion and extension. Results revealed insignificant differences in the dominant and nondominant leg. The authors did not specify whether they tested concentric strength, eccentric strength or both. Greenberger and Paterno[34] also used nonathletes, but assessed concentric knee extensor strength isokinetically at 240°/sec on the KinCom to determine the relationship between knee extensor strength and performance on a one-legged hop for distance test. They obtained mean peak torques of 3 maximal repetitions in 7 male and 13 female college students and suggested no significant differences in the dominant and nondominant leg. Dominant leg was assessed with the ball-kicking task. Bilateral concentric and eccentric strength symmetry was measured when Parkin et al.[72] evaluated 39 male rowers between the ages of 19 and 26 y using the KinCom Isokinetic Dynamometer at 3.5 radians per second (200°/sec) and 1.75 radians per second (100°/sec). Results showed a lack of significant differences between the right and left legs irrespective of hand dominance and rowing side that dictated leg dominance. This study was unlike the previous studies mentioned. Rowers were specifically used for the treatment group and dynamometer velocity was set in radians per second.

Most studies on the athletic population focused on soccer players. The majority of those studies suggested bilateral symmetry in knee flexor and extensor strength. Costain and Williams[20] examined bilateral quadricep and hamstring strength of 16 female high school soccer players using the Cybex II Isokinetic Dynamometer concentrically at slow speeds (30°/sec) and high speeds (180°/sec). Means of the 4 repetitions at slow speeds and 3 repetitions at high speeds were obtained and compared. Results demonstrated no significant differences in concentric quadricep and hamstring torques between the two legs. Likewise, Mangine et al.[63] suggested no significant differences in knee extensor and flexor isokinetic strength existed between the two legs of 83 soccer players. Unlike Costain and William's[20] study, Mangine et al.[63] used the Biodex Isokinetic Dynamometer at 60 and 450°/sec to evaluate isokinetic knee flexor and extensor strength in soccer players who were male and elite (Olympic level).

Some studies on soccer athletes suggested lower limb asymmetrical strength in knee flexors and extensors. McLean and Tumility[66] examined isokinetic knee flexion and extension on the Cybex II Isokinetic Dynamometer at 60, 180, and 240°/sec in 12 elite Australian soccer players with a mean age of 16.8 $\pm$ 0.7 y to investigate asymmetry in the characteristics of the low drive and chip kicks. Kicking leg was not established, however, authors revealed a significantly greater mean torque for the 3 trials for right knee extension versus mean torque for left knee extension at all testing speeds. In addition, performance of the low drive kick by the right leg was significantly better than the left. Two other studies isokinetically examined bilateral knee strength in soccer players and suggested the existence of lower limb asymmetries. Kellis et al.[48] measured concentric and eccentric knee extension and flexion peak torques at 60,120, and 180°/sec using the Cybex Norm dynamometer, and determined leg preference with the ball kicking task in 158 soccer players 13 $\pm$ 2.1 years old. Authors suggested a significantly stronger preferred leg than the nonpreferred leg. Similarly, Chin et al.[16] measured knee flexion and extension strength in the dominant and nondominant legs of 20 elite Asian soccer players between 16 and 18 years old. In their study, peak torque during 5 repetitions of concentric knee flexion and extension was measured on the Cybex II Isokinetic Dynamometer at 60 and 240°/sec. Results showed significantly greater dominant leg knee flexor strength versus the nondominant leg at both speeds and no significant differences in knee extensor strength. Conflicting results in the literature regarding bilateral strength between the lower limbs of soccer athletes have been presented.

Studies examining strength characteristics in different athletes of different sports are infrequent. Knapik et al.[51] measured preseason strength and flexibility imbalances in 138 female collegiate athletes from 8 weight-bearing sports: soccer, volleyball, field hockey, tennis, fencing, basketball, squash, and lacrosse. Knee flexion and extension peak torques from 3 to 5 test repetitions were measured isokinetically on the Cybex II dynamometer at 30 and 180°/sec. Since the authors were observing incidence of injury related to strength and flexibility measures, resultant measures suggested stronger right knee flexors 15% greater than left knee flexors at 180°/sec which correlated with a trend for higher injury rates. Yamamura et al.[100] examined concentric mean torque of both legs for knee flexion and extension performed on the Lido Active System at 60°/sec in 16 elite female synchronized swimmers. Since swimmers used both limbs equally during training and competition, combined mean torque values between the right and left limbs were used during the analysis. Although isokinetic strength was examined in swimmers, no bilateral comparison was attempted. One study measured concentric knee flexion and extension isokinetically in both legs. Thomas et al.[96] examined physiological and psychological correlates of success in different track and field athletes. Forty-four male collegiate athletes between the ages of 17 and 22 years old participated and were divided according to event specialty: distance runners, sprinters, and jumpers. Mean torques of 3 knee extension and flexion movements were measured isokinetically using the Cybex II Dynamometer at 60°/sec. Direct bilateral strength comparisons were made and represented as a ratio of the higher side value to the lower value of the opposite side. No direct comparisons were made among different athletes. This study examined one-legged athletes, however, strength differences and comparisons among athletes and nonathletes were not analyzed.

Perrin et al.[74] examined bilateral concentric knee flexor and extensor strength isokinetically at 60 and 180°/sec in 15 baseball pitchers, 15 swimmers, and 15 nonathletes all of whom were male collegiate athletes between the ages of 18 and 27 years old. Leg dominance was not assessed; however, right leg measures were compared to left leg measures. Results demonstrated similar peak torque values between the lower limbs during knee flexion or extension in all 3 groups. This is the only study that examined isokinetic strength differences in college-aged nonathletes and athletes of two completely different sports.

A review of literature revealed insufficient research in comparing knee flexor and extensor isokinetic strength between preferred and nonpreferred legs of male and female nonathletes, and athletes of different sports.

A review of literature showed reliable isokinetic strength measurements using isokinetic dynamometers. Perrin[73] examined the reliability of isokinetically obtained strength measurements in 15 college-aged male students using a Cybex Isokinetic Dynamometer. Concentric knee flexion and extension peak torque of 5 repetitions at 60°/sec and 3 repetitions at 180°/sec was obtained, and then retested one week later. The author suggested excellent peak torque reliability for concentric knee flexion and extension ranging from 0.83 and 0.93. Slightly higher r-values were noticed with knee flexion at 60°/sec and knee extension at 180°/sec at 0.92 and 0.93, respectively. Similarly, Quittan et al.[81] calculated high Interclass Correlation (ICC) values for isokinetically measured knee flexion and extension strength in 38 patients 56 $\pm$ 8 years old. Obtaining peak torque from 3 repetitions during knee flexion and extension at 60°/sec on the Cybex 6000 Dynamometer on a test day then 5 days after, resulted in ICC values ranging from 0.82 to 0.87 for knee flexion and 0.96 to 0.99 for knee extension. Both studies reinforce isokinetic dynamometer reliability for knee flexion and extension.

Eccentric knee flexion and knee extension reliability using isokinetic dynamometry has also been established in the literature. Li et al.[58] determined concentric and eccentric reliability of the Cybex 6000 in measuring knee flexion and extension peak torque in 18 male and 12 female subjects at 60 and 120°/sec. The authors suggested significant test-retest reliability in concentric and eccentric peak torque measures ranging between 0.82 and 0.91.

Isokinetic dynamometry has been extensively used to determine concentric and eccentric strength for knee flexion and extension. Subjects of different non-athletic and athletic backgrounds have been tested at high and low speeds for a variety of purposes with excellent reliability. Although many studies have suggested bilateral strength symmetry, others have suggested asymmetry. Studies correlating isokinetically measured strength asymmetries with leg preference in different types of athletes (one-legged and two-legged) are rare.

Muscular Endurance

Muscular endurance or resistance to fatigue is a physical characteristic needed to ensure adequate dynamic stability at times when fatigue begins to influence performance. Nyland et al.[70] fatigued 20 female intramural athletes (soccer, basketball, flag football, and tennis) aged 21.1 $\pm$ 1.6 y to assess fatigue induced dynamic stability at the knee during a crossover movement. Hamstring fatigue was induced isokinetically using Biodex isokinetic dynamometer and defined when eccentric knee flexion reached 20% peak torque production on 3 consecutive repetitions. The results showed a decrease in dynamic transverse knee plane control resulting from fatigue as measured by increased internal tibial rotation during a crossover movement. The authors suggested decreased knee joint stability during a pivoting movement resulting from fatigue. Increasing one's endurance capacity allows an athlete to prolong the time to performance deficits. Returning an athlete to competition with muscular endurance deficits may predispose them to early fatigue, submaximal performance, and possibly re-injury.

Very few studies have examined muscle endurance differences between the lower limbs. Demura et al.[24] examined lateral dominance in maximal muscle power, muscular endurance, and grading ability in 50 healthy active male subjects between 19 and 23 years of age. To assess muscular endurance, 30 reciprocal knee flexion and extension movements were performed continuously at 180°/sec. An endurance ratio consisting of the sum of total work in the first 6 trials divided by the sum of the last 6 trials multiplied by 100, represented muscular endurance. Dominant and nondominant leg were established using 6 tasks from a previous inventory[15] and results of the muscle endurance test revealed no significant differences between the limbs.[24] This study suggested muscle endurance symmetry and a pre-testing reliability range established at 0.72 to 0.95.

Pincivero et al.[77] suggested a difference in the reliability of the fatigue index between the dominant and nondominant leg. Eight male and 8 female volunteers aged 22.1 $\pm$ 1.9 y were used to evaluate test-retest reliability of 2 different measures of muscle fatigue. Subjects performed 30 reciprocal concentric isokinetic knee extension and flexion movements at 180°/sec with maximal effort on 2 separate occasions separated by a 1 to 2 week period. Muscle endurance was represented by a fatigue index (work performed during the last 5 repetitions divided by work done during the first 5, multiplied by 100), and the slope of work performed (determined via linear regression analysis by plotting the work values for each repetition across the 30 contractions for each subject). Results illustrated significantly lower reliability using the fatigue index for the dominant leg compared to the nondominant leg at 0.26 and 0.82, respectively. Reliability of the linear model was significantly greater for the dominant leg (0.82) and indifferent to the fatigue index reliability value of the nondominant leg (0.78). The difference in fatigue index reliability between the dominant and nondominant legs is not an indication that asymmetry exists; rather, the method of muscular endurance assessment is inconsistent. In agreement, Perrin[73] suggested that an endurance ratio is an unreliable indication of muscle endurance. Fifteen male college students with a mean age of 20.53 y underwent isokinetic testing for knee flexion and extension at 60 and 180°/sec. Reliability was determined by repeating the test protocol 1 week following initial testing. Subjects performed 25 maximal knee flexion and extension repetitions to produce an endurance ratio (total work in last 5 repetitions compared to total work done in the first 5).

Reliability of the endurance ratio was poor ranging from 0.21 to 0.62. In the literature, other muscle endurance protocols have been suggested and their reliabilities established.

Burdett and Swearingen[13] tested the reliabilities of 2 methods of measuring quadricep endurance using the Cybex II at 180 and 240°/sec in the dominant leg (undefined) 36 health young adults. A ratio of the work done during the first 5 and the last 5 of 25 repetitions was compared to the number of contractions until peak torque fell below 50% of initial peak torque. Testing occurred at both speeds on 2 separate occasions separated by a minimal 2-day rest period. Results suggested work ratio reliabilities were 0.48 and 0.56 at 180 and 240°/sec, respectively. Conversely, the number of contractions until 50% of initial peak torque as a test for quadricep muscle endurance was more reliable at 0.85 and 0.74 at 180 and 240°/sec, respectively.

The importance of muscle resistance to fatigue has been established in the literature. Methods of determining endurance varies; however, the literature has suggested better reliability by counting the number of contractions to 50% initial peak torque compared to the endurance ratios or fatigue indexes. Studies examining muscle endurance limb differences or leg preference correlations in different types of athletes are unseen.

Establishing the existence and or extent of lower limb differences in flexibility, stability, strength, power, and endurance of different types of athletes would be useful to clinicians and researchers. The relationship among these characteristics and the preferred and nonpreferred leg may clarify assumptions previously made by clinicians and researchers, and provide them with simple leg preference tools by which these assumptions can be made.

CHAPTER 3
METHODS

Subjects

College aged subjects (males and females aged 18-25 years old) was selected from three populations: sedentary/nonathletes (NAS), one-legged athletes (1LA), and two-legged athletes (2LA). NAS was classified as those individuals that regularly participate in non-specific training or recreational physical activity less than 3 days a week, less than 1 hour each day. 2LA were classified as those individuals that specifically train and compete at their particular activity 3 or more days a week, 1 or more hours each day. In addition, the training or activities that these individuals complete do not focus on one leg. 1LA was classified as those individuals that also specifically train and compete at their particular activity 3 or more days a week, 1 or more hours each day. However, their training or activities focus primarily on one leg. All athletes who participated in this study have been participating in their respective activity for at least 1 year prior to being tested.

Certain factors may affect test performances; therefore subjects were screened prior to enrollment. Subjects who have suffered any injuries to either lower extremity or lumbar spine 6 months prior to the start of the study and who have not completed a standard rehabilitation program was excluded from the study. Subjects with any vestibular disturbances, regardless of origin (e.g., ear infection, head trauma), were excluded as proprioceptive performance may be affected by such disturbances.

Instrumentation

Forms

Subjects completed a Subject General Information Form (APPENDIX A) and an Athlete Classification Form (APPENDIX B). The Subject General Information obtains general information (age, height, weight, age, gender, and previous injuries) about each subject. The Athlete Classification Forms was used to assign each subject to one of the three groups: NAS, 2LA, and 1LA.

Warm-Up

Subjects warmed up before any testing. They pedaled comfortably for 5 minutes on a Monark cycle ergometer (Monark Exercise AB, Varberg, Sweden).

Flexibility

Flexibility measurements of the hamstring was measured using an inclinometer (Johnson Level and Tool Mfg. Co, Mequon,WI) during the passive straight-leg raise. Quadricep flexibility was measured using the inclinometer during passive prone knee flexion.

Stability

Maximal vertical jump height was used during the stability measurement procedures and was assessed using the Vertec™. Stability data were obtained using a Bertec Force plate (Bertec Corporation, Columbus,OH) and the DataPac Software (Run Technologies, Laguna Hills, CA). Frequency of sampling from the force plate and data processing was 2000Hz.

Power

Power was represented by distanced hopped off one leg. The distance between the toes at the zero mark to the heel at landing was measured using a standard tape measure.

Strength

Concentric and eccentric strength for the knee extensors and flexors were assessed. Strength was measured isokinetically using the KinCom Isokinetic Dynamometer and accompanying software (Chattanooga Group, Hixson, TN).

Muscle Endurance

Muscle endurance for knee extensors and flexors was assessed. Endurance was evaluated isokinetically the KinCom Isokinetic Dynamometer and accompanying software (Chattanooga Group, Hixson, TN).

Measurements

Flexibility

Hamstring flexibility was measured using the passive straight-leg raise technique described by Hsieh et al.[42] Velcro™ straps was attached to both lower legs of the supine subject 5 cm proximal to the lateral malleoli. The inclinometer was attached to one leg resting on the table so that it reads 0°. Subjects were instructed to keep both legs relaxed while the test leg is raised passively into hip flexion. The leg was raised to the point in the range where the tester detects pelvic rocking while maintaining full knee extension. The leg was raised and lowered several times through a small arc to detect the onset of pelvic rocking. Inclinometer reading at the onset of pelvic rocking was recorded. Hsieh's et al.[42] passive straight-leg raise technique accounts for pelvic rotation, quadricep weakness, subjects with poor flexibility, and subjects with excessive flexibility. Intersession and intrasession reliability was reported as 0.97 and 0.88, respectively.[42] A pilot study assessing intersession reliability was conducted and established at 0.93.

Quadricep flexibility was measured using a passive prone knee-flexion test and recorded in degrees. Subjects started prone with the legs beside each other and their feet hanging off the edge of the table. Velcro™ straps were positioned on each leg 5cm proximal to the malleoli. The inclinometer was attached to the test leg so that reads 0°. The knee was moved into flexion until pelvic movement is detected upon anterior superior iliac spine (ASIS) palpation. The knee was flexed and extended several times in a small arc until the onset of pelvic movement is detected. Inclinometer reading at the onset of pelvic movement was recorded. Intrasession reliability was established during a pilot test by the primary investigator at 0.98. All flexibility measures were recorded in degrees and used in the analysis. Three inclinometer readings for the hamstring and the quadricep were recorded in degrees and the highest value was used in the analysis.

Stability

The procedures described by Ross et al.[85] were used to assess functional stability. Two-legged maximal vertical jump height was measured using the Vertec. Subjects stood on their toes under the Vertec reached up as high as possible and moved as many vanes as possible. The standing reach vane was noted. From a standing position, subjects jumped as high as possible, moving the highest vane possible. The difference between the standing vane and highest vane moved was recorded as their maximal jump height. The vane representing 50% of their maximal jump height was moved back to its starting position. Subjects were instructed to jump off two feet at a starting marker (70 centimeters away from the center of the forceplate), touch the 50% vane on the Vertec (the base of the Vertec stood 35 centimeters away from the center of the forceplate), and try to land on the center of the forceplate with the test leg. They were instructed to stabilize as quickly as possible and remain motionless (arms on hips and looking straight ahead) for 20 seconds. Subjects performed 3 practice jumps onto the forceplate until they feel comfortable before performing 5 test jumps. The first 3 seconds of data were analyzed in the same manner described by Colby et al..[17] Anterior-posterior (Mx) and medial-lateral (My) center of pressure time to stabilization (TTS) was defined as the point where the sequential average of the data collected data remained within ¼ standard deviation of the mean of the entire series. TTS for vertical force (Fx) was defined as the point at which the data points remained within 5% of the subject's body weight. The highest and lowest values were omitted and the mean of the remaining 3 trials was calculated and used in the analysis.

Power

Power was represented by the distance hopped during one-leg hop test (OLH) and was assessed as described by Bolgla et al.[10] Hop distance was measured using a standard tape measure secured to the floor. Subjects were instructed to stand on one leg with the toes aligned at a starting mark with their arms by their sides, hop as far as possible, and land on one or both feet in a controlled manner (hop foot stationary after landing). Subjects performed 3 submaximal familiarization trials alternating each leg. After a 1-minute rest, subjects performed 3 test hops as far as possible, landing in a controlled manner and alternating legs after hops to ensure adequate rest. The distance from the starting mark and the heel mark on landing was measured in centimeters. The trial was repeated if the subject falls, or the hop foot slides, pivots, or shifts during the landing. Test-retest reliability was reported in the literature at 0.96. The furthest hop distance of the 3 performed was used in the analysis.

Strength

Concentric strength of the knee flexors and extensors was assessed using similar methods described by Quittan et al.,[81] but using the KinCom Dynamometer. Subjects were seated in the upright position with their lateral femoral condyle aligned with the lever arm axis of rotation. According to the device's guidelines, stabilization straps around the thigh and chest were used to fix the knee and trunk, respectively. The resistance pad attached to the lever arm was secured around the distal tibia. Gravity correction procedures were followed according to the device's guidelines and distance between the tibial resistance pad and lever arm axis considered during protocol setup. Knee range of motion was set between 10 and 90° of flexion with the mechanical stops fixed according to the device's guidelines. Subjects kept their arms crossed during familiarization and testing. Subjects performed 3 sets of 3 submaximal concentric repetitions at 60°/sec with increasing effort for familiarization. After a 1-minute rest period, subjects performed 3 maximal knee flexion and extension repetitions concentrically. Highest peak torque values were recorded in Nm at 60 and 180°/sec. Reliability values for concentric knee flexion and extension were reported in the literature at 0.96 to 0.99 and 0.82 to 0.96, respectively. Eccentric knee flexion and extension strength was assessed using similar methods described by Li et al..[58] Eccentric strength was assessed at 60°/sec. Subjects performed 3 sets of 3 submaximal eccentric repetitions with increasing effort for familiarization. After a 1-minute rest period, subjects performed 3 maximal knee flexion and extension repetitions eccentrically and highest peak torque values in Nm were recorded. Test-retest reliability values for eccentric knee flexion and extension were reported in the literature to range from 0.82 to 0.91.[58] Highest peak torque values for concentric and eccentric knee flexion and extension were recorded and used in the analysis.

Muscular Endurance

Muscle endurance was assessed last in all subjects to ensure that fatigue developed from the endurance test does not influence the performance during any of the other tests. Endurance was assessed using the protocol described by Burdett and Swearingen,[13] but using the KinCom Dynamometer. Subject positioning and stabilization was carried out according to the device's guidelines and identical to the methods described during the isokinetic strength assessment. At 180°/sec, subjects were instructed to continuously flex and extend their knee with maximal effort through the full range of motion (0 to 90°). The number of contractions performed until torque produced falls below 50% of their peak torque for 2 consecutive contractions was recorded and used in the analysis. Reliability of this protocol was reported in the literature at 0.85.[13]

Leg Preference

Subjects filled out a questionnaire to determine leg preference (APPENDIX C). The questionnaire consists of 3 questions pertaining to task performance: the ball-kicking task,[15,35,71] stepping on an object,[35] and smoothing out sand.[15] The leg that performs 2 out of the 3 tasks was designated as the preferred leg.

Procedures

Proceeding University of Florida Institutional Review Board authorization, a total of 24 subjects (n=8) were asked to participate in the study. Procedures of the study were explained to the subjects and written consent was obtained. Subjects reported to the testing area comfortably dressed, wearing shoes and socks. After consent has been received the Subject General Information and Athlete Classification Forms were given to the subject to complete. The order of the following 5 tests has been established to reduce the testing/reactivity effect. Flexibility was measured first followed by stability and power. Strength was tested in the following order succeeding the other tests: concentric quadricep and hamstring strength at 60°/sec, eccentric quadricep and hamstring strength at 60°/sec, concentric quadricep and hamstring strength at 180°/sec. Finally, muscle endurance was tested at 180°/sec.

Subjects rested for 2 minutes between performance tests. For all tests, both legs were alternately tested. Choosing a number (1 or 2) out of a hat established the first leg tested. Last, subjects completed the Leg Preference Questionnaire.

Data Analysis

The dependent variables for this investigation are flexibility (hamstring, quadricep), stability (TTS), power (OLH), strength (hamstring and quadricep, concentric and eccentric), and muscular endurance (number of repetitions to 50% of initial peak torque). All measurements for each test were recorded as left leg and right leg performance on the data collection sheet (APPENDIX D). The independent variables for this investigation are leg preference (left, right) and group (NAS, 1LA, 2LA).

Outcome measures were analyzed using 2 x 3 (leg preference x group) ANOVAs for the dependent measures of flexibility, stability, power, strength, and muscular endurance. If any significant differences are revealed by the ANOVAs, Tukey's HSD Post Hoc Tests were performed to establish where the significant differences occur. Pearson Correlation Coefficients were calculated to determine if there are associations in the preferred leg or nonpreferred leg with the following characteristics: flexibility, stability, power, strength, and or muscular endurance.

Data were analyzed using SPSS 10.0 (SPSS, Chicago, IL). The level of significance was set *a priori* at $P < 0.05$.

CHAPTER 4
RESULTS

The purpose of this study was to determine if asymmetries in flexibility, stability, power, strength, and endurance existed between right and left legs. Additionally, asymmetries and their association with leg preference were examined. College aged males and females were recruited and grouped according to type of activity and total weekly participation time. Raw flexibility, stability, power, strength, and endurance data and leg preference data were collected and analyzed. Appendix E contains the raw data.

Two-way ANOVAs determined if any interactions occurred in leg preference (preferred, nonpreferred) by group (NAS, 1LA, 2LA). If significant differences were revealed Tukey's HSD post hoc analysis was used to locate where the differences occurred. ANOVA tables can be found in Appendix F.

Subject Demographics

A total of 24 subjects participated in this study. There were 4 males and 4 females in each of the 3 groups (n=8). The NAS and 2LA group consisted of University of Florida students considered inactive or active, respectively, based on the inclusionary criteria. The 1LA group consisted of University of Florida varsity track athletes (hurdlers, long jumpers, high jumpers) who also fulfilled the inclusionary criteria. The mean age, height, and weight of all subjects (N=24) was 20.7 $\pm$ 1.3 y, 173.5 $\pm$ 9.7cm, and 69.3 $\pm$ 12.3 kg, respectively. Twenty-one of 24 subjects had a right leg preference and 3 had a left leg preference (Table E-7). Descriptive statistics by group are listed in the Table 4-1.

Table 4-1 Descriptive statistics by group (mean ± SD)

	Age (y)	Height (cm)	Weight (kg)
NAS	21.0 ± 1.2	170.8 ± 6.9	68.5 ± 13.1
2LA	20.8 ± 1.3	169.9 ± 8.6	66.3 ± 10.0
1LA	20.3 ± 1.4	179.7 ± 11.1	72.9 ± 14.0

Flexibility

Quadricep (Table 4-2) and hamstring (Table 4-3) flexibility means and standard deviations for each leg and each group were recorded. The ANOVA revealed no significant interactions in leg preference (preferred, nonpreferred) by group (NAS, 1LA, 2LA) for quadricep [$F_{(2, 21)}$=1.643, P=0.217] and hamstring flexibility [$F_{(2, 21)}$=1.849, P=0.182].

Table 4-2 Quadricep flexibility (mean ± SD)

	Nonpreferred	Preferred
NAS	121 ± 15º	125 ± 17º
2LA	120 ± 16º	124 ± 13º
1LA	126 ± 6º	125 ± 8º

Table 4-3 Hamstring flexibility (mean ± SD)

	Nonpreferred	Preferred
NAS	56 ± 16º	59 ± 11º
2LA	65 ± 15º	65 ± 11º
1LA	71 ± 6º	69 ± 6º

Stability

Stability, represented by time to stabilization (TTS), was divided into three components: vertical force (Fz), anterior-posterior center of pressure (Mx), and medial-lateral center of pressure (My). The means and standard deviations for Fz, Mx, and My for each leg and each group were recorded in Tables 4-4, 4-5, and 4-6, respectively. The ANOVA revealed no significant interactions in leg preference by group for Fz [$F_{(2, 21)}$=0.008, P=0.993], Mx [$F_{(2, 21)}$=0.017, P=0.983], and My [$F_{(2, 21)}$ =1.213, P=0.317].

Table 4-4 Vertical force center of pressure (mean + SD)

	Nonpreferred	Preferred
NAS	1116 ± 306 msec	1203 ± 280 msec
2LA	1374 ± 413 msec	1482 ± 398 msec
1LA	1464 ± 448 msec	1556 ± 320 msec

Table 4-5 Anterior-posterior center of pressure (mean ± SD)

	Nonpreferred	Preferred
NAS	1582 ± 262 msec	1686 ± 201 msec
2LA	1657 ± 226 msec	1723 ± 284 msec
1LA	1529 ± 345 msec	1606 ± 201 msec

Table 4-6 Medial-lateral center of pressure (mean ± SD)

	Nonpreferred	Preferred
NAS	1514 ± 294 msec	1455 ± 200 msec
2LA	1417 ± 267 msec	1596 ± 270 msec
1LA	1531 ± 346 msec	1373 ± 412 msec

Power

Power was represented by one-legged hop distance (OLH) in centimeters. The means and standard deviations were recorded in Table 4-7. The ANOVA revealed no significant interactions in leg preference by groups for OLH [$F_{(2, 21)}$=0.740, P=0.489]. However, a group main effect was revealed [$F_{(2, 21)}$=13.357, P<0.001] when data for both legs were pooled. Tukey's HSD post hoc analysis showed that 1LA jumped significantly farther than 2LA and NAS.

Table 4-7 One-legged hop distance (mean ± SD)

	Nonpreferred	Preferred	Combined
NAS	147.7 ± 20.6 cm	146.7 ± 15.8 cm	147.8 ± 17.8 cm
2LA	154.4 ± 31.2 cm	149.2 ± 29.1 cm	151.0 ± 29.3 cm
1LA	211.5 ± 36.1 cm	212.4 ± 32.3 cm	212.0 ± 33.1 cm*

1LA significantly greater than 2LA and NAS (p< .05)

Strength

Concentric quadricep and hamstring strength means and standard deviations were recorded in Table 4-8 and 4-9, respectively. The ANOVA revealed no significant interactions in leg preference by group for concentric quadricep strength [$F_{(2, 21)}$=0.069, P=0.933] and concentric hamstring strength [$F_{(2, 21)}$=0.964, P=0.398). A significant main effect among groups was noted when preferred and nonpreferred legs were pooled together [$F_{(2, 21)}$=6.525, P=0.006]. Tukey's HSD post hoc analysis revealed that 1LA had greater concentric quadricep strength than 2LA and NAS. Similarly, 1LA had greater concentric hamstring strength than 2LA and NAS.

Table 4-8 Quadricep concentric strength (mean ± SD)

	Nonpreferred	Preferred	Combined
NAS	105.00 ± 28.69 Nm	103.25 ± 20.35 Nm	104.13 ± 23.05 Nm
2LA	111.38 ± 30.52 Nm	111.13 ± 32.27 Nm	111.25 ± 30.34 Nm
1LA	164.88 ± 54.14 Nm	165.63 ± 49.50 Nm	165.25 ± 50.12 Nm*

* 1LA significantly greater than 2LA and NAS (P < 0.05)

Table 4-9 Hamstring concentric strength (mean ± SD)

	Nonpreferred	Preferred	Combined
NAS	76.88 ± 23.98 Nm	87.63 ± 23.82 Nm	82.25 ± 23.75 Nm
2LA	82.25 ± 19.42 Nm	77.63 ± 25.59 Nm	79.94 ± 22.62 Nm
1LA	119.63 ± 35.22 Nm	125.88 ± 46.38 Nm	122.75 ± 39.91 Nm*

* 1LA significantly greater than 2LA and NAS (P < 0.05)

Quadricep and hamstring eccentric strength means and standard deviations were recorded in Table 4-10 and 4-11, respectively. The ANOVA revealed no significant interactions in leg preference by groups for eccentric quadricep strength [$F_{(2, 21)}$=0.345, P=0.712) and eccentric hamstring strength [$F_{(2,21)}$=0.301, P=0.743). However, when the preferred and nonpreferred legs were pooled together, main effects were noted for eccentric hamstring strength [$F_{(2,21)}$=4.455, P=0.024]. Tukey's post hoc analysis showed greater eccentric hamstring strength in 1LA compared to NAS.

Table 4-10 Quadricep eccentric strength (mean ± SD)

	Nonpreferred	Preferred	Combined
NAS	134.00 ± 37.98 Nm	131.25 ± 37.10 Nm	132.63 ± 36.26 Nm
2LA	135.13 ± 34.10 Nm	136.25 ± 42.89 Nm	135.69 ± 37.44 Nm
1LA	187.25 ± 54.28 Nm	179.13 ± 55.94 Nm	183.19 ± 53.41 Nm

Table 4-11 Hamstring eccentric strength (mean ± SD)

	Nonpreferred	Preferred	Combined
NAS	85.63 ± 17.95 Nm	91.63 ± 25.72 Nm	88.63 ± 21.65 Nm
2LA	92.75 ± 17.29 Nm	89.50 ± 31.46 Nm	91.13 ± 24.58 Nm
1LA	125.63 ± 36.78 Nm	130.63 ± 51.72 Nm	128.13 ± 43.43 Nm*

*1LA significantly greater than NAS ($P < 0.05$)

Muscle Endurance

Quadricep and hamstring muscle endurance was recorded as the number of repetitions to 50% initial peak torque. The means and standard deviations were recorded in Table 4-12 and 4-13. The ANOVA revealed no significant interactions in leg preference by group for quadricep [$F_{(2,21)}$=0.864, P=0.436] and the hamstring [$F_{(2,21)}$=0.252, P=0.779] endurance.

Table 4-12 Quadricep muscle endurance (mean ± SD)

	Nonpreferred	Preferred
NAS	26.8 ± 5.1 reps	29.8 ± 6.2 reps
2LA	27.1 ± 7.6 reps	26.0 ± 6.1 reps
1LA	27.1 ± 5.3 reps	28.0 ± 4.7 reps

Table 4-13 Hamstring muscle endurance (mean ± SD)

	Nonpreferred	Preferred
NAS	27.1 ± 6.1 reps	25.8 ± 7.4 reps
2LA	28.1 ± 7.5 reps	27.5 ± 4.4 reps
1LA	30.0 ± 6.7 reps	27.4 ± 7.4 reps

CHAPTER 5
DISCUSSION

The purpose of this study was to determine if asymmetries in flexibility, stability, power, strength, and muscular endurance existed between the preferred and nonpreferred legs of athletes and nonathletes; in addition, whether a relationship existed between these asymmetries and leg preference. This was the first study that compared physical and functional characteristics in the preferred and nonpreferred legs of NAS, 2LA, and 1LA. Three hypotheses were examined in this study.

The first hypothesis stated that there would be physical and functional asymmetries in the preferred and nonpreferred legs of 1LA as measured by the following tests: flexibility (quadricep and hamstring), time to stabilization, one-legged hop distance, strength (quadricep and hamstring, concentric and eccentric), or anaerobic endurance (quadricep and hamstring). The results of this study failed to reject the null hypothesis by revealing no significant differences in the preferred and nonpreferred legs of 1LA in any of the tests.

The second hypothesis stated that there would be no physical or functional asymmetries in the preferred and nonpreferred legs of 2LA. The results of this study failed to reject this hypothesis by revealing no significant differences in the preferred and nonpreferred legs of 2LA in any of the tests.

The third hypothesis stated that the preferred legs would be associated with greater hamstring flexibility and quadricep strength compared to the nonpreferred legs in 1LA. Additionally, the nonpreferred leg would be associated with greater quadricep flexibility, shorter stabilization times, longer hop distances, greater hamstring strength, and greater time to fatigue. The third hypothesis could not be supported since the results of this study failed to reveal significant differences in the preferred and nonpreferred legs of the 1LA; hence, no associations with leg preference could be made.

Flexibility

Similar to Agre et al..[2] and Knapik et al..[51] the present study found no significant differences in the preferred and nonpreferred legs for hamstring and quadricep flexibility. However, neither Agre et al..[2] or Knapik et al..[51] strictly examined NAS or 1LA.

Agre et al..[2] did not report significant differences for hamstring flexibility in the preferred and nonpreferred legs of college aged soccer players. Hamstring flexibility was determined by using a goniometer measuring hip flexion at the greater trochanter during a passive straight-leg raise. They concluded that although favoring one leg more for kicking and handling the ball, soccer players did not develop any asymmetries in flexibility. In this study, only male soccer players were assessed.

Knapik et al..[51] did not report significant differences for quadricep flexibility, as measured by prone active knee flexion at the knee with a goniometer, in the legs of female athletes from a variety of sports. Additionally, no significant differences were reported for hamstring flexibility measured during an active straight-leg raise with a goniometer at the greater trochanter. Both studies used collegiate athletes; however, Knapik et al.. only used female athletes.

The present study is in contrast to Sullivan et al..[94] who reported a significant difference in the legs for hamstring flexibility. They examined pelvic position and stretching method on hamstring muscle flexibility in 10 male and 10 female NAS subjects. Hamstring flexibility was measured using an inclinometer during an active knee extension test (starting hip and knee position at 90° flexion). Each subject was randomly assigned a static stretching (SS) protocol on one leg and a proprioceptive neuromuscular facilitation stretching (PNF) protocol on the other to determine the effect of each technique on flexibility. Since, leg preference was not considered in this study, the difference was attributed to stretching technique efficacy.

In the present study, it was hypothesized that quadricep and hamstring flexibility would be symmetrical in NAS and 2LA. The results of this study support this hypothesis. However, it failed to support the hypothesis that the preferred leg hamstring and the nonpreferred leg quadricep would have greater flexibility than their twin on the contralateral side as a result of training in 1LA. Hence, leg preference could not be associated with flexibility.

In the present study, quadricep flexibility was determined using a prone knee-flexion test; however, unlike the method used by Knapik et al..[51] knee flexion was passive. Like Agre et al..,[2] hamstring flexibility was evaluated using a passive straight-leg raise. However, an inclinometer around the lower leg was used instead of a goniometer at the greater trochanter. The inclinometer reading at initial ASIS movement, not tissue resistance, was recorded. Intratester reliability for measuring quadricep flexibility was ICC (2,1)=0.98 and hamstring flexibility was IC (2,1)=0.93.

Measurements may potentially have been affected by several factors. Subcutaneous adipose over the ASIS on some athletes and abdominal movement during respiration possibly obscured the palpation. Also, the weight of the subject's leg made it difficult for the tester to focus on ASIS movement. Nevertheless, reliability for the methods assessing flexibility was high.

The preferred leg was deemed the leg that performed 2 or more of the following tasks: kicking a soccer ball, stomping on an object, and smoothing out sand. The preferred leg was deemed the leg that performed 2 or more of the following tasks: kicking a soccer ball, stomping on an object, and smoothing out sand. A stretching program or movements requiring above average quadricep or hamstring flexibility may not be performed on a regular basis (as in the NAS and 2LA). As a result, specific adaptations in the legs may not have developed. Results of this study fail to reject the null hypothesis suggesting that flexibility asymmetries between the legs do not exist. However, if a specific stretching program or movements requiring muscle flexibility were repeated with volition over a significant amount of time, adaptations should occur. In 1LA, the quadricep of the nonpreferred leg and the hamstring of the preferred leg would have greater flexibility than their twin on the contralateral side. The results of this study failed to reject the null hypothesis.

Some ideas may explain why these adaptations did not occur in 1LA. The Overload Principle suggests that physical changes occur in tissues if imposed stresses are greater than what the tissues are accustomed.[38] The volume of exercise and the range of motion (ROM) of the movements needed to elicit changes in flexibility may have been inadequate. The preferred leg is the leg used to manipulate an object or to lead out during a jump.[75] This widely used definition suggests that leg preference is independent of volume of exercise or ROM. Even the 1LA group was not able to illicit expected differences between the legs due to inadequate asymmetrical exercise volume or flexibility training modification. Additionally, the relative amount of work performed by one leg versus two is minute compared to the relative amount of work performed by one arm versus two. Krahl et al..[55] noted significant structural asymmetries between the arms of tennis players. These athletes during training and activities of daily living (ADL) notably use one arm more than the other. However, jumping and kicking athletes, even during training do not use one leg independently of the other for long periods of time. With ADLs, the sole repeated use of one leg is scarce.

Stability

Similar to Harrison et al..[36] and Goldie et al..,[32] the present study observed no significant differences in the preferred and nonpreferred legs. In contrast, Colby et al..[17] noted significant differences.

Harrison et al..[36] did not report significant time to stabilization (TTS) differences in the preferred and nonpreferred legs of a recreationally active control group between 17 and 45 years old. Static stability was assessed using an observational method of balance evaluation and the Balance System forceplate. The observational method was based on a 3-point ordinal scale: 1 representing poor performance, 2 representing fair, and 3 representing good. The Balance System used of 2 forceplates to calculate postural sway. The authors concluded that leg preference had no effect on single-leg standing balance.

Similarly, Goldie et al..[32] reported no significant interaction in leg preference by steadiness during a one-legged stance (eyes open, eyes closed) in physically active subjects between 18 and 40 years old. Stability testing was performed using the Kistler six-component force platform system. In contrast, Colby et al..[17] reported significantly longer TTS times in the nonpreferred leg compared to the preferred leg in physically active, non-impaired individuals aged 31$\pm$ 9.1 y with the step-down test. Subjects stepped from a 19cm height onto a forceplate and held a stable single-leg stance position while data was collected for 20 seconds.

In the present study, TTS was assessed using a sport-specific movement described by Ross et al..[85] Subjects jumped 50% their maximal vertical jump height onto a forceplate from a marker 70cm away. Upon landing, subjects were instructed to stabilize as quickly as possible and hold the position (hands on hips, looking straight ahead) for 20 seconds. This method employed a sport-specific movement that considered relative physical ability (vertical jump) versus the methods described by Colby et al..[17] which considered relative anatomical differences (greater trochanter to lateral malleolus). Although reliability for Ross's et al..[85] methods was not established, components of the test were standardized among subjects. Data were sampled and processed similar to the methods described by Colby et al...[17] The first 3 seconds of data points for medial-lateral and anterior-posterior moments were collected and smoothed using a sequential average. TTS was defined as the point in time where the sequential average line remained within a ¼ standard deviation of the overall series mean. The first 3 seconds of vertical force data points were collected and graphed. TTS was defined as the point at which the raw data curve remained within 5% of the subject's body weight.

In the present study, it was hypothesized that the nonpreferred leg in 1LA would have better TTS times compared to the preferred leg. The results of this study failed to support the null hypothesis since no significant differences in the legs were noted. As a result, leg preference and stability performance could not be associated.

Contrasting results among the different studies could be attributed to different testing methods and subjects used. The subjective method of balance assessment used by Harrison et al.[36] allowed the possibility of human judgment errors. Harrison et al.[36] and Goldie et al.[32] tested their subjects from a stationary double leg stance into a single-leg stance which is not a typical sport movement. Colby et al.[17] compared reliability measures between two sport-specific movements: a step-down and a hop. Performing a single-leg stance from a functional movement may be much more challenging.

The time of a single trial in Harrison's et al.[36] study lasted 10 seconds, in Goldie's et al.,[32] a trial lasted only 5 seconds, and in Colby's et al.,[17] 20 seconds. Fatigue, distraction, or loss of concentration may have caused instability in the longer lasting trials. Oppositely, a brief collection period may not allow the subject enough time to stabilize completely.

Harrison et al.,[36] Goldie et al.,[32] and Colby et al.[17] utilized a wide age-range of physically active individuals between the ages of 17 to 40 y, 18 to 40 y, and 31$\pm$ 9.1 y, respectively. In studies done by Balogun et al.[6] and Hoffman and Payne[40] where static stability was evaluated, college aged and high school aged subjects were used, respectively. However, whether the subjects were considered non-athletic or athletic was not clarified and no comparison between the lower limbs was addressed. Balogun et al.[6] evaluated static stability using a non-criterion single-leg stance timed balance test and Hoffman and Payne[40] analyzed stabilometry recordings from a Kistler forceplate. No previous studies have been found examining TTS in the lower limbs of 3 different groups: NAS, 2LA, and 1LA.

Other factors may have influenced the results of the present study. First, reaching a target with the same hand may have made it difficult to land on one leg versus the other. Landing on the left leg with the right arm reaching overhead may have created different landing forces and hence, different compensatory movements on the lower extremity compared to landing on the right foot with the right arm reaching overhead. Reaching with both hands during each jump off either leg may reduce this effect. Second, true TTS may not have been reached since the first 3 of 20 seconds after landing was used. Analyzing 5 or 10 seconds of data instead of 3 may reduce some of this effect. Placing an actual target in front of the patient, having the researcher and others stand quietly behind the subject, allowing more recovery time between trials, may prevent subjects from becoming unstable as a result of loss of focus/concentration, distractions, and fatigue, respectively. Third, the minimum amount of time each TTS variable needs to remain within their corresponding range to be considered stable was not defined previously or in the present study. The exact moment the variable entered the range and remained within varied considerably with vertical force. Hence, the researcher selected the point where the curve intersected and noticeably stayed within the range until the end of the 3 seconds data set. Collecting vertical force data at a lower frequency (1000Hz instead of 2000Hz), smoothing the curve using a running average, and defining the minimum amount of time the curves have to remain within their corresponding range in order to be considered stable (e.g., 500 data points) may reduce some of these effects.

Leg preference is determined using 3 tasks designating a manipulating leg and a stance or support leg.[75] According to Previc's Theory, postural control performed by stance/support leg (nonpreferred leg) developed as a result of fetal position. The right side vestibular dominance leading to a left-otolithic advantage saves the left side for postural control while the right side perfects motor functions.[79] MacNeilage's Postural Origins Theory suggests an evolutionary influence where instinctive traits of early primates such as hanging from tree branches with one leg, are passed down to modern primates who sometimes support themselves on one leg and manipulate with the other.[61]

According to these theories, the support function by the nonpreferred leg enhanced compared to the preferred leg. Although NAS and 2LA do not try to accentuate these asymmetries in ADL or training, a difference would still be insinuated according to the theories. However, no significant difference was observed. Similarly, athletes in the 1LA group (e.g., long jumpers, high jumpers, and hurdlers) did not have differences between their legs.

Beling et al.[7] examined lower limb task performance while standing and sitting and suggested that dynamic activity (manipulation) is typically lateralized regardless of posture (e.g., standing or seated). Therefore, the inherent use of the support limb does not determine which leg one chooses to perform a task contradicting the theories by Previc and MacNeilage. One leg does not solely support the body on a regular basis during ADL or non-specific lower leg training in NAS and 2LA, respectively. During long jump, high jump, or hurdle training, the 1LA does not focus on improving single-leg standing balance. Therefore, symmetry in stability performance in the legs is expected. In the present study, the lack of kickers/punters in the 1LA group may have influenced the TTS results of this particular test because their skill/activity requires them to spend relatively more time on one leg during training and competition compared to jumpers. By doing so, possible improvements in TTS may develop.

Power

The results of the present study are similar to those reported by Mangine et al.,[63] Booher et al.,[11] and Jarvela et al..[43] No studies reporting asymmetrical performance in the preferred and nonpreferred legs were found.

Like the present study, Mangine et al.[63] reported no significant differences in the preferred and nonpreferred legs during OLH testing of elite male soccer players of 3 levels (elite, competitive, and major recreational). The authors constructed a physiological profile consisting of several physical and physiological attributes. Leg preference was not established, however, the authors used a symmetry index (percent of limb symmetry).

Similarly, Booher et al.[11] did not report differences in the legs of males and females for the OLH. In establishing reliability of single-leg hop tests, the authors did not mention whether these subjects were athletes or nonathletes. Likewise, Jarvela et al.[43] revealed no significant differences in the legs for OLH in older males and females aged 30.4 $\pm$ 9.2 who have undergone ACL reconstruction 5-9 y before the start of their study. Like Booher et al.,[11] Jarvela et al.[43] did not mention whether their subjects were athletes or not; however, it may be insinuated that these people opted for surgery because of an active lifestyle. Studies examining college-aged 1LA were not found.

In the present study, it was hypothesized that OLH performance would be symmetrical in NAS and 2LA. The results of this study support this hypothesis. However, it failed to support the hypothesis that OLH performance of the nonpreferred limb would be better than the preferred limb in 1LA. Again, leg preference could not be associated with power.

The previous studies[11,43,63] and the present study used similar methods described by Bolgla et al.[10] Several factors still may have affected the results of the study.

In the present study, subjects were instructed to hop as far as possible and land with the take-off foot still on the ground regardless of whether or not another part of the body touched the ground. The distance from the toe of the test foot to the heel of the test foot on single or double leg landing was measured.

Bolgla et al.[10] measured the same distance; however, subjects were instructed to land on the same leg in a single-leg stance. Focusing on the landing rather than hopping as far as possible may not have produced true maximal jump distances. In the present study, although instructed appropriately, some subjects deferred their focus. If hop landing was inconsistent between legs, then the results may be affected. Instructing subjects to jump as far as possible and land on two feet comfortably enough so the landing heel of the test leg could be marked, focuses the subjects concentration on maximal hop distance, not landing. The OLH details in the studies by Jarvela et al.[43] and Mangine et al.[63] were not clearly described.

The distance from the starting toe mark to the landing heel mark was measured. Foot length differences in the feet ranging from 0.02 to 1.4cm has been noted in the literature;[64] therefore, measuring from starting toe to landing heel may obscure hop distance measurements if the feet were asymmetrical. Measuring from toe to toe or heel to heel would eliminate this confounding variable. Some factors may have affected the results of the present study; however, Bolgla et al.[10] reported test-retest reliability at 0.96.

Laterality, determined by specific tasks, may not necessarily dictate a jumper's take-off leg. In a study by Augustyn and Peters,[5] a right-foot advantage/preference was noted in right-handers. Friberg and Kvist[29] examined the extent to which handedness and leg length inequality correlated with a jumper's instinctive choice of take-off leg and reported no statistically significant correlation between handedness and take-off leg, but a correlation between take-off leg and contralateral leg length. Therefore, a right take-off leg is not necessarily associated with a right leg preference, but with a longer left leg. Whether leg length inequality caused or resulted from choice of take-off leg was not explained. According to this explanation, the preferred leg may be correlated with shorter OLH measures. In the present study, this asymmetry was absent in the NAS and the 2LA. However, expected asymmetry should be amplified in the 1LA group. Again, no significant differences were found between the preferred and nonpreferred legs in this group. As noted earlier, the amount of independent and specific training the jumping leg performs relative to the opposite leg is very small and ineffective in producing asymmetries.[38]

Interestingly, Mangine et al.[63] also reported a significant difference in mean hop distance among levels (elite, competitive, major recreational). Elite soccer players hopped significantly farther than competitive and major recreational athletes. The authors suggested that the better hop distances resulted from increased training elite level players underwent outside of games. Local athletes tended to only play games; very few trained outside of games. In the present study, a similar trend was noticed. The means of the preferred and nonpreferred legs were pooled for each group and compared. The results revealed that 1LA jumped significantly farther than both the NAS and 2LA. This was probably due to the difference in training regimens among the groups. Although the athletic groups (1LA and 2LA) and the non-athletic group were divided by weekly volume of activity (3 days/week, 1 hour each day) differences between the 2 athletic groups were noted. The 1LA group consisted of varsity track athletes that actually trained 6 days per week, 2 hours per day. The 2LA group consisted of athletes that varied weekly volume between 3 and 6 days per week, 1 to 3 hours each day. The large disparity among weekly volumes may have influenced this difference among groups.

Strength

The present study revealed similar results to studies done by Greenberger and Paterno,[34] Perrin et al.,[74] Parkin et al.,[72] Costain et al.,[20] Capranica et al.,[14] Spry et al.,[93] Lucca and Kline,[60] and Quittan et al..[81] In contrast to the present study, Siqueira et al.,[92] Thomas et al.,[96] Kellis et al.,[48] McLean and Tumilty,[66] and Chin et al.,[16] revealed strength differences in the legs.

Similar to the present study, Greenberger et al.[34] evaluated concentric knee extensor strength isokinetically on the Kinetic Communicator (KinCom) at 240º/sec in 20 male and female students and reported no significant differences in the dominant and nondominant legs. Spry et al.[93] evaluated knee extensor and flexor strength of 76 male and female students, however, they used the Cybex II isokinetic dynamometer at 60º/sec. The authors did not state whether concentric or eccentric strength was evaluated. Like Greenberger et al.,[34] Spry et al.[93] also reported no significant differences in the legs. Lucca and Kline[60] tested knee extensors and flexors as well. Concentric strength of 54 male and female students was evaluated using the Cybex II isokinetic dynamometer at 60, 120, and 240º/sec. The authors reported no significant differences between the legs, suggesting that the legs have less opportunity to develop asymmetric strength and dexterity since lower extremity work (e.g., walking, running, stair climbing) is commonly bilateral. Unlike the previously mentioned studies, Quittan et al.[81] examined an older population (56 $\pm$ 8 y) on the Cybex 6000 at 60º/sec. No significant differences in the legs for concentric knee extensor and flexor strength were revealed.

Many studies have researched bilateral isokinetic knee strength in non-athletic individuals and reported symmetry between the lower limbs. A few studies examined athletes and reported similar findings. Costain and Williams[20] studied knee extensor and flexor strength concentrically in teenage female soccer athletes. Results revealed no significant differences in the legs after being tested on the Cybex II at 30 and 180º/sec. Capranica et al.[14] tested preadolescent male soccer players and a non-athletic control group. Unlike the previous studies and the present study, the authors used an isokinetic bicycle ergometer and tested subjects at 5 isokinetic loads. Regardless, no significant differences in the preferred and nonpreferred legs were exposed. The authors explained that subjects participated in soccer training that does not favor one leg, resulting in lateral dominance. Two-thirds of practice time was designed to enhance physical fitness activities emphasizing symmetrical bilateral development. Parkin et al.[72] investigated strength asymmetries in male oarsmen and nonathletes. Testing concentric and eccentric knee flexion and extension at 3.5 and 1.75 radians revealed no significant differences between the right and left legs. Unlike studies previously mentioned, Perrin et al.[74] studied bilateral strength in different types of athletes and a control group. Concentric knee extension and flexion was assessed in baseball pitchers, swimmers, and nonathletes. Evaluation on the Cybex II at 60 and 180º/sec revealed no significant differences in the legs.

In contrast to the present study, several studies reported significant differences in the lower limbs. Kellis et al.[48] reported a significant main effect suggesting greater knee strength in the preferred leg than the nonpreferred leg of soccer players. Concentric and eccentric knee extensor and flexor strength was tested using the Cybex Norm dynamometer at 60, 120, and 180º/sec. Authors could not make specific inferences on muscle group (extensors, flexors) or action (concentric, eccentric) because no significant interactions were revealed. McLean and Tumilty[66] also reported strength differences in the legs of soccer players. Knee extensor strength testing using the Cybex II at 60, 180, and 240º/sec revealed a significantly stronger right knee compared to the left at each speed. Like Kellis et al.[48] and McLean and Tumilty,[66] Chin et al.[16] reported asymmetries in the legs of soccer players. They reported stronger knee flexors in the dominant leg compared to the nondominant leg with no difference in the extensors. They evaluated isokinetic knee extensor and flexor strength on a Cybex II isokinetic dynamometer at 60 and 240º/sec.

Thomas et al.[96] examined physiological and psychological correlates of success in track athletes and measured bilateral quadricep and hamstring concentric strength using the Cybex II at 60º/sec. The authors expressed amount of asymmetry with a low-high (e.g., weaker-stronger) strength ratio. An indication of which leg is stronger was not given. Relatively low ratios for the quadricep (0.86) of jumpers and sprinters compared to runners (0.93) suggested greater quadricep strength asymmetry in these athletes; however, statistical significance was not calculated.

Only one study closely parallels the present study; however, with conflicting results. Siqueira et al.[92] investigated concentric knee extensor and flexor strength in the dominant and nondominant legs of 3 groups: nonathletes, jumpers (triple and distance), and runners/sprinters. After testing subjects on the Cybex 6000 at 60 and 240º/sec the following points were made: in nonathletes at 60º/sec, dominant leg flexors were significantly stronger than the nondominant flexors; although, dominant leg extensor strength was higher, the difference was not statistically significant; in jumpers and runners at 240º/sec, nondominant leg extensors were significantly stronger than dominant leg extensors.

In the present study, it was hypothesized that knee strength would be symmetrical in NAS and 2LA. The results of this study support this hypothesis. However, it failed to support the hypothesis that the nonpreferred limb would be significantly stronger than the preferred limb in 1LA. As a result, leg preference could not be associated with strength.

Differences in subjects, sample size or methods between the present study and previous studies may have attributed to conflicting results. In the present study, the sample of convenience was limited to 4 males and 4 females for the 1LA group. Hence, 4 males and 4 females for each group were tested to attain a better representation of the population. In contrast, the studies done by Siqueira et al.[92] and Thomas et al.[96] tested 54 and 39 male subjects, respectively. Chin et al.,[16] Kellis et al.,[48] and McLean and Tumilty[66] did not specify whether they used males, females, or both. In contrast to the present study and the studies done by Siqueira et al.[92] and Thomas et al.,[96] Chin et al.[16] tested elite Asian athletes (N=21), Kellis et al.[48] examined elite Greek athletes (N=158), and McLean and Tumilty[66] assessed elite Austrialian athletes (N=12).

Subjects in the present study were grouped according to training regime. NAS rarely exercised (less than 3 days/week, less than 1 hour/session), and 2LA and 1LA exercised regularly (3 or more days/week, 1 hour or more/session). 1LA trained for a specific task/skill involving one leg (e.g., jumping/kicking). In contrast to the present study Siqueira et al.[92] described athletes (jumpers, runners) as those who have been training 6 days/week, 3 hours daily for at least 1 year. Nonathletes were those that did not meet these criteria. Similarly, Chin et al.[16] used athletes that trained 6 days/week, 3 hours daily for 10 months of the year. These discrepancies in inclusionary criteria may be related to the differences in results between the present study and others.

In the present study, quadricep and hamstring strength was tested concentrically and eccentrically at 60º/sec on the KinCom. No two studies had identical protocols. Although methods differed among studies in muscles tested (flexors, extensors, or both), muscle action (concentric, eccentric, or both), testing speed (ranged from 30 to 240º/sec, 1.75 to 3.5 radians), warm-up protocol (cycle ergometer for 5 or 15 minutes), familiarization repetitions (3 to 5 submaximal and 3 to 5 maximal), test repetitions (3 to 5), order of testing (speed, muscle action, muscle group), rest periods (30 seconds to 5 minutes), variable measured (peak torque, average torque, total work) and equipment used (Cybex or KinCom), comparisons between the legs are still valid as long as methods on the one side are identical to those on the other.

Several factors that may have affected strength results were addressed. To negate a learning effect between limbs, the order for leg tested first was randomized. After testing on one side, subjects were unstrapped and allowed to actively recuperate before testing on the opposite side. Subjects were encouraged to physically remember seated position and strap tightness (over the shoulders, hips and thigh) so that they can be positioned and secured identically. Dynamometer head height, lever length, seat angle, and seat height were kept constant. Bilateral structural differences in anatomy (tibial or femoral length) may affect positioning (lever arm length and axis alignment), thereby affecting torque readings. Verbal encouragement and subject mannerisms (breathing pattern, choice of visual feedback) during maximal exertion were consistent. Motivation may affect effort and torque readings. Regardless of testing protocol and considering possible confounding variables, isokinetic assessment of knee flexor and extensor strength was found to be reliable.[44,58, 73]

Although the methods and procedures used to assess concentric and eccentric quadricep and hamstring strength were consistent between the legs and subjects in the present study, several ideas may explain why the results failed to support the third hypothesis. Capranica et al.[14] assessed knee flexor and extensor strength in young soccer players. Subjects who participated in this study trained for at least 2 y, 2 days/week, and at least 90 minutes/practice. The authors stated that since the majority of time spent during practice sessions was donated to enhancing fitness by utilizing soccer specific drills emphasizing symmetrical development, asymmetry in the preferred and nonpreferred legs did not develop. Likewise, a 1LA may spend the majority of practice time enhancing performance; however, the amount of time diverted to focusing on unilateral development may not have been significant enough to elicit significant asymmetries. In the present study, 1LA trained 3 or more days/week, 1 or more hours each/session at their track event (high jump, triple jump, long jump, hurdles). It is unclear how much of this time was dedicated to specific one-leg training. Specific details of daily training schedule of the 1LA were unknown. Regardless, no differences in the legs were revealed.

As noted earlier, 1LA displayed significantly stronger concentric quadricep and hamstring and eccentric quadricep strength than 2LA and NAS. Eccentric hamstring strength in 1LA and 2LA was greater than NAS. Again, this was probably due to the difference in training regimens among the groups. Although the athletic groups (1LA and 2LA) and the non-athletic group were divided by weekly volume of activity (3 days/week, 1 hour each day) differences between the 2 athletic groups were revealed. The 1LA group consisted of varsity track athletes that actually trained 6 days per week, 2 hours per day. The 2LA group consisted of athletes that varied weekly volume between 3 and 6 days per week, 1 to 3 hours each day. The large disparity among weekly volumes may have influenced this difference among groups.

Muscle Endurance

Only one study evaluated asymmetries in the preferred and nonpreferred legs for muscle endurance. Similar to the results of the present study, Demura et al.[24] reported no significant differences in the dominant and nondominant legs. The authors assessed endurance ratio in the dominant and nondominant legs of 50 inactive males. Knee flexion and extension were tested on the Cybex 325 at 180º/sec. The endurance ratio consisted of total work during the first 6 of 30 repetitions divided by the last 6 repetitions multiplied by 100. The authors suggested this symmetry stemmed from consistent use of both legs during ADL. Interestingly, they noted that the nondominant leg showed superior muscular endurance and the dominant leg showed superior power exertion. Although the difference in the legs for endurance tended to be larger than the difference for power, none were statistically significant.

In contrast, the present study tested 2LA and 1LA along with NAS, using a more reliable endurance protocol. Burdett and VanSwearingen[13] reported a high reliability value (ICC=0.84) when counting the number of repetitions a muscle group performs to where torque produced is below 50% initial peak toque for 2 consecutive repetitions. Perrin[73] and Burdett and VanSwearingen[13] assessed endurance ratio reliability and reported low ICC values (.21-.62 and .48, respectively).

In the present study, it was hypothesized that quadricep and hamstring muscle endurance would be symmetrical in NAS and 2LA. The results of this study support this hypothesis. However, it failed to support the hypothesis that the preferred limb would have better endurance in 1LA. Hence, leg preference could not be associated with muscle endurance.

1LA training regimen and testing methods may explain why the results failed to support this third hypothesis. As mentioned in the previous section, subjects physically active 3 or more days/week, 1 or more hours each/session were classified as 2LA or 1LA depending on their activity. Although 1LA trained several times during the week, the amount of specific asymmetrical training during that time is unknown. Results imply that the amount of asymmetrical training was inadequate to stimulate testable differences.

The endurance protocol was performed after the isokinetic strength testing on the KinCom. Although testing procedures were identical on both sides, methodological inconsistencies in subject setup and leg testing may have influenced results. In setting up the subject, several factors were considered. Varying tightness in the straps around the torso, thigh, and lower leg may affect torque output. Asymmetries in tibial length affect lever length and distance from axis of rotation hence torque. Asymmetrical femur length may affect axis of rotation alignment also affecting distance between axis of rotation and lever length, hence torque. Keeping setup parameters consistent between the legs minimizes this confound. Testing one leg first may produce a learning effect on the opposite leg. Randomization of the leg tested first eliminated this problem. Finally, verbal instructions and encouragement during the test was kept consistent to maintain a high level of motivation and effort.

Leg Preference

Gender and age were addressed due to their potential impact on the results of the present study. Sex related asymmetries have been previously studied. Levy and Levy[57] observed right-handed males with larger right feet and right-handed females with larger left feet suggesting that sex steroids govern cerebral and pedal asymmetrical maturation. Interestingly, others have found asymmetries in the opposite direction (e.g., right-handed males with larger left feet and right-handed females with larger right feet).[64] In contrast, Means and Walters[67] reported a significant association between hand size asymmetry and handedness, but no significant association with foot-size. Since structural asymmetries in the legs may be influenced by gender, keeping gender consistent may eliminate this potential confound. Unfortunately, inferences made by the results would be limited to that gender. The present study examined males and females to obtain a better representation of the population. Additionally, since the sample of convenience consisted of 4 males and 4 females, combining the two genders increased sample size.

Age related asymmetries have also been noted previously. Gentry and Gabbard[31] observed choice of foot preference in 956 males and females of different age groups between 4 and 20 years of age and suggested that footedness in the younger groups was nonspecific. However, they noticed a significant shift towards right-footedness between 8 and 11 years old, after which preferences remained stable. Researchers examining preference behaviors or asymmetries in younger individuals[14,48] must be cautious in interpreting their results. In the present study, this was not a concern.

Leg preference was established using tasks focusing on manipulation of an object (e.g., kicking a soccer ball, smoothing sand, stomping on an object). However, leg preference did not always dictate take-off leg in the present study. Since the preferred leg has been defined as the leg that manipulates or leads out during a jump and the nonpreferred leg as the leg that supports the activities of the preferred leg,[75] it would be expected that a preferred right leg individual would always jump off their left leg.

However, this was not the case. In the present study, 3 out of the 8 1LA jumped off their preferred leg. If the athlete's hand preference were opposite to their leg preference, this may explain why they jump off the nonpreferred leg. Sport skills involving unilateral upper limb manipulation (e.g., throwing, basketball lay-up) usually involve contralateral lower limb support. For example, the support leg during the follow-through phase in a baseball pitch or take-off leg during a right handed lay-up. Interestingly, those 3 jumpers have a leg preference on the same side as their hand preference and their take-off leg. Further research is necessary to explain these inconsistencies.

Since no asymmetries were revealed in the present study, the preferred leg could not be associated with physical and functional characteristics. Therefore, leg preference does not influence or predict asymmetries in flexibility, stability, power, strength, and muscle endurance in the lower extremities. Regardless of whether leg preference is inherent,[79] matures over time,[31] or develops over task repetition,[33,38] it is not expressed as a physical or functional asymmetry.

Summary

The results of the present study demonstrated that no asymmetries in flexibility, stability, power, strength, and muscle endurance in the preferred and nonpreferred legs existed in NAS, 2LA, and 1LA. Hence, limb asymmetry is not associated with leg preference. Therefore, a bilateral comparison is a valid pre-injury model for the injured lower limb allowing clinicians to accurately organize rehabilitation goal and return-to-play criteria. Also, researchers may simplify methods by testing flexibility, stability, power, strength, and muscle endurance of one lower extremity and not be concerned with the confounding variable of asymmetry.

Conclusions

The following conclusions may be drawn from this study:

- No asymmetries in flexibility, stability, power, strength, muscle endurance exist in the preferred and nonpreferred legs of 1LA
- No asymmetries in flexibility, stability, power, strength, and muscle endurance exist in the preferred and nonpreferred legs of 2LA.
- Limb asymmetry is not associated with leg preference in athletes and nonathletes.

Implications for Future Research

To our knowledge, this is the only study that examined asymmetries in several characteristics (flexibility, stability, power, strength, muscle endurance) of 2 types of athletes (1LA, 2LA) and a non-athletic group (NAS). Future studies examining these characteristics bilaterally in athletes of different sports, different playing positions, , and different levels may provide clinicians with a more accurate pre-injury model during a bilateral comparison. Studies such as these may also prepare a researcher to adjust subject criteria or consider possible data misinterpretation if athletes are utilized in their study. Studies examining bilateral asymmetries (or symmetry) related to successful performance may provide the coach, strength and conditioning specialist, and athlete with the knowledge that will help the athlete excel in his or her sport. Examining other characteristics such as reaction time, joint position sense, and dexterity in the preferred and nonpreferred legs may broaden the knowledge base used by sport medicine clinicians and researchers. Future research examining asymmetries between the preferred and nonpreferred legs should consider stringent inclusionary criteria (e.g., subject training regimen and gender). Weekly training volume may influence the extent to which training adaptations occur. Additionally, strength, power, and flexibility differences between males and females may increase the variability observed in these characteristics.

Interestingly, one study examined rehabilitation success following dominant versus nondominant leg amputation[49] and reported those with a left leg prosthesis (nondominant leg) spent less time in rehabilitation than those with a right leg prosthesis (dominant leg). Although the details and goals of rehabilitation were not mentioned, the significant difference in the dominant and nondominant leg suggests that neuromuscular or motor behavior mechanisms are involved. Research exposing these mechanisms may give insight as to what makes a limb dominant.

APPENDIX A
SUBJECT INFORMATION FORM

SUBJECT___

NAME ____________________________________

PHONE AND EMAIL _________________________________

DATE ___________ TIME __________

M____ F____

AGE ______

HEIGHT _______

WEIGHT ________

DOMINANT HAND R L

ANY LOWER EXTREMITY OR VESTIBULOCOCHLEAR (INNER EAR) INJURIES WITHIN THE LAST 6 MONTHS
____
____

CATEGORY
- NONATHLETE/SEDENTARY
- TWO-LEGGED ATHLETE

ONE-LEGGED ATHLETE (take-off leg) _________

APPENDIX B
ATHLETE CLASSIFICATION FORM

SUBJECT ___

1. Which activities have you participated in before? (Circle all that apply)
   a. Soccer (striker/mid/defense, keeper) (kicking leg R or L)
   b. Basketball
   c. Baseball (pitcher, fielder, catcher)
   d. Football (DB/receiver, lineman, QB, kicker/punter)
   e. Ice hockey (offence/defense, goalie)
   f. Rugby
   g. Field hockey (offence/defense, goalie)
   h. Lacrosse (offence/defense, goalie)
   i. Swimming
   j. Water polo
   k. Wrestling
   l. Jogging
   m. Short sprints (100m, 200m)
   n. Long jump (take off leg R or L)
   o. High jump (take off leg R or L)
   p. Short hurdles (60m, 100m) (trail leg R or L)
   q. Pole vault
   r. Other ____

2. What have been your three main activities over the last year? (List in order of most dedication first) State the level at which you train or compete at (varsity, intramural, club, recreational).
   i. ________________________________
   ii. ________________________________
   iii. ________________________________

3. How much time during the week do you dedicate to each of your three main activities?

Days/week – less than (<) 3 days, 3 days or more
Hours /day – less than (<) 1 hour, 1 hour or more

Activity	Days/week	Hours/day

APPENDIX C
LEG PREFERENCE QUESTIONNAIRE

1. Which leg would you kick a soccer ball with?

    Left   Right

2. Which leg would you step on an object with? (e.g., step on a bug)

    Left   Right

3. Which leg would you use to smooth out sand with?

    Left   Right

APPENDIX D
DATA COLLECTION FORM

SUBJECT _______
ATHLETE TYPE: Sedentary/Nonathlete _____
Two-legged athlete _____
One-legged athlete _____

Flexibility (degrees)

Extensors (quadricep)		Flexors (hamstring)	
Left	Right	Left	Right

Stability (time to stabilization)

	Left	Right
1		
2		
3		

One-legged Hop (centimeters)

	Left	Right
1		
2		
3		

Strength (N*m)

	Left		Right	
	Extensors	Flexors	Extensors	Flexors
Concentric peak torque 60 º/sec				
Concentric peak torque 180 º/sec				
Eccentric peak torque 60 º/sec				

Muscular endurance (number of repetitions)

	Left		Right	
	Extensors	Flexors	Extensors	Flexors
50% PT				

LEG PREFERENCE R L

APPENDIX E
RAW DATA

Table E-1 Subject demographic raw data

Subject	Age (y)	Height (cm)	Mass (kg)
1	21	172.72	61.29
2	20	162.56	55.39
3	23	175.26	77.18
4	21	172.72	65.83
5	19	160.02	47.67
6	22	167.64	77.18
7	21	175.26	77.18
8	21	180.34	86.26
9	20	152.40	52.21
10	22	170.18	70.37
11	19	162.56	63.56
12	20	175.26	69.92
13	21	172.72	63.56
14	20	177.80	74.91
15	23	170.18	54.03
16	21	177.80	81.72
17	19	182.88	70.82
18	19	193.04	97.61
19	19	185.42	72.64
20	21	195.58	89.89
21	22	167.64	61.29
22	21	172.72	70.37
23	19	170.18	59.02
24	22	170.18	61.74

Table E-2 Quadricep and hamstring flexibility raw data (degrees)

Subject	NPQflex	PQflex	NPHflex	PHflex
1	131	135	78	74
2	125	132	65	66
3	101	96	48	48
4	120	134	61	63
5	149	148	64	67
6	121	125	39	45
7	115	122	49	58
8	104	105	45	49
9	131	135	64	60
10	115	129	61	58
11	146	147	96	83
12	128	126	52	59
13	125	120	46	48
14	99	114	70	72
15	120	115	70	67
16	97	105	62	70
17	125	120	76	71
18	115	118	66	68
19	122	120	65	64
20	125	126	67	65
21	131	136	70	68
22	126	116	66	63
23	136	135	74	74
24	129	129	83	80

Table E-3 Time to stabilization raw data (msec)

Subject	NP FZ	NP MX	NP MY	P FZ	P MX	P MY
1	1137.96	1306.04	1327.01	1038.27	1554.50	1535.20
2	1156.08	2060.97	1173.89	1323.49	1520.94	1640.50
3	914.90	1335.17	1758.42	978.56	2037.59	1120.26
4	590.01	1776.28	1778.71	835.15	1537.80	1407.52
5	1123.32	1764.50	1195.97	1133.20	1479.07	1656.85
6	1569.03	1465.70	1399.44	1348.82	1803.06	1257.53
7	986.77	1522.50	1505.65	1220.39	1872.93	1370.82
8	1453.48	1425.67	1971.50	1744.52	1683.46	1651.30
9	1290.40	1830.92	1561.66	1974.39	2100.35	1880.20
10	1161.98	1808.28	1592.99	2072.67	1345.50	1281.05
11	2135.03	1873.62	1337.73	1724.05	1530.20	1669.71
12	810.64	1212.18	1143.56	1234.13	1702.59	2026.42
13	1795.44	1557.60	1573.78	1483.32	1839.97	1417.61
14	1171.58	1841.40	1812.11	1175.07	1635.22	1295.89
15	1216.51	1572.31	1313.03	1139.96	1494.59	1687.97
16	1409.88	1562.16	999.34	1051.59	2134.46	1509.57
17	1708.61	1864.04	1747.88	1347.81	1178.90	839.91
18	1023.30	1717.76	1052.59	1333.83	1545.85	1753.20
19	1218.50	1057.08	1226.33	1159.10	1597.27	1213.68
20	1812.45	944.75	1218.83	1610.58	1720.75	1028.46
21	1435.18	1693.79	1797.97	1526.55	1775.81	1938.76
22	1254.62	1635.54	1903.49	1603.10	1745.22	1602.59
23	2287.23	1501.42	1395.07	2229.99	1770.84	959.89
24	969.55	1814.28	1909.47	1636.22	1512.06	1646.37

Table E-4 One-legged hop distance raw data (cm)

Subject	NPOLH	POLH
1	131.4	139.7
2	139.5	133.3
3	152.5	156.1
4	176.5	168.2
5	119.4	125.1
6	165.1	160.7
7	130.2	132.7
8	167.0	157.5
9	129.4	126.3
10	153.7	146.6
11	127.0	134.7
12	155.5	146.0
13	199.4	205.1
14	200.7	178.4
15	118.7	115.6
16	150.5	141.0
17	267.3	253.4
18	242.6	257.8
19	218.5	200.7
20	240.7	240.0
21	174.6	187.8
22	172.8	187.2
23	197.4	190.5
24	178.4	181.6

Table E-5 Quadricep and hamstring concentric raw data (Nm)

Subject	NPQCON	NPHCON	PQCON	PHCON
1	97	72	95	77
2	82	58	95	65
3	157	82	130	111
4	123	82	126	92
5	70	52	71	53
6	111	61	121	84
7	92	79	93	92
8	108	129	95	127
9	85	59	71	50
10	118	82	123	81
11	67	59	85	42
12	125	93	102	84
13	116	84	110	85
14	130	101	136	87
15	87	68	90	64
16	163	112	172	128
17	207	161	203	123
18	184	127	175	213
19	214	145	193	125
20	245	168	252	175
21	111	90	104	80
22	124	96	124	107
23	103	78	125	80
24	131	92	149	104

Table E-6 Quadricep and hamstring eccentric raw data (Nm)

Subject	NPQECC	NPHECC	PQECC	PHECC
1	108	84	104	73
2	143	92	139	84
3	191	110	171	113
4	192	91	192	119
5	99	58	80	49
6	106	62	106	85
7	111	86	117	85
8	122	102	141	125
9	111	84	100	68
10	145	93	132	93
11	113	71	98	37
12	129	106	132	112
13	133	96	138	99
14	169	92	169	81
15	87	75	98	82
16	194	125	223	144
17	229	180	227	126
18	245	135	165	204
19	221	124	206	128
20	241	177	262	193
21	107	86	82	44
22	171	115	174	134
23	123	87	131	87
24	161	101	186	129

Table E-7 Quadricep and hamstring muscle endurance raw data (repetitions)

Subject	NPQMMEND	NPHMMEND	PQMMEND	PHMMEND
1	21	18	29	16
2	20	33	26	31
3	28	19	20	26
4	33	34	36	36
5	26	28	36	16
6	23	28	23	25
7	30	25	33	23
8	33	32	35	33
9	22	25	25	25
10	28	26	14	27
11	16	26	23	26
12	27	31	28	21
13	26	26	34	29
14	43	42	31	35
15	26	16	24	25
16	29	33	29	32
17	28	36	27	35
18	27	27	29	19
19	26	27	33	25
20	39	29	35	30
21	22	19	24	24
22	23	28	25	27
23	24	33	30	19
24	28	41	21	40

Table E-8 Limb preference raw data

Subject	Preferred hand	Preferred leg	Take off leg
1	R	R	
2	R	R	
3	R	R	
4	R	R	
5	R	R	
6	R	R	
7	L	L	
8	R	R	
9	R	R	
10	R	R	
11	R	R	
12	L	L	
13	R	R	
14	R	R	
15	R	R	
16	R	R	
17	R	R	L
18	R	R	R
19	R	R	L
20	R	R	L
21	R	R	L
22	L	L	L
23	R	R	L
24	R	R	R

APPENDIX F
ANOVA TABLES

Table F-1 Quadricep flexibility (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	56.333	1	56.333	2.846	0.106
Group x preference	65.042	2	32.521	1.643	0.217
Error	415.625	21	19.792		

Table F-2 Quadricep flexibility between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	114.292	2	57.146	0.171	0.844
Error	7026.375	21	334.589		

Table F-3 Hamstring flexibility (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	0.187	1	0.187	0.017	0.897
Group x preference	40.625	2	20.313	1.849	0.182
Error	230.688	21	10.985		

Table F-4 Hamstring flexibility between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	1276.792	2	638.396	2.918	0.076
Error	4594.187	21	218.771		

Table F-5 Vertical force (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	109470.060	1	109470.060	1.645	0.214
Group x preference	999.096	2	499.548	0.008	0.993
Error	1397269.194	21	66536.628		

Table F-6 Vertical force between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	1073603.371	2	536801.686	2.668	0.093
Error	4225393.082	21	201209.194		

Table F-7 Anterior-posterior center of pressure (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	81263.569	1	81263.569	0.899	0.354
Group x preference	3118.717	2	1559.358	0.017	0.983
Error	1898035.683	21	90382.652		

Table F-8 Anterior-posterior center of pressure between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	121106.232	2	60553.116	1.410	0.266
Error	902002.634	21	42952.506		

Table F-9 Medial-lateral center of pressure (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	1939.928	1	1939.928	0.020	0.890
Group x preference	241071.780	2	120535.890	1.213	0.317
Error	2087091.748	21	99385.321		

Table F-10 Media-lateral center of pressure between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	23831.337	2	11915.668	0.136	0.873
Error	1833820.042	21	87324.764		

Table F-11 One-legged hop for distance (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	38.226	1	38.226	0.754	0.395
Group x preference	75.094	2	37.547	0.740	0.489
Error	1065.015	21	50.715		

Table F-12 One-legged hop for distance between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	41804.051	2	20902.025	13.357	0.000*
Error	32862.288	21	1564.871		

* Significant at $P < 0.05$

Table F-13 Quadricep concentric strength (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	2.083	1	2.083	0.023	0.881
Group x preference	12.667	2	6.333	0.069	0.933
Error	1916.250	21	91.250		

Table F-14 Quadricep concentric strength between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	35749.500	2	17874.750	6.525	0.006*
Error	57526.750	21	2739.369		

* Significant at P < 0.05

Table F-15 Hamstring concentric strength (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	204.188	1	204.188	0.788	0.385
Group x preference	499.875	2	249.937	0.964	0.398
Error	5444.437	21	259.259		

Table F-16 Hamstring concentric strength between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	18552.042	2	9276.021	5.750	0.010*
Error	33880.437	21	1613.354		

* significant at P < 0.05

Table F-17 Quadricep eccentric strength (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	126.750	1	126.750	0.507	0.484
Group x preference	172.625	2	86.313	0.345	0.712
Error	5247.645	21	249.887		

Table F-18 Quadricep eccentric strength between groups (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Group	25718.375	2	12859.187	3.463	0.050*
Error	779990.62	21	3713.839		

* not significant at p >.05

Table F-19 Hamstring eccentric strength (ANOVA)

Source	Sum of Squares	d.f	Mean square	F	Significance
Preference	80.083	1	80.083	0.234	0.634
Group x preference	206.167	2	103.083	0.301	0.743
Error	7195.750	21	342.655		

Table F-20 Hamstring eccentric strength between groups (ANOVA)

Source	Sum of Squares	d.f	Mean square	F	Significance
Group	15656.000	2	7828.000	4.455	0.024*
Error	36899.250	21	1757.107		

* Significant at P < 0.05

Table F-21 Quadricep muscle endurance (ANOVA)

Source	Sum of Squares	d.f	Mean square	F	Significance
Preference	10.083	1	10.083	0.512	0.482
Group x preference	34.042	2	17.021	0.864	0.436
Error	413.875	21	19.708		

Table F-22 Quadricep muscle endurance between groups (ANOVA)

Source	Sum of Squares	d.f	Mean square	F	Significance
Group	23.042	2	11.521	0.228	0.798
Error	1060.875	21	50.518		

Table F-23 Hamstring muscle endurance (ANOVA)

Source	Sum of Squares	d.f.	Mean square	F	Significance
Preference	28.521	1	28.521	1.763	0.199
Group x preference	8.167	2	4.083	0.252	0.779
Error	339.813	21	16.182		

Table F-24 Hamstring muscle endurance between groups (ANOVA)

Source	Sum of Squares	d.f	Mean square	F	Significance
Group	41.167	2	20.583	0.283	0.756
Error	1527.312	21	72.729		

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BIOGRAPHICAL SKETCH

I grew up mostly in Toronto after immigrating to Canada from the Philippines. In 1992, I attended York University, Toronto, Ontario, majoring in kinesiology and health science. In my third year, I was accepted to the Sport Therapy Certificate Program. While in the certificate program, I worked as Assistant Student Athletic Therapist for the men's varsity basketball team, worked as Head Student Athletic Therapist for the varsity football team, and played on the men's varsity basketball team. I graduated in 1998 with a Bachelor of Arts (Specialized Honors) and a Certificate in Sport Therapy.

I spent the next year working under Chris Broadhurst and Dr. Michael Clarfield of the Toronto Maple Leafs, personal training and teaching First Aid/CPR courses. Next, I worked for the University of Toronto Varsity Blues Football Team, under the supervision of Toronto Raptors' team physician, Dr. Doug Richards.

During the spring of 2001, I was offered a graduate assistant position at the University of Florida. As a graduate assistant, I worked for the Division of Recreation Sports. I was responsible for providing athletic training services to the general student population, intramural participants, and club sport athletes. After completing my work at the University of Florida, I look forward to the exciting possibilities ahead.