EVALUATING BALANCE AS AN INJURY RISK FACTOR IN GIRLS’ BASKETBALL

By

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Abstract

Portable, fast, and cost effective screening tests are needed to identify areas of weakness that could potentially lead to injury in female middle school and high school basketball athletes. Deficits in balance have been correlated with increased ankle sprains, and specific training can help alleviate these deficits and reduce risks. The Y balance test (YBT) determines dynamic balance deficits in three reach directions. As part of a larger study, this project is concerned with testing the Y balance test in pediatric female basketball athletes. Scores did not improve with age from the under fourteen group to the fourteen and older group supporting data that, unlike their male counterparts, motor control in females does not improve with age. Asymmetries between legs, which have been observed as a risk indicator previously, were also observed in every reach direction with a peak seen around eleven years old. Pilot data gathered in this study may help form a baseline for injury risk prediction in this population.

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**Introduction**

Children’s participation in sports has seen big increases over the past couple of decades. In 1994 it was reported that girls’ participation in sports had increased 600% since 1972 due to title IX implementation, with only a 20% increase seen in boys’ sports participation over the same period (Messina, Farney, & DeLee, 1999). Over the last decade there has been a 21% increase in sports participation with around 30 million children aged 5-18 participating in organized sports (Barber Foss, Myer, & Hewett, 2014).

With this increase in participation there comes an increase in total number of pediatric injuries. Some of these injuries can be very costly with knee ligament repair surgeries costing up to $15,000 (Frisch, Croisier, Urhausen, Seil, & Theisen, 2009). Including the rehabilitation needed to regain function, the cost to repair an anterior cruciate ligament (ACL) rupture can be up to $17,000 (Frisch et al., 2009). It is estimated that sports injuries in children ages 5-18 cost over $480 million dollars over the course of four years (Frisch et al., 2009). Foss et al estimated that sports related injuries cost up to $2 billion a year (Barber Foss et al., 2014). Besides the monetary cost, an injury typically requires a player to take time off of the sport. Depending on the injury this time off could be anywhere from a couple sessions to multiple months (Eils, Schröter, Schröder, Gerß, & Rosenbaum, 2010; Frisch et al., 2009). Sometimes this time off could be the end of the athlete’s career with an estimated 8% of athletes completely ceasing participation due to injury (Emery, Rose, McAllister, & Meeuwisse, 2007). After rehabilitation many patients who have suffered an ankle sprain or knee injury report loss of function, or persisting symptoms for years post injury (Frisch et al., 2009).

Basketball athletes, in particular, have an increased risk of knee and ankle injuries compared to other sports (Frisch et al., 2009). While overall injury rates seem to be similar
between males and females, the incidence of knee injuries in females is significantly higher than that in males (Messina et al., 1999). Females are also more likely to suffer an ACL injury than male counterparts, but this difference is not apparent for ankle injuries (Slobounov, 2008). While ankle injuries as a whole may not be more common in either gender, there is evidence that inversion ankle sprains appear to be more common among women (Luke & Ma, 2014). Basketball players have been shown to have decreased postural stability compared to both soccer players and gymnasts which “may be a predisposing [risk] for the ankle instability/injury” common to basketball athletes (Slobounov, 2008). In 2005-2006 high school female basketball athletes suffered ankle injuries at a rate of 6.93 injuries per 10000 athletic exposures (Nelson, Collins, Yard, Fields, & Comstock, 2007). In high school athletes the ankle is the most commonly injured part of the body. In middle school athletes the knee is the most commonly injured joint suggesting that age may play a factor in vulnerability to injury as well (Nelson et al., 2007)(Barber Foss et al., 2014).

Evaluating someone’s risk of injury is time consuming, expensive and not easily accessible (Eils et al., 2010). Therefore research has been focused on performance tests that are able to predict injury, but are faster, easier to use, and less expensive (Plisky, Rauh, Kaminski, & Underwood, 2006). The star excursion balance test (SEBT) measured balance to show that high school female basketball athletes were at a higher risk of injury than their male counterparts (Plisky et al., 2006). However, the SEBT has lower than ideal inter-rater and intra-rater reliability and required more time to complete (Plisky et al., 2009). This led to the development of the Y balance test (YBT). As described by Plisky et al. the YBT is a “dynamic test that requires strength, flexibility, and proprioception” (Plisky et al., 2009). Though research has been
done on this population with the SEBT, research on the YBT is limited, and baseline data collection would improve injury prevention screening (Coughlan et al., 2012; Plisky et al., 2009).

The purpose of the present study is to analyze the effectiveness and reliability of the YBT in girls’ basketball athletes. In the future the data collected can be used to compare injury rates and determine if the YBT is a good measure for injury risk in middle school and high school female basketball athletes and other populations. Balance training has proven to be an effective method to reduce injury, therefore research in this field is warranted (Boccolini, Brazzit, Bonfanti, & Alberti, 2013; Eils et al., 2010). For example, in athletes with previous ankle injuries, a balance training program has been shown to reduce the risk of subsequent injury (Slobounov, 2008). Therefore if the YBT proves to be an effective way to measure injury risk, balance-training programs could be developed and implemented for athletes at higher risk.
Anatomy and Injury

Lower Limb

The lower limb is composed of many bones, ligaments, tendons, and muscles. The pelvic girdle is the most superior portion of the lower extremity and is composed of three fused components: pubis, ischium, and ilium. Traveling distally the thigh is the next portion of the lower extremity.

The femur is the only bone of the thigh and articulates with the pelvic bones at the acetabulum forming the hip joint. The femur articulates with the tibia and fibula at the knee joint where the patella also resides. Many of the muscles that stabilize the hip also stabilize the knee, and provide stabilization of the pelvis over the knee (MacKinnon & Morris, 2005).

The tibia and fibula make up the bones of the leg, or the part of the lower extremity below the knee joint. The tibia bears 90% of the weight while the fibula bears 10% (Dolores B. Bertoti & Peggy A. Houglum, 2012). The tibia articulates with the talus of the foot and forms the ankle.

The foot is an incredibly complex part of the body being composed of 26 bones including the talus, calcaneus, cuboid, lateral cuneiform, middle cuneiform, medial cuneiform, navicular, five metatarsal bones, and fourteen phalanges (Thompson, 1989).

Many of the muscles of the lower extremity can be seen well in FIG 2a and 2b.
The lower extremity is an important chain of joints, bones, and muscles. If there is a problem in one joint it could very easily cause issues in other joints as well due to misalignment.

Joints

Throughout the human body there are three major types of joints: fibrous, cartilaginous, and synovial. There are three factors that affect the mobility of each type of joint and affect each individual joint: the type of material at the joint, the amount it can be distorted or moved, and how much the surrounding muscles are able to produce the movement of said tissue (MacKinnon & Morris, 2005).
A fibrous joint is where the two bones are connected by fibrous tissue such as the tibio-fibular joint in the leg (MacKinnon & Morris, 2005). This type of joint exhibits very little movement, and in the case of the tibio-fibular joint, it allows for reduced bone mass while maintaining area for muscle attachment.

A cartilaginous joint has two subdivisions, primary and secondary. Primary cartilaginous joints have hyaline cartilage in between the two bones, and is seen in between the diaphysis and epiphyses of long bones during development, and does not allow any movement (MacKinnon & Morris, 2005). Secondary cartilaginous joints also contain hyaline cartilage on the surface of the bones, but connecting the bones is fibrocartilage (MacKinnon & Morris, 2005).

Synovial joints are the most common type in the human body, and can allow for a wide range of movement, from considerable to very little. In synovial joints the articulating surfaces of the bones are enclosed within the synovial capsule, covered in hyaline cartilage, and bathed in synovial fluid to lubricate the articulating surfaces.
Typically there are other structures within a synovial joint, such as a fat pad, or a meniscus in the case of the knee (MacKinnon & Morris, 2005). The hip, knee, and ankle are all examples of synovial joints.

**Ligament/Tendon Structure**

Ligaments, tendons, and retinacula are all forms of connective tissue comprised primarily of collagen and elastin. Tendons link muscle to bone, while ligaments link bone to bone. While made of similar materials, the function of ligaments and tendons does differ. Ligaments are primarily responsible for stabilizing a joint, but also provide the nervous system with information about that joint such as its position. Tendons on the other hand “transmit muscle force to bone or cartilage”, and therefore aid in the movement of a joint (Enoka, 1988). Retinacula often serve to hold tendons or ligaments in place to enable them to function appropriately.

**Bone Structure**

There are multiple types of bones in the human body including long bones, short bones, flat bones, sesamoid bones, and irregular bones. No matter the shape, each bone has an outer layer of compact bone, with trabeculae in the center. The trabeculae align due to stress placed on the bone and allow them to strengthen their resistance to these stresses as seen in FIG 4 (MacKinnon & Morris, 2005). These stresses can be due to gravity and weight-bearing or to the pull of muscles on their boney attachments during contractions.

Bone is constantly going through what is referred to as remodeling, through a balance of deposition and resorption of the bone matrix. Depending on the repetitive stresses a bone faces different areas will be reinforced. Due to this athletes, with increased overall muscle
contractions, tend to have a higher bone density, particularly the bones of the lower leg in athletes who’s sports require running or repetitive forceful movements on the lower extremity (Enoka, 1988).

**Hip**

The hip joint is made of four bones: the femur of the thigh, and the ilium, ischium, and pubis of the pelvis. All three pelvic bones and the transverse ligament form the acetabulum, which is the site of femur articulation (MacKinnon & Morris, 2005). The joint itself is a ball and socket synovial joint which allows for movement in all directions as well as rotation (Thompson, 1989). Further stabilizing this joint is the acetabular labrum made of fibrocartilage which serves to deepen the socket (MacKinnon & Morris, 2005). Three ligaments, the iliofemoral, pubofemoral, and ischiofemoral, also stabilize the hip joint while reducing the amount of extension possible by the femur (MacKinnon & Morris, 2005). These ligaments can be seen in FIG 5.
Multiple muscles move the femur at the level of the hip in a variety of directions, but by crossing the joint they also provide stabilization. These muscles include the psoas major, iliacus, pectineus, rectus femoris, gluteus group, the hamstrings, tensor fasciae latae, and the adductors (MacKinnon & Morris, 2005).

While the hip is indeed well supported, protecting it from injury, some injuries do occur. In particular, common sports injuries of the hip include adductor sprains due to quick changes in direction made by the athlete (Coel, Hoang, & Vidal, 2013).

**Knee**

The knee is the middle joint of the lower extremity and a hinge joint meaning that it only has movement in one plane of direction. This is very similar to the elbow, however the anatomy of the elbow and knee are very different. The knee is essentially two bones (femur and tibia) resting on each other, as seen below in FIG 6, while the elbow has interlocking pieces of bone that provide more stability. Multiple ligaments articulate on both the femur and tibia providing stabilization. The fibula is the smaller lateral bone of the leg, which is the site of attachment for
the lateral collateral ligament. The patella is also an important part of the knee, and is the bone that lies in the tendon of the quadriceps femoris muscle (MacKinnon & Morris, 2005).

Patellofemoral overuse syndrome is a common injury in sports that require running or similar repeated stresses of the lower extremity. Different causes of this are joint misalignment of the lower extremity, core weakness affecting knee biomechanics, muscle strength/development/flexibility imbalances, tight muscles, and other mechanical issues. If the patella is tracking incorrectly over the knee joint due to any of the above reasons it can cause abnormal and painful wear on the cartilage covering the bone of either the tibia and/or femur (Luke & Ma, 2014).

Osgood-Schlatter’s disease is a common injury in adolescents where the quadriceps tendon pulls on the apophysis of the tibia and partially separates it from the diaphysis (MacKinnon & Morris, 2005). It is common in children experiencing a growth spurt while participating in sports that involve repetitive jumping and cutting movements (Frisch et al., 2009).

The knee is stabilized primarily through ligaments, tendons, and menisci (Coel et al., 2013). The knee is supported by multiple ligaments that ensure an individual maintains the ability to bear weight and full motion of the leg (Morton et al., 2011a). There are five ligaments in the knee that resist movement in various directions and can be seen above.

The medial collateral ligament (MCL) and the lateral collateral ligament (LCL) are located on the sides of the knee, and stabilize the knee during varus (lateral) and valgus (medial) movements (Coel et al., 2013).

The anterior cruciate ligament (ACL) is made of two bundles (Coel et al., 2013). The ACL resists movement in three directions: hyperextension of the knee, the femur sliding backwards, and femur rotation medially when the leg is fully flexed (Grant & Anderson, 1978). Most ACL injuries are seen during movements of “deceleration, twisting, and cutting” (Coel et al., 2013), all common movements in basketball. ACL ruptures typically require surgery in young athletes particularly if there is serious instability. This injury is quite severe as return to sport cannot be achieved until a minimum of six months after surgery, which can be performed 2-6 weeks after initial injury. Initially the largest effect is the cessation of sports participation. An ACL injury can affect a patient for a very long time with 14-27% of patients having undergone an ACL repair reporting “severe loss of function” while 35% of non-operated
pediatric patients reported an inability to return to pre-injury performance after 3.9 years (Frisch et al., 2009). Clearly an ACL injury can become a lifelong problem very quickly.

ACL injuries appear to be more common in girls than in boys due to differing risk factors (Frisch et al., 2009). Some non-modifiable risk factors associated with higher ACL injuries in female athletes are decreased muscle strength, decreased coordination and proprioception, and an increased joint laxity compared to their male counterparts (Frisch et al., 2009). After puberty women have increases of their valgus knee angles, or of the incidence of knees moving in upon landing or being “knock-kneed” (Ito, Iwamoto, Azuma, & Matsumoto, 2014). They are also characterized by a decreased intercondylar notch width compared to males (Ito et al., 2014). Both of these differences from their male counterparts are proposed risk factors for ACL injuries.

The two bundles of the posterior cruciate ligament (PCL) run from the medial femoral condyle to the posterior tibial plateau. The PCL resists posterior dislocation of the tibia, which is very uncommon (Coel et al., 2013). The PCL particularly plays a role when the knee is flexed.

The knee also contains two menisci, medial and lateral, and are comprised of cartilage which is thicker on the outer edge and thin down towards the middle of the joint (Thompson, 1989). These allow for improved stability by slightly increasing the depth of the ‘socket’ on the top of the tibia and smoother movement of the knee. The menisci also act as a shock absorber in the knee protecting surrounding tissues from damage (Luke & Ma, 2014). Tears in the menisci can cause difficulty in extension and flexion as well as severe pain (MacKinnon & Morris, 2005). Depending on the severity of the meniscus tear, the best course of treatment may be an arthroscopic repair (Luke & Ma, 2014).

Muscles that cross the knee joint also play a role in its stability. These muscles include the three branches of the hamstrings (semimembranosus, semitendinosus, and biceps femoris) and
three of the four branches of the quadriceps (vastus intermedius, vasus medialis, and vastus lateralis (MacKinnon & Morris, 2005). Both of these muscle groups are very active in running or jumping motions seen in basketball (Thompson, 1989).

Ankle

The ankle is composed of multiple bones including the tibia and fibula of the lower leg, and two of the tarsal bones, the calcaneus and talus. The deltoid ligament is the strongest ligament in the ankle and originates at the medial malleolus (Handel & Gaines, 2011). The lateral ligament complex is weaker than the medial ligament and is the more common place for sprains especially at the anterior ligament (Handel & Gaines, 2011). The lateral ligament complex is made of three separate ligaments, while the deltoid, or medial, ligament is a fan shape with three less distinct branches (MacKinnon & Morris, 2005). The ligaments of the ankle can be seen in FIG 7. The ankle is stabilized by the lateral and medial ligaments as well as the interosseous membrane between the tibia and fibula forming the syndesmosis at the distal portion of the fibula and tibia (Dolores B. Bertoti & Peggy A. Houglum, 2012). The syndesmosis binds the tibia and fibula together by stabilizing the ankle mortise joint. (Coel et al., 2013).
When a ligament in the ankle partially tears or ruptures it is considered a sprain, and the severity is graded from 1-3 dependent on the amount of damage. Ankle sprains are commonly caused by walking on uneven surfaces or rotations of the ankle that mimic the effects of walking on uneven surfaces (MacKinnon & Morris, 2005). According to a review on pediatric sports injuries done by Frisch et al (2009) basketball athletes had a high incidence of ankle sprains (1.56/1000 hours). Persisting symptoms such as pain and perceived instability were found 2.5 years later in 74% of patients who had forgone surgery for an inversion, or lateral, ankle sprain (Frisch et al., 2009). Ankle sprains become concerning because they have a high incidence of recurrence once the first injury has occurred. This was specifically observed in youth soccer where a previous ankle sprain was associated with a 6.5 time greater risk of injury (Frisch et al., 2009). Deficits in balance, a modifiable risk factor, have been associated with ankle sprains and
in some cases associated with a seven times greater risk of injury compared to subjects with good balance (Frisch et al., 2009). However this issue is controversial with some studies reporting that balance is not a risk factor for ankle sprains (McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006).

No muscle bellies directly pass over the ankle joint, but many of the tendons of the flexor and extensor muscles do pass over the ankle and into the foot. These include the soleus and gastrocnemius that give rise to the Achilles tendon, tibialis anterior, extensor hallucis longus, and the extensor digitorum longus (MacKinnon & Morris, 2005). Around the ankle are also different retinacula that hold the various tendons in place (MacKinnon & Morris, 2005). Two retinacula, superior extensor retinaculum and the inferior extensor retinaculum, on the dorsal side of the foot hold the extensor muscle tendons in place. The flexor retinaculum tethers tendons to the medial side of the ankle as they proceed to the bottom of the foot. These can be seen below in FIG 8. The fibular retinaculum is not pictured, but it keeps the tendons of associated muscles in place on the lateral side of the ankle. Without the retinaculum the tendons would be able to move and desired motions may not be produced with a muscle contraction (Morton, Foreman, & Albertine, 2011c).
Ankle injuries are common in pediatrics, but the type of injury is dependent on maturity. Younger children who are still growing typically suffer from skeletal injuries while skeletally mature children/teenagers typically suffer from ligamentous injuries similar to adults (Coel et al., 2013). A study of 38,000 high school basketball players over 3 years found that 36% of female participants, and 38% of male participants had at least one foot or ankle injury (McGuine, Greene, Best, & LeVerson, 2000). There is a slight decrease in injury incidence in collegiate athletics with 23% of female injuries and 25% of men injuries pertaining to the ankle (McGuine et al., 2000).

In the United States 5 to 10 million ankle injuries occur every year with the most at risk group being 21-30 year olds. More than 80% of these ankle injuries are sprains of the ankle (Cardell & O’Rorke, 2012). Ankle sprains can be long lasting with one study reporting 35.4% of athletes with ankle sprains missing more than 8 days of competition or practice (McGuine & Keene, 2006). Overall, ankle injury incidences are similar among males and females, but women are more likely to suffer from an inversion ankle injury than men (Luke & Ma, 2014).
The foot is an incredibly complex part of the body being composed of 26 bones, over 20 muscles, and more than 100 ligaments (Thompson, 1989). The tarsals make up seven of those bones and include the calcaneus, talus, cuboid, medial cuneiform, middle cuneiform, and lateral cuneiform. The foot is stabilized by ligaments that connect all 26 bones as well as create the arch of the foot (Thompson, 1989). The sole of the foot also contains a sheet of dense fibrous connective tissue called the plantar aponeurosis that runs the length of the foot and splits into five segments attaching to the toes (MacKinnon & Morris, 2005).

There are many different joints of the foot that allow it to move in a variety of directions, even though the movement may be limited. The tarsal bones form an arthrodial joint, which allows limited gliding movement (Thompson, 1989). Beneath the talus is the subtalar joint which is a synovial joint allowing for eversion and inversion of the foot. This joint is stabilized by the medial and lateral ligaments of the ankle (MacKinnon & Morris, 2005).

Other joints of the foot include the calcaneocuboid joint and mid-tarsal joint that allow for other movements of the foot (MacKinnon & Morris, 2005).
The arch of the foot is a very complex system, and functions largely as a shock absorber for the leg. The spring ligament plays an important role in preventing the talus from slipping in between the navicular and calcaneus and essentially forms the posterior portion of the plantar arch (MacKinnon & Morris, 2005). The arch also receives support from the long and short plantar ligaments, muscles on the sole of the foot, and muscles of the leg and the ligaments that run under the sole of the foot (MacKinnon & Morris, 2005).

Females are 9 times more likely to have foot pain (Cardell & O’Rorke, 2012). Injuries specific to the foot, however, are commonly grouped together with injuries of the ankle. Therefore many studies report foot and ankle injuries together instead of separating them into two distinct categories.

**Developmental and Gender Issues/Differences**

Female and male children develop at different paces, but there are also children of the same gender that mature at different times. This creates large differences in height and weight within teams and can lead to a higher risk of injury (Frisch et al., 2009). It also makes predicting injuries difficult as children of the same age may not face the same issues.

The bones of the lower extremity are not fully fused, diaphyses with epiphyses, until around 18 years of age, and all bones generally are fully fused by twenty-two years of age (Grant & Anderson, 1978). Until the bones fully fuse epiphyseal plates composed of hyaline cartilage exist between the epiphyses and diaphysis and is the site of elongated bone growth (MacKinnon & Morris, 2005). Similarly, the bones of the pelvis (ischium, ilium and pubis) are separate, and do not fuse until the person reaches maturity (Thompson, 1989). Bone growth also consists of appositional growth, or the increase in girth of the bone (MacKinnon & Morris, 2005). FIG 10 shows these areas of bone development.
Children are more susceptible to fractures in two areas during the stage of development that includes bone growth. The first of these is at the epiphyseal plate, or the growth plate, and the second is at the apophyseal cartilage. Both of these locations can be pulled on by a tight muscle or tendon and may result in an avulsion fracture or traction apophysitis (Frisch et al., 2009).

Hormonally, a pubescent athlete has many androgens circulating throughout their body that cause quick growth spurts of muscle and bone (Frisch et al., 2009). During these times of growth the elongation of muscles and tendons occurs after and as a direct result of the growth in bone, which causes a tightness of these muscles and tendons as they are stretched over the larger bone before they too elongate (Frisch et al., 2009). This non-synchronous growth can be an important factor contributing to many of the injuries seen in developing athletes.
Balance

Balance as defined by the Merriam-Webster online dictionary is “the ability to move or to remain in a position without losing control or falling” (“Definition of BALANCE,” n.d.). In contrast a medical textbook defines balance as the “ability to control the center of mass with respect to gravity and the support surface” (Sudarsky, 2015). Balance, and the ability to maintain it, is integral to normal human function on a daily basis. Without it, walking, running, or even standing would be impossible. In order to maintain balance multiple components are important including “eye-motor coordination, kinesthetic response, ampular sensitivity, and vertical semicircular canal function” (Slobounov, 2008). According to Thompson there are seven factors that apply to balance: a person’s center of gravity in relation to their base, the size of the base, mass of the person, height of the center of gravity, rotation around an axis compared to a stationary object, and sensory factors (Thompson, 1989). Sensory information comes from a variety of areas including visual, vestibular, and proprioceptive information from the muscle spindles and joints (Sudarsky, 2015). By synthesizing all of this input you are able to better understand your surroundings as well as your body’s position and make any necessary adjustments.

Throughout the human lifespan our perception of what constitutes good balance changes as well. When a child is first learning to walk the ability to stay upright for more than five seconds is impressive. It is similar near the end of life when falls are more expected, indicating that the expectation of balance has decreased once again. In contrast one would find it abnormal for a healthy college-aged student to fall while walking down a flight of stairs. A recent article by Bullock et al recorded balance scores of basketball athletes of different skill levels ranging from middle school to professional (Bullock, Arnold, Plisky, & Butler, 2016). Their results
indicate that areas of strength change over time, and skills may increase or decrease over a course of a career, and not only increase with time (Bullock et al., 2016).

Balance, and posture, can be characterized in two ways: static and dynamic. Static balance pertains to the ability to maintain an upright posture while standing or sitting without moving (Enoka, 1988, p. 198). To stay standing many unconscious adjustments are occurring to ensure that the center of mass remains over the base (Sudarsky, 2015). In fact, even when we believe we are standing completely still our bodies sway back and forth as small corrections are made to remain upright (Enoka, 1988, p. 198). Small amounts of sway are normal; however, when they become exaggerated it becomes an issue. Dynamic balance concerns maintaining balance while moving during activities such as running, walking, or playing sports (Enoka, 1988). During movements such as running not only the lower limb is moving, but the arms are swung to act as balancers (MacKinnon & Morris, 2005).

Many methods to measure balance are expensive, must be performed in a lab, and/or are time consuming (Plisky et al., 2006) Some studies use force platforms that are able to track a subject’s sway as they stand still (McGuine et al., 2000). This requires an expensive force plate as well as the subject having to travel to a laboratory to complete the needed measurements. If a study were to involve tracking of balance through a training program this would require multiple trips. Occasionally force plates were able to be transported and thus available to teams before practices, but this would require the transportation of expensive equipment (McGuine et al., 2000).

The star excursion balance test (SEBT) was developed as an alternative to these expensive and time-consuming options. Historically the SEBT had eight reach directions (directions the subject reaches within a 360° range), but it was proven to be redundant, so it was
subsequently reduced to the anterior, posteriolateral, and posteriomedial reach directions (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). In order to perform the modified SEBT a participant reaches one foot along any of the three directions, while maintaining a stance position at the center of the “star” (Plisky et al., 2006). A representation of a subject completing the modified SEBT can be seen below in FIG 11.

While the SEBT has proven beneficial in measuring balance deficits, it does have major flaws in data collection. There is a considerable potential for subject mistakes such as resting the reach foot on the ground when touching down, which does not allow for an accurate measurement of balance. The researcher is also required to make an educated assumption as to where the foot was placed down as there is no indicator to maintain the position and give an exact measurement. This inaccuracy was demonstrated in a moderate to good score of intrarater reliability and a poor to good score of interrater reliability (Plisky et al., 2009). These factors led to the creation of the Y balance test.
The Y balance test (YBT) also measures balance in the anterior, posterolateral, and posteromedial directions through the use of a kit seen below in FIG 12 (Plisky et al., 2009).

![FIG 12. Subject performing YBT for picture purposes only.](image)

To perform the YBT the subject stands on the center platform on one leg with their toe behind the red line. They then push the indicator along the PVC pipe or wood as far as possible while maintaining balance. These indicators help reduce the uncertainty of measurements.

**Balance as a Risk Factor for Injury**

Some basketball players have displayed deficits in postural balance that could be indicative of future ankle injuries (Bressel, Yonker, Kras, & Heath, 2007). Furthermore this
study proposed that potentially the sport played may affect the level of balance in specific athletes (Bressel et al., 2007). McGuine et al. monitored basketball players throughout their season and found that those with low balance scores at the beginning of the season had a much higher incidence of ankle injuries during their season than those players with high beginning balance scores (McGuine et al., 2000). Another study followed girls and boys basketball through their seasons and tracked injury rates. Girls who scored below a 94% composite score on the SEBT when taken as a percentage of leg length were 6 times more likely to become injured while there was no significant relationship with the male athletes (Plisky et al., 2006). The same study also found that an asymmetry in reach distance between right and left legs in the anterior reach direction was a significant risk indicator. Another article utilizing the modified SEBT found that football players with less than an 89.5% composite score as a percentage of leg length were 3.5 times more likely to suffer a lower extremity injury during the season (Butler, Lehr, Fink, Kiesel, & Plisky, 2013). Balance deficits are present after injury as well with one study noting that participants with a previous injury had greater postural sway than their uninjured counterparts, which suggests that these athletes are now at even greater risk for future injury (McGuine et al., 2000).

**Balance Training as a Way to Reduce Injury Risk**

Some authors are starting to produce evidence which suggests that good balance and neuromuscular control could be important in preventing ACL tears (Slobounov, 2008). Multiple studies have shown that balance training can aid in preventing injury and be important in rehabilitation (Slobounov, 2008). Other authors argue that by solely implementing balance training future ankle ligament sprains can be reduced, but only if after an initial sprain (Slobounov, 2008).
McGuine and Keene performed a study that monitored ankle sprain incidences between a balance training group and a control group. The injury incidence was lower in the balance training group and injuries that did occur were less severe with an average time lost being only 5.8 days compared to 8.1 days in the control group (McGuine & Keene, 2006).

A training program implemented by Eils et al found that a multi-station proprioceptive training program was effective in decreasing the number of ankle sprains in high school basketball players. They also found that with increased neuromuscular control postural sway decreased (Eils et al., 2010).

While the specifics of the most effective training plans are not completely set in stone, there is convincing research indicating that training programs involving balance can decrease the risk of injury.
METHODS

This study was part of a larger data collection project evaluating a variety of performance and injury-screening tests in female middle school and high school basketball athletes, and was approved by the Institutional Review Board at Northern Arizona University and The University of Arizona. Five tests were run: the tuck jump assessment, single hop for distance, standing broad jump, countermovement vertical jump, and the Y balance test (YBT). These tests assess strength, balance, and other skills useful in basketball performance. The YBT, as previously described, is a dynamic balance test that requires multiple traits such as proprioception, strength, and flexibility (Plisky et al., 2009).

When the tests are run the subjects are assigned a random order to perform the 5 tests using a random number generator. Data was collected at basketball tournaments hosted at LEAD Athletics in Tucson, Arizona from June 2015 to March 2016. Teams participating came from Southern Arizona and across the western United States.

Concerning the YBT, participants were instructed to watch an instructional video describing the test and test procedures. They were then asked to remove their shoes and socks. They placed their stance leg behind the red line on the center platform of the apparatus, and the non-stance foot in the gap behind them on the ground. This is the starting position. The subject then pushed the block in the appropriate direction as far as they could while maintaining balance, and returned to the starting position. The indicator block was then moved back to the starting position.
No instruction was given regarding the stance leg besides instructing them to stay on the central block behind the red line. Participants completed four to six practice trials per direction on each leg until the distances plateaued. Feedback was given to the participant after each practice trial if any infractions were committed. After completing the practice trials three trials were run per leg per direction in the following order: right anterior, left anterior, right posteriomedial, left posteriomedial, right posteriolateral, and left posteriolateral where the right/left indicates the stance leg. These directions are labeled below in FIG 14.
Distances were not recorded if the subject committed any of the following infractions: touching down with the contralateral leg or falling off of the central platform, loss of contact with indicator, inability to return to start position without losing balance, pushing/kicking the indicator at the end of the trial to increase distance, and placing the foot on any side of the indicator other than the closest side. The subject completed as many trials as needed until there were three recorded trials.

Following completion of three trials in the three reach directions the subjects leg length was measured. The subject was instructed to stand with equal weight distributed on both legs. Right leg length was measured from the anterior superior iliac spine to the most distal portion of the medial malleolus.
The averages of each reach direction were calculated per leg. Composite scores were taken using the following formula, which normalized the score to leg length.

\[
Composite\ Score = \frac{(Average\ Anterior + Average\ PM + Average\ PL)}{leg\ length\ or\ height}^{\frac{1}{3}} \times 100
\]

Asymmetries between legs for each reach directions were also determined. Finally, an independent t-test was run on the data with the significance set at \( p=0.05 \).
Results

Data was gathered on female middle and high school basketball athletes. Demographic information can be seen below in FIG 15.

<table>
<thead>
<tr>
<th>Value</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>13</td>
<td>8</td>
<td>15</td>
<td>11.85</td>
<td>2.267</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>13</td>
<td>122</td>
<td>173</td>
<td>155.31</td>
<td>15.761</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>13</td>
<td>65</td>
<td>145</td>
<td>108.69</td>
<td>24.841</td>
</tr>
<tr>
<td>R Leg Length (cm)</td>
<td>13</td>
<td>70</td>
<td>95</td>
<td>81.654</td>
<td>8.5887</td>
</tr>
</tbody>
</table>

![Distribution of Age](image)
Raw mean data separated by age group for each reach direction is shown above in FIG 16. Reach directions increase with increasing age except for a drop in the right anterior 11 year olds, right posteromedial 14 year olds, left posteromedial 14 and 15 year olds, and steadily decreasing with age for both composite scores except for a rise again at 15 years old.

When data was normalized with leg length, by taking the scores as a percentage of the leg length, scores appear to decrease with age but also become more consistent across the various directions. Data was also taken as a percentage of leg length and compared across all age groups for each reach direction, and can be seen in FIG 17.

<table>
<thead>
<tr>
<th>Age</th>
<th>number of subjects</th>
<th>Mean Height (cm)</th>
<th>Mean R Leg Length (cm)</th>
<th>R Anterior Mean (cm)</th>
<th>L Anterior Mean (cm)</th>
<th>R Posteromedial Mean (cm)</th>
<th>L Posteromedial Mean (cm)</th>
<th>R Posterolateral Mean (cm)</th>
<th>L Posterolateral Mean (cm)</th>
<th>R Composite Mean (cm)</th>
<th>L Composite Mean (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1</td>
<td>122</td>
<td>65</td>
<td>47</td>
<td>44</td>
<td>71</td>
<td>70</td>
<td>77</td>
<td>79</td>
<td>92.7</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>101.5</td>
<td>102.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>143.67 ± 11.55</td>
<td>72.83 ± 3.17</td>
<td>53 ± 1.76</td>
<td>84 ± 1.76</td>
<td>87 ± 2.28</td>
<td>65.4 ± 3.19</td>
<td>101.5 ± 4.40</td>
<td>102.3 ± 6.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>11.55 ± 4.91</td>
<td>52 ± 7.90</td>
<td>84 ± 1.76</td>
<td>87 ± 2.28</td>
<td>85 ± 3.19</td>
<td>4.0 ± 3.19</td>
<td>4.40 ± 6.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>10.61 ± 5.73</td>
<td>91 ± 7.57</td>
<td>84 ± 2.28</td>
<td>87 ± 3.19</td>
<td>90 ± 5.38</td>
<td>6.3 ± 6.84</td>
<td>84.9 ± 3.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>5.13 ± 3.51</td>
<td>57 ± 7.31</td>
<td>91 ± 7.93</td>
<td>84 ± 2.28</td>
<td>83 ± 3.19</td>
<td>6.3 ± 6.84</td>
<td>85.8 ± 3.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>3.54 ± 3.63</td>
<td>72 ± 10.37</td>
<td>84 ± 2.28</td>
<td>87 ± 3.19</td>
<td>82 ± 3.19</td>
<td>7.9 ± 6.84</td>
<td>22.0 ± 2.52</td>
<td>22.52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When asymmetries are compared over age groups, a peak was observed at eleven years of age with one subject having an asymmetry of 12 cm in the posteromedial reach direction, and two subjects having greater than a four cm asymmetry in the anterior reach direction.
Asymmetries Posteriomedial Reach Direction

Asymmetries Posteriolateral Reach Direction
FIG 18. Asymmetries across all subjects in all reach directions.

We hypothesized that subjects 14 years of age or older (n=5) would show improved scores compared to subjects less than 14 years of age (n=8). However, this hypothesis was not supported by the data, and the null hypothesis could not be rejected. The mean raw scores in the two subgroups can be seen below in FIG 19.
Mean Raw Scores Subdivided by Age Groups

Reach Distance (cm)

Under 14 Years of Age
14 Years of Age or Older

Reach Direction

FIG 19.
Discussion

The Y balance test (YBT) was an efficient test to run on female pediatric athletes. Preliminary data shows trends of scores across the population. Scores normalized to leg length showed a decrease with increasing age. The data was also interesting when it pertained to asymmetries in different age groups, with 11 year olds having the highest asymmetries. This is an area that warrants more research to determine if these trends are seen across the entire population or only in the current sample.

Previous research has shown that asymmetries in balance reach directions from side to side can be a risk factor for lower extremity injuries (Plisky et al., 2006). Specifically greater than a 4 cm asymmetry in the anterior reach direction of the SEBT was identified as risk in high school girls basketball athletes (Plisky et al., 2006). In the present study two subjects demonstrated a greater than 4 cm asymmetry in the anterior reach direction. These asymmetries may also cause deficits in performance. During one testing period a subject remarked how much harder it was for her on one side, and then disclosed that the side where better balance was observed was the stance leg when she kicked a ball when playing a sport like soccer. While it is never expected for a basketball player to kick a ball this may have an effect on layups or other important skills relevant to basketball performance.

We did observe a peak in asymmetries around 11 years of age, but due to the small subject number it is difficult to identify the significance of this finding or to attribute a potential cause. For example, it cannot be concluded if this was due to our four 11 year old subjects simply having poor balance, or if poor balance around eleven years of age is consistent in the population and a symptom of an underlying factor. There is research supporting that the greatest growth spurts occur around 11 or 12 years of age in girls, which could decrease neuromuscular
control (Hewett, Myer, & Ford, 2004). It is possible this accelerated growth is a factor in the decreased balance, but more research with a larger sample size is needed to investigate this issue.

Another risk indicator that has been proposed is having a composite score of less than a certain percentage of leg length on the SEBT that varies by population (Butler et al., 2013; Plisky et al., 2006). The SEBT is very similar to the YBT, and it is possible similar risk assessments may apply. By taking the score as a percentage it is easier to compare scores between participants. Our data shows that averages across ages seem to vary according to reach direction, with a leveling out across reach directions with increased age. Once again with our small study population it is impossible to make conclusions, but does warrant itself as an area that needs more research.

One other study has looked at the YBT in populations from middle school through professional basketball players (Bullock et al., 2016). This study however failed to identify the gender composition of their population. Due to differences in male and female athletes, especially during puberty in the middle school and high school groups, gender is a factor that needs to be known. This is especially important as the YBT may be a suitable way to infer deficits in motor control. Current research shows that in female athletes motor control does not improve throughout puberty, and possibly decreases, while male athletes improve their motor control through this same time frame (Ford, Shapiro, Myer, Van Den Bogert, & Hewett, 2010; Hewett et al., 2004). Hewett et al. found that in late-puberty female athletes have decreased neuromuscular control around the knee, which the authors theorized could be a risk factor for ACL injury (Hewett et al., 2004). Due to the lack of improved scores in in our sub groups (i.e. under and over 14 years of age) our data supports the lack of improvement of motor control
through puberty. More research is warranted to investigate balance in association with neuromuscular control in female athletes throughout puberty.

**Limitations**

**Sample Size**

The largest limitation faced in this study was sample size. Due to the small sample size it is impossible to determine whether trends seen are actually significant. Furthermore a sample with more equal numbers with respect to each age group would give a more accurate average per age group.

**Parental Consent**

In a tournament situation many parents were protective of their children, and they wanted to ensure that the child had the most rest time as possible. There were also circumstances where a child had traveled with the team from outside the area without their parents, preventing us from obtaining consent. It is possible that obtaining consent prior to tournament participation could reduce some of these barriers to participation.

**Motivation**

Due to the parents providing consent for the child there were children who were participating solely because their parents wanted them to. There was also an instance where one participant noticed her friend, who was completing the test concurrently, reached a further distance than she had and proceeded to reach significantly further than she previously had done. When it comes to the motivation of the subject it is important to keep in mind the social aspects of the population. During one data collection subjects were very concerned by the fact that they
must take their shoes and socks off due to being self-conscious of their feet. These various aspects specific to this age group and population are important factors to consider.

Environment

Basketball tournaments are loud and full of distractions. Many participants were observed completing the trials with less than ideal concentration. This could also be a factor in lower scores than expected or large differences in scores. The environment also made it difficult for participants to hear the video before completing the test. This could easily affect the performance on the test.
Reflection

This thesis project served as a great tool to integrate all of my collegiate experiences. It felt great to finally use knowledge from my courses in a real-world application. By forming my own experiences I felt my comprehension of the information taught in class improve. Outside of strictly “book” knowledge I was able to apply skills I’ve gained from volunteering at the VA Hospital, working with children at a local church, and observing physical therapists working with patients. It only seems fitting that these experiences culminated in a yearlong project researching an area of interest to me and relevant to my future career as a physical therapist.

Perhaps the greatest thing I’ve learned over the past year is that research is messy. When you read a final paper it sounds simple-1) come up with an idea, 2) test subjects, 3) make an unbelievable discovery. The truth is research is so much more than those three “simple” steps. There will be days when you sit outside in the Arizona summer heat for eight hours and test less than ten participants. The project will never feel complete in time for the next presentation. Data may not turn out at all how the team hypothesized. Yet through it all I learned to go with the flow, that it will all work out if you keep trying, and that you may discover something you didn’t expect.

Overall this project taught me many things about preventative care, the lower extremity of the human body, and the process of research. While the process was not always the most smooth, I would not change the experience in any way as it taught me more research and working with human subjects than I would have learned otherwise.
Bibliography


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