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Ankle dorsiflexion range of motion, dynamic balance, and static balance in Division III collegiate gymnasts

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The Relationships Between Ankle Dorsiflexion Range of Motion, Dynamic Balance, and Static Balance in Artistic Gymnasts

by

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Abstract

Introduction: Artistic gymnastics is a demanding sport composed of high intensity activities. Decreased range of motion can increase the risk of lower extremity injury due to the inability to disperse forces properly upon landing. Landing from a height demands dynamic balance, which may be influenced by ankle range of motion. Due to the complexity of the sport, identifying potential deficits at the ankle could lead to the development of injury prevention programs. **Purpose:** The purpose of this study is to investigate if correlations exist between active ankle dorsiflexion range of motion (AROM) and static balance and/or AROM and dynamic balance in artistic gymnastics. **Methods:** A quasi-experimental study examined AROM and dynamic balance utilizing the Weight-Bearing Lunge Test (WBLT) and Star Excursion Balance Test (SEBT), respectively. Lunge distance and reach distance from each test was recorded in centimeters. A force plate was used to provide an addition objective measure on single limb balance. This study took place in a laboratory setting on the SUNY Cortland campus. **Conclusions:** This study provides evidence to a unique population in sport. Division III collegiate artistic gymnastics is underrepresented in the literature and this study may be able to guide preventative programs created by medical personnel. Although this study looks at a unique population, no significant correlations were found between measures. A moderate correlation was found between the WBLT and the posteromedial direction of the SEBT.

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CHAPTER 1

Introduction

From a young age, millions of children around the world participate in gymnastics activity or similar sport (Francia et al., 2020). Artistic gymnastics is a form of gymnastics that involves routines on various apparatuses, including balance beam, floor exercise, uneven bars, and vault. It is a demanding sport on both the upper and lower extremities. Many forms of landing occur in gymnastics, including landing after tumbling, jumping, or leaping, during dismounts from the bars and balance beam, and landing following vaulting off the vaulting platform. Adequate active range of motion (AROM) is necessary to ensure proper landing mechanics for the lower extremity. In general, sport activity can negatively affect the integrity of the ankle joint, both anatomically and functionally (Francia et al., 2020). If there is decreased ROM at the ankle, the risk of injury increases as forces are not dispersed properly during landing which could be due to restricting the ability for the legs to move forward over the feet (Mason-Mackay et al., 2015). An individual with reduced dorsiflexion ROM may compensate with subtalar and midfoot pronation or knee valgus which are also risk factors of injury (Mason-Mackay et al., 2015). Normal active ankle dorsiflexion ROM is 10-30 degrees (Shultz et al., 2016), and Frutuoso et al. (2016) found that international level gymnasts (17.9± 4.0 years of age) fall within that range, with participants ranging from 13-29 degrees. Due to the nature of the sport and the importance of landing mechanics, normal dorsiflexion is imperative for gymnasts to decrease risk of injury associated with landing.

When the individual performs the specific ROM volitionally, active ROM can be assessed in a few ways. Most commonly, goniometry is used to objectively measure ROM at any joint, but when testing active dorsiflexion ROM at the ankle the Weight-Bearing Lunge Test (WBLT) can be used. This test provides a more functional measure since it is performed in a weight-bearing position. WBLT is a reliable and valid test for active dorsiflexion AROM (Chisholm et al., 2012). The WBLT is done in close-packed position, with maximum joint stability due to the congruency of articular surfaces, and allows osteo- and arthrokinematics to be evaluated, allowing for stability and ROM to be assessed (Chisholm et al., 2012). This test may be particularly important for evaluating ankle function in gymnasts considering the frequent dorsiflexion motion while the joint is loaded they experience in the sport.

Static balance is the ability to keep the body in a specific position. Although this can be observed on the ground or uneven surface; to objectively measure static balance a force plate can be used to track an individual's center of pressure during single limb balance. A common clinical test to measure static balance is the balance error scoring system (BESS) test. This test measures the number of errors during various challenging conditions. The BESS test is cost effective and not time consuming but the total score of the BESS test is not reliable due to discrepancies in the inter-rater and intra-rater reliability (Finnoff et al., 2009). The ability to combine the components of the BESS test, such as single limb balance with eyes open and closed, with the objective data from a force plate may provide more concrete measures regarding static balance (Richmond et al., 2020). Both dynamic and static balance are required for several skills and techniques on each apparatus of artistic gymnastics. The most apparent need for static balance in

gymnastics would be on the balance beam, but there are other skills on the other apparatuses that require static balance or possibly toggle from dynamic to static balance during landings or leaps. Measuring this population's stability may provide valuable information that can be translated to their routines. Not only can this data be utilized to improve abilites for routines, but recognizing deficits could also aid in creating injury prevention strategies for these athletes.

Dynamic balance is the ability to maintain stability while an individual's base of support is changing (Dunsky et al., 2017). Dynamic balance control is important in artistic gymnastics with the amount of tumbling and leaps that gymnasts do on each apparatus. Motion must be arrested before transitioning to the next skill or for remaining stationary at the conclusion of the event. A common test for dynamic stability is the Star Excursion Balance Test (SEBT), which is an effective test to assess dynamic balance (Olmsted et al., 2002). Dynamic balance in gymnastics plays a role in each apparatus that is competed in this sport. Assessing this population's dynamic balance abilities could help with various routines by identifying those at risk for injury and/or improving performance. Deficits in dynamic balance would guide clinicians to introduce stretching, strengthening, proprioceptive training, and/or other treatments with the purpose of avoiding injury and enhancing competitive scoring (i.e., less motion on landing results in a higher judge's score). The WBLT and SEBT have been linked to showing deficits following an ankle or lower extremity injury, especially in those with chronic ankle instability (CAI) (Olmsted et al., 2002).

Gymnastics requires flexibility, strength, and stability. The WBLT assesses AROM which could contribute to mobility, the SEBT examines dynamic balance control

and components of the BESS test look into static balance ability, all of which play a role in sports specific skills completed by gymnasts. Although these tests have been used post-injury, there has been no research utilizing the WBLT, objective static balance measures, and SEBT as screening tools, particularly with gymnasts. The results of the current study may indicate the potential need for ankle mobility program to increase ROM at the joint.

Statement of the Problem

The artistic gymnast population in Division III athletics is underrepresented in the literature. In general, the skills and routines they complete demand excellent balance and flexibility to achieve peak performance. If balance deficits are related to ankle AROM deficits, the need for a targeted training and rehabilitation program could reverse some of the deficits present and return measures to within normal limits.

Purpose

The purpose of this study is to utilize three effective clinical tools, the WBLT and the SEBT, and components of the BESS test measured using a force plate to see if ankle dorsiflexion AROM is associated with dynamic balance ability and/or static balance ability.

Hypotheses

H_0: There will be no correlation between ankle dorsiflexion AROM and the anterior, posterolateral, and/or posteromedial direction of the SEBT in division III collegiate gymnasts.

H_0: There will be no correlation between ankle dorsiflexion AROM and anterior-posterior and/or medial-lateral sway distance during static balance in division III collegiate gymnasts.

H_1: There will be a correlation between ankle dorsiflexion AROM and the anterior, posterolateral, and/or posteromedial direction of the SEBT in division III collegiate gymnasts.

H_2 There will be a correlation between ankle dorsiflexion AROM and the anterior-posterior and/or medial-lateral sway distance during static balance in division III collegiate gymnasts.

Delimitations

The delimitations of this study include:

1. NCAA Division III gymnasts at SUNY Cortland were selected for this study.
2. Only females were allowed to participate in this study.
3. Participants had sustained a lower extremity injury in the past 6 months.
4. Participants had sustained a concussion in the past month.

Limitations

The limitations of this study include:

1. There was no control group.
2. History of previous injury, prior to the past 6 months, was not controlled in the study but could impact dynamic balance abilities.
3. Reduced ROM could be an anatomical issue, which would present challenges because these predisposing factors cannot be altered through therapeutic means.

Assumptions

The following assumptions were made about this study:

1. Participants reached as far as they could during the trials of the SEBT.
2. Participants were honest about their previous injury history relevant to the lower extremity.

Definition of Terms

Weight Bearing Lunge Test (WBLT)	This test assesses ankle dorsiflexion active ROM. This is done by having the individual lunge into a wall until the knee makes contact, but the heel must stay on the ground. The length from the wall to the big toe is measured in centimeters.
Star Excursion Balance Test (SEBT)	This test assesses dynamic balance. Four tape lines are placed on the floor, two forming an 'x' and the other two form a '+'. The subject stands at the intersection point on one leg and reaches in the eight directions with the other leg.
Active Range of Motion (AROM)	The available angular movement of a joint created entirely by the individual performing the motion. There is no external aid on the movement.
Chronic Ankle Instability (CAI)	A condition characterized by a recurring "giving way" of the lateral side of the ankle. It usually develops as a result of repeated lateral ankle sprains.

Significance of the Study

The WBLT and SEBT have been used to detect deficits post-injury, but there is limited research utilizing both these clinical tests as a screening tool to detect deficits in AROM or balance. The addition of the force plate can provide valuable objective information about a gymnast's static balance ability.

CHAPTER 2

Literature Review

The artistic gymnastic population in collegiate gymnastics is underrepresented in studies regarding ankle joint mobility, yet there have been numerous studies on rhythmic gymnasts looking at various aspects of the sport including balance and kinematics, but the data may not be transferrable. As previously mentioned, artistic gymnastics involves competing in four routines on various apparatuses, floor, bars, vault, and balance beam. In contrast rhythmic gymnastics is performed on a floor involving a prop, such as a hoop, ball, ribbon or rope. Rhythmic gymnastics involves elements of gymnastics, dance, and calisthenics. Since rhythmic gymnastics is done solely on the floor, there could be great variation between active ankle dorsiflexion and balance ability between rhythmic and artistic gymnasts.

Ankle dorsiflexion range of motion

Ankle mobility is an important component of landing mechanics, thus assessing dorsiflexion AROM is crucial to determine a potentially increased risk of injury during landing due to a dorsiflexion restriction. Francia et al. (2020) assessed active ankle joint mobility in young female artistic gymnasts in comparison to soccer, volleyball, basketball athletes and ballet dancers. The young gymnasts had increased dorsiflexion range of motion compared to all other athletes except the ballet dancers (Francia et al., 2020). Additionally, the overall ankle joint mobility of gymnasts in this study was in line with normal values, 10-30 degrees, determined in previous literature. Although decreased

mobility at the ankle joint can result in increased risk of injury greater flexibility that gymnasts may demonstrate does not always equate to greater mobility (Berisha & Oktay, 2021). Flexibility can be defined as "the ability of a muscle or muscle groups to lengthen passively through a range of motion" (Mobility vs Flexibility, 2022), while mobility is defined as "the ability of a joint to move actively through a range of motion" (Mobility vs Flexibility, 2022).

One study examined asymmetries of the lower extremity of rhythmic gymnasts comparing their preferred limb to the nonpreferred (Frutuoso et al., 2016). The participants' mean age was 17.9 years. Researchers found that all AROM at the hip, knee, ankle showed no significant differences between the two limbs except for in dorsiflexion, where the preferred limb (25.9 degrees) had greater ROM than the non-preferred (21.7 degrees). Although there was a noticeable difference between the two limbs for dorsiflexion AROM, both limbs were within what is considered the normal range for dorsiflexion of 10-30 degrees (Frutuoso et al., 2016). This study did not examine artistic gymnasts. It is unknown if this data could be generalizable to other gymnastics populations. The researchers found that the preferred limb had greater dorsiflexion AROM compared to the nonpreferred limb, despite other lower extremity joints showing no significant differences.

Berisha & Oktay (2021) examined various gymnastics techniques that required mobility and flexibility. These are two motor skills necessary for the sport of gymnastics, because they impact other motor skills such as coordination, strength, and speed (Berisha & Oktay, 2021). This study did not examine flexibility and mobility specifically at the ankle, but from the results at the other joints, the statements regarding flexibility and

mobility may apply to the ankle joint as well. It was noted that mobility and flexibility fall fourth and fifth in terms of motor skill importance behind coordination, strength, and speed. One limitation of this study was participant age, which ranged from 7 to 9 years (Berisha & Oktay, 2021). The results of the present study may be different with an older population in terms of flexibility and mobility.

Ankle dorsiflexion ROM can be assessed among gymnasts while comparing the limbs within participants or it can be assessed between groups, specifically gymnasts and non-gymnasts. Another study assessed active dorsiflexion ROM between groups, which is different from the previous study that looked at the two limbs of each gymnast (Kesilmis et al., 2017). These authors found that compared to non-gymnast counterparts, dorsiflexion AROM is greater in gymnasts. This study measured dorsiflexion AROM utilizing a goniometer. Although goniometry is a standard method used to measure AROM, measuring ankle dorsiflexion in a weight-bearing position provides a more functional measurement. This position can be transferred to landing in gymnastics, when gymnasts go into end-range dorsiflexion upon landing after a skill.

Static Balance

There are various ways to clinically test an individual's static balance ability. The BESS test is a common way to assess static balance. The BESS is scored by a clinician who counts the number of errors an individual makes during various stances on either a firm or uneven surface, with eyes closed. The BESS test has been used as a baseline concussion assessment as well as a tool to target an individual's balance progression following an ankle injury. Bressel et al. (2007) investigated dynamic and static balance in gymnasts, basketball, and soccer players. Their results showed gymnasts overall had the

least number of errors during the BESS test. They also found no significant difference in static ability on the dominant versus non-dominant limb in gymnasts. The results of this study are not surprising when considering the demands of each sport. Although the BESS test provides objective balance information, how it is scored limits the value of the results because interrater reliability may be low (Finnoff et al., 2009). Due to this limitation of the BESS test, utilizing a different method to obtain data on static balance may provide more valuable information.

Static balance can also be measured using a force plate that measures center of pressure. These types of devices provide objective data and stores a record of the individual's center of pressure through the duration of each trial from which numerous dependent variables may be derived. Istenič et al. (2015) compared artistic gymnasts and rhythmic gymnasts as well as junior and senior gymnasts compared to younger gymnasts on their single leg stance on a force plate. The parameters analyzed included sway path and sway average amplitude fatigue index. Sway path was broken into anterior-posterior and medial-lateral, along with total sway path. The other parameter measured, sway average amplitude fatigue index is defined as the average amplitude of the center of pressure (COP) sway in the selected direction during the final time interval divided by the average amplitude of the COP sway in the first time interval, each lasting 30 seconds (Istenič et al., 2015). No significant differences were found between types of gymnasts, but there were significant differences between age groups, this could be due to development of an individual's motor, musculoskeletal, and nervous systems as they age (Istenič et al., 2015).

Another aspect of balance that can be analyzed is vision. Vision is an integral part of balance. When this sense is removed an individual's perception of where they are in space can be altered. Vuillerme et al. (2001) found the removal of vision does not affect artistic gymnasts' balance during a unipedal task. This study suggests that more experienced, older gymnasts will have increased static balance ability compared to young athletes (Vuillerme et al., 2001). These studies suggest that single limb balance with eyes closed would not be significantly different from single balance with eyes opened in collegiate gymnasts.

Dynamic Balance

Dynamic balance "is the ability to maintain postural stability and orientation with center of mass over the base of support while the body parts are in motion" (O'Sullivan & Portnry, 2014). This type of balance can be investigated in a variety of ways. The SEBT is a reliable low-cost method to assess dynamic balance (Olmsted et al., 2002). The SEBT is considered a battery of lower extremity tests that assesses maximal reach of one limb while the contralateral lower extremity maintains balance (Hoch et al., 2010). This test gives a functional measure of dynamic balance. Previous research on the SEBT has shown that having subjects complete all 8 yields redundancy. A factor analysis study found that an individual's reaching distance in one direction was highly correlated with reach distance in the other 7 directions (Hertel et al., 2006). Hertel et al. (2006) also reported other notable findings, including that the posteromedial (PM) best represented overall performance and the anteromedial (AM), medial (MD), and PM directions identified significant reach deficits in individuals with CAI. CAI is a condition that

individuals with multiple lateral ankle sprains may have and the chief complaint is often recurrent “giving way” of the ankle.

Previous research has utilized the SEBT with individuals with unilateral CAI and found this test can effectively highlight any dynamic motor control deficits. Multiple studies have utilized a pretest and posttest measurement for individuals with CAI who went through a balance program to analyze the effects of such program (Anguish & Sandrey, 2018; McKeon et al., 2008; Olmsted et al., 2002). Although this clinical test has been used for assessing deficits post-ankle injury, this balance test can be used as a screening tool in sport at the beginning of the season. While research exists on the efficacy of the test for CAI, no literature was found using the SEBT as a screening tool for artistic gymnasts, a population that requires high dynamic balance motor control abilities.

Dynamic balance measures can be used following an injury to track improvement, but they can also be used as a screening tool. The comparison of dynamic balance between athletes who participate in different sports allows medical professionals, as well as coaches and athletes to understand the role their sport specific training may have on dynamic balance abilities. Bressel et al. (2007) investigated dynamic balance of collegiate gymnasts compared to that of collegiate soccer and basketball athletes. The SEBT was used to assess dynamic balance with three trials in each of the 8 directions. They reported no differences in SEBT outcomes between limbs or across multiple sports, including soccer and gymnastics. Bressel et al. (2007) recognize that sport training increasing balance is not a new concept, but this study shows that different sports present different sensorimotor challenges which are important for optimizing balance ability.

Although gymnasts did not score the highest of the three populations investigated, the results do show that sport specific training does improve dynamic balance in gymnasts and other athletes.

Dynamic balance testing can be used to examine how different sports may affect balance abilities, but it can also be used as a measurement to assess if a program is improving dynamic balance. The SEBT has been analyzed in terms of efficacy particularly for those with CAI. Olmstead et al. (2002) concluded from their results that the SEBT effectively shows deficits in reach measurements in individuals with unilateral CAI, both between injured and uninjured limbs as well as the matched limb of the control group. McKeon et al. (2008) report that a progressive dynamic balance program can improve ankle function in regards to self-reported function, static postural control and dynamic postural control relative to the CAI group's pretest data as well as the control group. The improvements that resulted from each study's 4-week balance program were self-reported function measured through patient-reported outcomes, specifically the Foot and Ankle Ability Measure (FAAM) or the Foot and Ankle Disability Index (FADI) and objective measures (Anguish & Sandrey, 2018; McKeon et al., 2008). In the study carried out by Anguish & Sandrey (2018) which carried out a similar balance program to McKeon et al. (2008), there was improvement following both the single-limb balance and the progressive hop to stabilization balance program (PHSB). Specifically, an average increase of 5.2 points on FAAM-activities of daily living (ADL) and a mean increase of 6.1 on FAAM-Sports in the PHSB program. There was a moderate effect size of 0.7 for this group for the FAAM-Sports category. McKeon et al. (2008) saw significant improvements in the FADI measures reported by the patient. The measures of the FADI

and FADI-sport were significantly greater in the balance training group when pretest and posttest were compared. Patient-reported outcomes are a useful measure to better understand how the individual perceives their condition and function of a specific limb.

The balance programs utilized by Anguish & Sandrey (2018) and McKeon et al. (2008) incorporated objective measures to track any improvement made by participants. Anguish & Sandrey (2018) used the SEBT for pretest and posttest measurements. Following the PHSB program, reach distances increased in each of the three directions tested, with a large time effect size in the posterolateral direction and moderate to large effects sizes in the anterior and posteromedial directions. McKeon et al. (2008), also used the SEBT as a measurement. The SEBT was used to assess the impact of the balance training, but the intervention group did multiple exercises that required dynamic postural control. This study saw an increase in the PM and posterolateral (PL) directions of the SEBT. Anguish & Sandrey (2018) and McKeon et al. (2008) are beneficial intervention studies that utilize a dynamic balance program when a chronic ankle problem is identified. These studies provide evidence that an individual's dynamic balance ability plays an integral role in the function of the ankle joint.

Summary

Ankle mobility and dynamic balance are both important components of artistic gymnastics for each apparatus and tumbling. Utilizing both the WBLT and SEBT as a screening tool to see if there is a correlation between dorsiflexion AROM and dynamic balance is potentially beneficial to the gymnastic population. This relationship could allow a targeted intervention program to increase AROM, balance abilities, or both.

There is significantly less research done using the artistic gymnastics population compared to the rhythmic gymnastics population. For this literature review, 5 articles with rhythmic gymnasts participants were used and 5 articles with artistic gymnasts were used. Although the same number of articles from both types of gymnastics were used, during the search the number of articles about the rhythmic gymnastic population that came up far outweighed the artistic gymnastics articles, as well as the inability to find articles on collegiate artistic gymnasts. These two variations of gymnastics are quite different because artistic gymnasts compete on four different apparatuses, while rhythmic gymnasts only compete on floor. Although both sports utilize floor exercise, the routines are very different. Artistic gymnasts are more explosive resulting in greater magnitudes of force during landing. Thus, the demands of the two sports are extremely different and data from rhythmic gymnasts is not necessarily transferable to the artistic gymnastics population.

Previous research has not established a relationship between ankle AROM and dynamic balance, or ankle AROM and static balance. Although previous studies utilized different tools to measure AROM, the present study utilized the WBLT, that assesses ankle dorsiflexion AROM in a weight-bearing position, providing a measurement that can be used functionally in the sport. Dynamic balance is also an integral part of the variety of routines performed in artistic gymnastics. Despite ankle injury history not being controlled for in the present study outside of the last 6 months, utilizing an objective measure to see if reach deficits exist in the SEBT would be beneficial in the gymnastics population. If deficits are recognized, athletic trainers and other medical professionals could create an intervention program to increase dynamic balance abilities.

Determining if there are correlations between ankle dorsiflexion AROM, dynamic balance and static balance could guide sports medicine professionals to screen for deficits in these areas and develop specific training programs to address any deficits that were flagged.

CHAPTER 3

Methods

Participants

Participants from the SUNY Cortland Women's Gymnastic team were recruited by sending all rostered athletes an email to participate in the study. Inclusion criteria included being a DIII female gymnast and being at least 18 years of age. Thirteen gymnasts participated in the study.

Instruments

The FAAM sports subscale was completed by each participant to confirm how they perceive their dominant ankle joint's function prior to data collection. The FAAM was created to allow patients to self-report changes of their leg, ankle, or foot musculoskeletal injury and evaluate the changes over time (Martin et al., n.d.). The FAAM includes two separately scored subscales, the ADL scale is 21 items and the Sport scale is 8 items (Carcia et al., 2008). The score totals range from 0 to 84 for the ADL and 0 to 32 for the sports subscale, scoring on a 5-point Likert scale ranging 0-4; 0 is marked as unable to do and 4 having no difficulty completing the task. The higher the score the higher an individual feels their physical function is. This patient-reported outcome, including the ADL and sports subscale, is a valid measure that can be used for patients with various lower leg, ankle and foot musculoskeletal disorders (Martin et al., n.d.).

To measure active ankle dorsiflexion ROM, the WBLT was used. This test is a valid and reliable measure of dorsiflexion AROM (Chisholm et al., 2012). Each

measurement was recorded in centimeters of the distance the foot is from the wall during the lunge. Single limb balance was measured using a force plate (Bertec 6090, Columbus, Ohio) in the SUNY Cortland Biomechanics lab. The SEBT was used to measure dynamic balance abilities. Scores were recorded in centimeters of each reach distance that participants perform.

Demographics and Descriptives

Once informed consent was obtained, participants self- reported their height (63.62 ± 2.14 in) and weight (57.64 ± 5.9 kg) (Table 1). Gymnasts were asked how long they have been competing in artistic gymnastics competitively (12 ± 1.87 years) (Table 1). The events they currently train in college were noted as well. Each participant's age, height, weight, and gymnastics experience was recorded on the data collection sheet in Microsoft Excel (Appendix A).To ensure health of the athlete and verify each participant is not currently recovering from injury, the FAAM sports subscale was completed. This patient-reported outcome measure ensured each participant perceives their ankle joint to be healthy and injury-free. Separately, any self-reported lower extremity injury within the last 6 months disqualified them from the study.

Dominance and limb length was determined to guide data collection. Only the participant's dominant limb was measured for this study. Dominance for these athletes was determined by asking each participant which limb they prefer to do a single limb landing with during gymnastics skills. Limb length was later be used to normalize SEBT measurements (Gribble & Hertel, 2009). The researcher measured limb length using a tape measure in centimeters. The participant was instructed to lay supine. Each of the

participants' lower limb measurements were taken from the anterior superior iliac crest of the hip to the medial malleolus of the lower leg.

Design and Procedures

IRB approval was obtained from the SUNY Cortland IRB committee in January 2022. This study examined if there is a correlation between dorsiflexion AROM, dynamic balance, and static balance. Participants who met the inclusion criteria were contacted via email to schedule an appointment to complete the tests. Upon arrival to their session, informed consent was obtained using a written consent form (Appendix B). All testing was completed barefoot. First, each participant completed three trials of the WBLT utilizing their dominant ankle (Appendix C). A piece of tape was placed on the floor that begins at the wall and extends out for the participant to stand on. The lead researcher demonstrated the test prior to the participant completing it to ensure it was done properly. The individual was instructed to stand on the tape and touch their knee to the wall, as a lunge, but their heel must stay on the ground during the trial. The non-test leg was off to the side and did not need to follow the same guidelines with the heel staying on the ground. The participant continued to slide their test leg back until their knee only slightly touched the wall with their heel still on the ground. At this point the measurement from their big toe to the wall was recorded. This distance to the nearest 0.1 cm represented active dorsiflexion in a weight bearing position. After three trials on their dominant leg, the average was determined and recorded (Appendix A).

After the WBLT, each participant completed the static balance portion of testing. This included two separate trials of single limb balance on the force plate. Components of the BESS test were utilized for this portion. The participant performed both trials on their

dominant leg that was determined prior to the WBLT. The static balance was measured utilizing a force plate. The two separate trials of single limb balance include, once with their eyes open followed by a trial with their eyes closed. The subject was instructed to stand on the force plate, place their hands on their hips, lift their non-dominant leg to 90 degrees of knee flexion and not allow the non-dominant leg to touch the dominant limb. Each trial was 20 seconds long. The trial was repeated if the participant took their hand(s) off their hips, moved into more than 30 degrees of hip flexion, or put their other foot down. Each participant completed the eyes open trial first followed by a minute of rest and then the eyes closed trial. The force plate was set to sample at 100 Hz and the data were exported to Excel (Microsoft, Redmond, Washington) as a text file for calculation of dependent measures.

For the final procedure, participants completed the SEBT, which assessed dynamic balance abilities. The dominant limb was tested in three directions since previous researchers have found testing all eight directions gives redundant results (Hoch et al., 2010). The three directions each participant completed are the anterior (ANT), PM, and PL. Four pieces of tape were placed on the ground, two making an ‘x’ and two making a ‘+’, together making a star-like figure. Although only three directions were measured, the whole figure for the SEBT was set up to ensure the correct angles are created with the tape on the floor (Appendix C). This test was demonstrated by the lead researcher to ensure participants performed it correctly. The participant stood at the intersection point of these pieces of tape on their dominant leg. With the other leg, they reached as far as they could in each of the three directions, while staying balanced. Prior to the recorded trials, each participant was able to perform 6 practice trials to become

familiar with the test (Hertel et al., 2000). A line was drawn on the tape where the participant tapped their foot, and the distance was measured in centimeters to the nearest 0.1 cm. If during one trial, the participant lost balance or wobbled, the trial was redone. The lead researcher watched each participant and marked their distances on the tape. Each direction consisted of the three trials. If a participant came to rest at the touchdown point, heavily touched with the reach foot, made contact with reaching foot to maintain balance or shifted any part of the stance limb foot during a trial, that trial was considered incomplete (Gribble & Hertel, 2012). The average of the three trials for each direction was determined and recorded.

Data Processing

The average of each completed trial of the WBLT and SEBT were be used for statistical analysis. After the average of the SEBT measures was determined, the distances were normalized relative to the individual's leg length (reach distance/leg length x 100= percentage of leg length) (Bressel et al., 2007). The data utilized from the static balance on the force plate for statistical analysis was the sway path in the anterior-posterior (AP) and medial-lateral (ML) directions as well as the resultant total excursion (TOTEX) distance. Romberg ratios were calculated to compare the two conditions of static balance (Kalron, 2017; Prieto et al., 1996). The data input into Excel from the force plate was utilized to compute each of the above sway distance measures. The AP distance was calculated by inputing the following equation into the Excel spreadsheet, $TOTEX_{AP} = \sum_{n=1}^{N-1} |AP[n+1] - AP[n]|$. The equation for the ML distance was also entered into Excel using $TOTEX_{ML} = \sum_{n=1}^{N-1} |ML[n+1] - ML[n]|$. The third equation calculated in Excel utilizing the data collected from each trial of static balance was for

the resultant distance, $TOTEX = \sum_{n=1}^{N-1} [(AP[n+1] - AP[n])^2 + (ML[n+1] - ML[n])^2]$. Each of the three equations used to process the static balance data were taken from Prieto et al. (1996).

Statistical Analysis

Simple correlations were performed to determine if any direction of dynamic or static balance were associated with ankle dorsiflexion ROM. The probability for type I error was set at 0.05. The correlation coefficient strength was described as trivial (<.10), small (.10-.30), moderate (.30-.50), and large (>.50) (Cohen, 1992).

CHAPTER 4

Manuscript

Introduction

It has been reported that about 23% of young females partake in gymnastics activity or similar sport (Francia et al., 2020). The artistic gymnastic population in collegiate gymnastics is underrepresented in studies regarding ankle joint mobility, yet there have been numerous studies on rhythmic gymnasts looking at various aspects of the sport including balance and kinematics, but the data may not be transferrable. Artistic gymnastics is a form of gymnastics that involves routines on various apparatuses, including balance beam, floor exercise, uneven bars, and vault. In contrast, rhythmic gymnastics is performed on a floor involving a prop, such as a hoop, ball, ribbon, or rope. Rhythmic gymnastics involves elements of gymnastics, dance, and calisthenics. Since rhythmic gymnastics is done solely on the floor, there could be great variation between rhythmic gymnasts' measurements and artistic gymnasts' of active ankle dorsiflexion and balance ability. Artistic gymnastics is a demanding sport on both the upper and lower extremities. Many forms of landing occur in gymnastics, including landing after tumbling, jumping, or leaping, during dismounts from the bars and balance beam, and landing following vaulting off the vaulting platform.

Adequate active range of motion (AROM) is necessary to ensure proper landing mechanics for the lower extremity. In general, sport activity can negatively affect the integrity of the ankle joint, both anatomically and functionally (Francia et al., 2020). If there is decreased ROM at the ankle, the risk of injury increases as forces are not

dispersed properly during landing which could be due to restricting the ability for the legs to move forward over the feet (Mason-Mackay et al., 2015). An individual with reduced dorsiflexion ROM may compensate with subtalar and midfoot pronation or knee valgus which are also risk factors of injury (Mason-Mackay et al., 2015). Normal ankle dorsiflexion AROM is 10-30 degrees (Shultz et al., 2016), and Frutuoso et al. (2016) found that international level gymnasts fall within that range, with participants ranging from 13-29 degrees. AROM can be assessed in a few ways. Most commonly, goniometry is used to objectively measure ROM at any joint, but when testing dorsiflexion AROM at the ankle the Weight-Bearing Lunge Test (WBLT) can be used. This test provides a more functional measure since it is performed in a weight-bearing position. WBLT is a reliable and valid test for dorsiflexion AROM (Chisholm et al., 2012). The WBLT is done in close-packed position, with maximum joint stability due to the congruency of articular surfaces, and allows osteo- and arthrokinematics to be evaluated, allowing for stability and ROM to be assessed (Chisholm et al., 2012). This test may be particularly important for evaluating ankle function in gymnasts considering the frequent dorsiflexion motion while the joint is loaded, they experience in the sport. Ankle mobility is an important component of landing mechanics, thus assessing dorsiflexion ROM is crucial to determine a potentially increased risk of injury during landing due to a dorsiflexion restriction. Due to the nature of the sport and the importance of landing mechanics, normal dorsiflexion is imperative for gymnasts to decrease risk of injury associated with landing.

Static balance is the ability to keep the body upright in a standing position without falling. Although this can be observed on the ground or uneven surface; to objectively

measure static balance a force plate can be used to track an individual's center of pressure during single limb balance. A common clinical test to measure static balance is the balance error scoring system (BESS) test. This test measures the number of errors during various challenging conditions. The BESS test is cost effective and not time consuming but the total score of the BESS test is not reliable due to discrepancies in the inter-rater and intra-rater reliability (Finnoff et al., 2009). The ability to combine the components of the BESS test, such as single limb balance with eyes open and closed, with the objective data from a force plate may provide more concrete measures regarding static balance. Both dynamic and static balance are required for several skills and techniques on each apparatus of artistic gymnastics. The most apparent need for static balance in gymnastics would be on the balance beam, but there are other skills on the other apparatuses that require static balance or possibly toggle from dynamic to static balance during landings or leaps. Measuring this population's stability ability may provide valuable information that can be translated to their routines.

Bressel et al. (2007) investigated dynamic and static balance in gymnasts, basketball, and soccer players. Their results showed gymnasts overall had the least number of errors during the BESS test. They also found no significant difference in static ability on the dominant versus non-dominant limb in gymnasts. Due to the limitations of the BESS test, utilizing a different method to obtain data on static balance may provide more valuable information. Static balance can also be measured using a force plate that measures center of pressure. These types of devices provide objective data and stores a record of the individual's center of pressure through the duration of each trial from which numerous dependent variables may be derived. Istenič et al. (2015) compared artistic

gymnasts and rhythmic gymnasts as well as junior and senior gymnasts compared to younger gymnasts on their single leg stance on a force plate. The parameters analyzed included sway path and sway average amplitude fatigue index. No significant differences were found between types of gymnasts, but there were significant differences between age groups, this could be due to development of an individual's motor, musculoskeletal, and nervous systems as they age (Istenič et al., 2015).

Dynamic balance "is the ability to maintain postural stability and orientation with center of mass over the base of support while the body parts are in motion" (O'Sullivan & Portnry, 2014). Dynamic balance control is important in artistic gymnastics with the amount of tumbling and leaps that gymnasts do on each apparatus. Motion must be arrested before transitioning to the next skill or for remaining stationary at the conclusion of the event. This type of balance can be investigated in a variety of ways. A common test for dynamic stability is the Star Excursion Balance Test (SEBT), which is an effective test to assess dynamic balance (Olmsted et al., 2002). Dynamic balance in gymnastics plays a role in each apparatus that is competed in this sport. The SEBT is a reliable low-cost method to assess dynamic balance (Olmsted et al., 2002). The SEBT is considered a battery of lower extremity tests that assesses maximal reach of one limb while the contralateral lower extremity maintains balance (Hoch et al., 2010). Assessing this population's dynamic balance abilities could help with various routines by identifying those at risk for injury. Deficits in dynamic balance would guide clinicians to introduce stretching, strengthening, proprioceptive training, and/or other treatments with the purpose of avoiding injury and enhancing competitive scoring (i.e., less motion on landing results in a higher judge's score). The WBLT and SEBT have been linked to

showing deficits following an ankle or lower extremity injury, especially in those with chronic ankle instability (CAI) (Olmsted et al., 2002).

Previous research has utilized the SEBT with individuals with unilateral CAI and found this test can effectively highlight any dynamic motor control deficits. Multiple studies have utilized a pretest and posttest measurement for individuals with CAI who went through a balance program to analyze the effects of such program (Anguish & Sandrey, 2018; McKeon et al., 2008; Olmsted et al., 2002). Although this clinical test has been used for assessing deficits post-ankle injury, this balance test can be used as a screening tool in sport at the beginning of the season. While research exists on the efficacy of the test for CAI, no literature was found using the SEBT as a screening tool for artistic gymnasts, a population that requires high dynamic balance motor control abilities.

Dynamic balance measures can be used following an injury to track improvement, but they can also be used as a screening tool. Bressel et al. (2007) investigated dynamic balance of collegiate gymnasts compared to that of collegiate soccer and basketball athletes. The SEBT was used to assess dynamic balance with three trials in each of the 8 directions. They reported no differences in SEBT outcomes between limbs or across multiple sports, including soccer and gymnastics. Bressel et al. (2007) recognizes that sport training increasing balance is not a new concept, but this study shows that different sports present different sensorimotor challenges which are important for optimizing balance ability. Although gymnasts did not score the highest of the three populations investigated, the results do show that sport specific training does improve dynamic balance in gymnasts and other athletes.

Gymnastics requires flexibility, strength, and stability. The WBLT assesses ROM which could contribute to flexibility, the SEBT examines dynamic balance control and components of the BESS test look into static balance ability, all of which play a role in sports specific skills completed by gymnasts.

Methods

Participants

Participants from the SUNY Cortland Women's Gymnastic team were recruited by sending all rostered athletes an email to participate in the study. Inclusion criteria included being a DIII female gymnast and being at least 18 years of age. Thirteen gymnasts participated in the study.

Participants self- reported their height (63.62 $\pm$ 2.14 in) and weight (57.64 $\pm$ 5.9 kg) (Table 1). Gymnasts were asked how long they have been competing in artistic gymnastics competitively (12 $\pm$ 1.87 years) (Table 1). The events they currently train in college were noted as well. To ensure health of the athlete and verify each participant is not currently recovering from injury, the Foot and Ankle Ability Measure (FAAM) sports subscale was completed. This patient-reported outcome measure ensured each participant perceives their ankle joint to be healthy and injury-free. Separately, any self-reported lower extremity injury within the last 6 months disqualified them from the study.

Dominance and limb length was determined to guide data collection. Only the participant's dominant limb was measured for this study. Dominance for these athletes was determined by asking each participant which limb they prefer to do a single limb landing with during gymnastics skills. Limb length was later be used to normalize SEBT measurements (Gribble & Hertel, 2009). The researcher measured limb length using a

tape measure in centimeters. The participant was instructed to lay supine. Each of the participants' lower limb measurements were taken from the anterior superior iliac crest of the hip to the medial malleolus of the lower leg.

Instruments

The FAAM sports subscale was completed by each participant to confirm how they perceive their dominant ankle joint's function prior to data collection. The FAAM was created to allow patients to self-report changes of their leg, ankle, or foot musculoskeletal injury and evaluate the changes over time (Martin et al., n.d.). The FAAM includes two separately scored subscales, the ADL scale is 21 items and the Sport scale is 8 items (Carcia et al., 2008). The score totals range from 0 to 84 for the ADL and 0 to 32 for the sports subscale, scoring on a 5-point Likert scale ranging 0-4; 0 is marked as unable to do and 4 having no difficulty completing the task. The higher the score the higher an individual feels their physical function is. This patient-reported outcome, including the ADL and sports subscale, is a valid measure that can be used for patients with various lower leg, ankle and foot musculoskeletal disorders (Martin et al., n.d.).

To measure active ankle dorsiflexion ROM, the WBLT was used. This test is a valid and reliable measure of dorsiflexion AROM (Chisholm et al., 2012). Each measurement was recorded in centimeters of the distance the foot is from the wall during the lunge. Single limb balance was measured using a force plate (Bertec 6090, Columbus, Ohio) in the SUNY Cortland Biomechanics lab. The SEBT was used to measure dynamic balance abilities.

Design and Procedures

This study explored possible correlations among dorsiflexion AROM, dynamic balance, and static balance. Upon arrival to their session, informed consent was obtained using a written consent form. All testing was completed barefoot. First, each participant completed three trials of the WBLT utilizing their dominant ankle. The individual was instructed to stand on the tape and touch their knee to the wall, as a lunge, but their heel must stay on the ground during the trial. The non-test leg was off to the side and did not need to follow the same guidelines with the heel staying on the ground. The participant continued to slide their test leg back until their knee only slightly touched the wall with their heel still on the ground. At this point the measurement from their big toe to the wall was recorded. This distance to the nearest 0.1 cm represents active dorsiflexion in a weight bearing position. After three trials on their dominant leg, the average was determined and recorded.

After the WBLT, the static balance portion was completed. This included two components of the BESS test, single limb balance with eyes open and single limb balance with eyes closed. The static balance was measured utilizing a force plate. The subject was instructed to stand on the force plate, place their hands on their hips, lift their non-dominant leg to 90 degrees and not allow the non-dominant leg to touch the dominant limb. Each trial was 20 seconds long. Successful trials met the following criteria: hands stayed on the hips, there was no more than 30 degrees of hip flexion, and the non-test limb did not touch the ground. Each participant completed the eyes open trial first followed by a minute of rest and then the eyes closed trial. The force plate was set to 100 Hz and the data utilized from this trial were the total distance of the center of pressure

(COP) as well as the anterior-posterior (AP) and medial-lateral (ML) path length distances.

For the final procedure, participants completed the SEBT, which assessed dynamic balance abilities. The dominant limb was tested in three directions, the anterior (ANT), posteromedial (PM), and posterolateral (PL). Four pieces of tape were placed on the ground, two making an 'x' and two making a '+', together making a star-like figure. The participant stood at the intersection point of these pieces of tape on their dominant leg. With the other leg, they reached as far as they could in each of the three directions, while staying balanced. Prior to the recorded trials, each participant was able to perform 6 practice trials to become familiar with the test (Hertel et al., 2000). A line was drawn on the tape where the participant taps their foot, and the distance was measured to the nearest 0.1 cm. If during one trial, the participant lostbalance or wobbled, the trial was redone. The lead researcher watched each participant and marked their distances on the tape. Each direction consisted of the three trials. If a participant came to rest at the touchdown point, heavily touched with the reach foot, made contact with reaching foot to maintain balance or shifted any part of the stance limb foot during a trial, that trial was considered incomplete (Gribble & Hertel, 2012). The average of the three trials for each direction was determined and recorded.

Statistical Analysis

Pairwise simple correlations were performed using JASP software (University of Amsterdam, version 0.14.1.0). Pearson's r, *p*, and effect size (r^2) are reported. Correlation magnitudes were interpreted as trivial (<.10), small (.10-.30), moderate (.30-.50), and large (>.50) (Cohen, 1992). Type I error rate was set at .05.

Results

The simple correlations among all pairs of variables measured are listed in Table 3. The WBLT was not significantly correlated to any other measure in this study, but had a moderate correlation to the PM direction of the SEBT (r= .460; p= .114). Thus, this correlation's effect size (r^2) is .2116 which indicates that 21.16% of the variation in the PM direction of the SEBT can be explained by the amount of ankle dorsiflexion a gymnast has in the WBLT. Significant correlations exist between parts of the overall measure. For example, a significant correlation was found between the TOTEX Romberg ratio and AP Romberg ratio (r=.932; p= <.001). The other strong correlations were between the ANT and PM directions (r=.832; p= <.001), as well as between the ANT and PL (r=.797; p= .001) directions of the SEBT.

Table 1. Participant demographics.

Parameter	Age (years)	Gymnastics Experience (years)	Height (in)	Weight (kg)	Leg Length (cm)
Mean	19.231	12.000	63.615	57.636	85.385
Standard Deviation	0.927	1.871	2.142	5.904	3.751
Minimum	18.000	9.000	60.000	43.500	77.700
Maximum	21.000	16.000	68.000	68.040	92.700

Table 2. Descriptive Statistics of Dependent Variables.

	WBLT	ANT (%)	PM (%)	PL (%)	Romberg TOTEX	Romberg ML	Romberg AP
Valid	13	13	13	13	13	13	13
Missing	0	0	0	0	0	0	0
Mean	8.603	68.354	111.632	106.531	1.985	2.011	1.962
Standard Deviation	2.801	8.435	18.709	17.191	0.356	0.339	0.478

Table 3. Pearson's Correlations.

Variable		WBLT	ANT (%)	PM (%)	PL (%)	Romberg TOTEX	Romberg ML	Romberg AP
WBLT	Pearson's *r*	-						
	p-value	-						
ANT (%)	Pearson's *r*	0.292	-					
	p-value	0.333	-					
PM (%)	Pearson's *r*	0.460	0.832***	-				
	p-value	0.114	<.001	-				
PL (%)	Pearson's *r*	0.325	0.797***	0.666*	-			
	p-value	0.279	0.001	0.013	-			
Romberg TOTEX	Pearson's *r*	0.105	-0.085	-0.103	-0.113	-		
	p-value	0.732	0.783	0.737	0.737	-		
Romberg ML	Pearson's *r*	-0.172	-0.174	-0.142	-0.142	0.651*	-	
	p-value	0.574	0.569	0.644	0.644	0.016	-	
Romberg AP	Pearson's *r*	0.209	-0.024	-0.051	-0.51	0.932***	0.343	-
	p-value	0.494	0.937	0.867	0.867	<.001	0.251	-

* $p < .05$, ** $p < .01$, *** $p < .0001$

Discussion

The purpose of this study was to utilize three effective clinical tools, the WBLT, a force plate for static balance, and the SEBT to see if ankle dorsiflexion AROM correlates with any aspect of static or dynamic balance. No significant results were found in regard to the hypotheses presented for this study. Due to the findings of this study, rejecting the null hypotheses is not possible. The only significant correlations found were within measures, such as significant correlations existing between two SEBT directions as well as between two measures from the static balance (Table 3). Although this study lacked significant results, one finding to consider is between the WBLT and the PM direction of the SEBT. The correlation between these two measures was moderate and had an effect size of .2116. The practical application of this finding is that clinically the WBLT is responsible for 21.16% of the variation in the PM direction of the SEBT. With this information, clinicians could create a rehabilitation or treatment protocol to address AROM or dynamic balance deficits if they exist.

No studies were found that used the same measures in gymnastics populations. In comparison to previous literature utilizing the SEBT, the mean reach distances for this population were greater in the PM and PL directions and lower in the ANT direction (Table 2) (Anguish & Sandrey, 2018; Gribble & Hertel, 2012; Hertel et al., 2006; McKeon et al., 2008; Olmsted et al., 2002). Studies that focused on the SEBT, mostly surround chronic ankle instability, which was not identified in this study. It is also difficult to compare the results of the present study to previous research because the present study did not examine non-gymnasts or other athletes. Despite the lack of similar studies, there are notable results from previous studies that relate to the present study.

Anguish and Sandrey (2018) and McKeon et al. (2008) utilized participants with CAI, which as previously stated was not examined in the present study. Both of these studies found significant increases in the PM direction following a balance program. Hertel et al. (2006) factor analysis study showed that the PM direction is most representative of overall performance. This direction had a moderate correlation with the WBLT, thus making it more important if deficits are seen in either area to address them. These studies that were previously done highlight the clinical significance and importance of the PM direction in the SEBT.

The FAAM sports subscale was used prior to testing to ensure the participant perceived their ankle to be healthy. All participants stated they felt their dominant ankle joint was at least 90% when asked to rate their level of function during sport. The only discrepancy in other items on this scale came from one participant who stated “slight difficulty” in landing, jumping, and being able to participate in sports as long as she would like. When comparing this subjective measure to the objective measures this individual had lower scores on the WBLT and the ANT and PL directions of the SEBT compared to the average of the participants, but higher than the mean for the PM direction. The stated difficulty and lower scores could potentially be due to a CAI issue that was not controlled for in this study.

Although there are other sports that require jumping and landing, due to the aesthetic nature of this sport, landing mechanics and proper range of motion might be more important for these athletes in comparison to others. In collegiate gymnastics, a gymnast can have deductions taken from their score due to an uncontrolled landing, whether it be in a dismount, tumbling, or following a jump (NCAA.org, 2021). Not only

can a gymnast receive a lower score due to an improper landing, but the risk of injury increases astronomically if a landing is done incorrectly due to the amount of force that goes through the ankles during gymnastics landings (Bruggeman, 1994). The nature of this sport calls for numerous landing repitions each day, which can add up significantly in just a month, which could make this population more unique than other sports that involve jumping and landing. The importance of landing mechanics for these athletes warrants further research, because the ankle joint and dynamic control both play a large role.

The strengths of this study include having a standard protocol that each participant will follow for completing both measures. Another strength of this study is it utilizes a clinical tool rather than a goniometer to measure ankle dorsiflexion ROM, which is more functional since it is in the weight bearing position. This data is also more applicable to gymnasts since dorsiflexion is necessary for proper landing mechanics. Finally, a third strength to this study is that the results of this study could open up further investigation into the artistic gymnastic population.

Despite this study adding relevant knowledge to the field and having strengths, limitations still exist. The most notable limation is the small sample size. The limited number of participants may be the reason for the lack of significant correlations. Another limitation is that a control group is not used in this study. A third limitation for this study is that while participants can not currently be recovering from an injury, injury history is not being controlled for, which could impact dynamic balance abilities, especially any previous ankle injury. Although the dominant limb will be noted in the study, it has seemed that gymnasts do not necessarily have a dominant leg and some participants may

be unsure when answering this question. In regards to the present study, 3 or 4 participants were unsure which leg to choose and upon completion of the testing felt they would have done better using their other lower leg, especially for the balance. In future studies, these limitations could be controlled to refine the relationship between ankle dorsiflexion ROM and dynamic balance.

Conclusion

This study adds information for a population that is underrepresented in literature. The measures used are beneficial screening tools for such a demanding sport as gymnastics. While the SEBT has been shown to be beneficial for those with CAI, although a significant relationship did not exist between the WBLT and the SEBT, this knowledge can lead to creating intervention programs that could target either ROM or dynamic balance deficits or both. Replicating this study with a larger experimental group and the addition of a control group could yield clinically applicable information and provide insight on deficits and necessary steps to improve areas thus improving performance.

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Appendix A – Data Collection Sheet

Raw Data Collection

Participant ID	Age	Height (in)	Weight (kg)	Leg length (in)	WBLT 1	WBLT 2	WBLT 3	ANT 1	ANT 2	ANT 3	PL 1	PL 2	PL 3	PM 1	PM 2	PM 3
101																
102																
103																

Data Used for Statistic Analyses

Participant ID	Age	Height (in)	Weight (kg)	Leg length (cm)	WBLT	ANT (%)	PL (%)	PM (%)	TOTEX (Romberg)	TOTEX ML (Romberg)	TOTEX AP (Romberg)
101											
102											
103											

Appendix B – Informed Consent

CONSENT TO PARTICIPATE AS A SUBJECT IN A RESEARCH STUDY

You are invited to participate in a research project about ankle active range of motion (AROM), static and dynamic balance. This research is being conducted by Emily Sabo, ATC. Your informed consent is requested if you wish to participate as a research subject in this project. Before you consent to participate, please read the following regarding the details of the study so that you fully understand what your involvement will be and what risks and benefits you may experience as a participant in this research. If you have questions about anything related to the study or your involvement in the study, please ask.

Purpose and brief description of the study. The purpose of this study is to investigate if active ankle dorsiflexion range of motion predicts any component dynamic balance and if ankle AROM predicts either component of static balance being measured in artistic gymnasts.

Your involvement as a participant. Each participant will complete three different tests on their dominant limb. Three trials of the Weight Bearing Lunge Test (WBLT) will be completed for ankle dorsiflexion measurements. Static balance will be measured using a force plate. Participants will complete two 20 second trials, both single limb, one eyes open and one eyes closed. The sway distance in the anterior-posterior and medial-lateral distance will be recorded. Finally, participants will complete 3 trials in 3 different directions of the Star Excursion Balance Test to assess dynamic balance.

Before agreeing to participate you should understand the following:

- **Your participation is completely voluntary**. You are free to withdraw from this study at any time without penalty. To withdraw from this study contact Emily Sabo and ask that your signed informed cosent form be removed from the envelope of participants. Additionally, you may ask the researcher to destroy any data collected from you as part of the study.
- **Confidentiality**. All data collected will be maintained by the researcher and each participant will be assigned a code number. The participant code and data will be maintained on a password protected personal device. The data will be kept for at least three years after the completion of the study.
- **Duration of participation**. The total amount of time needed for participation is 20-30 minutes for data collection.
- **Risks.** The potential risk of falling during single limb balance with eyes closed will be minimized by instructing participants prior to the trial that if they feel like they are beginning to lose balance to open their eyes and regain balance.
- **Benefits.** One possible benefit gained from this study is if there is a deficit present in range of motion or balance, the participant may decide this is something they would like to improve on. The major benefit of this study is for future clinicians to utilize these clinical tools to determine if deficits exist and provide intervention accordingly, to potentially decrease risk of injury.
- **Contact Information**. If you have any questions concerning the purpose or results of this study, you may contact Emily Sabo, ATC by phone (585)729-3265 or by email Emily.sabo@cortland.edu. For questions or concerns about your rights as a research participant, contact the SUNY Cortland Institutional Review Board by email at irb@cortland.edu, or by phone 607-753-2511.

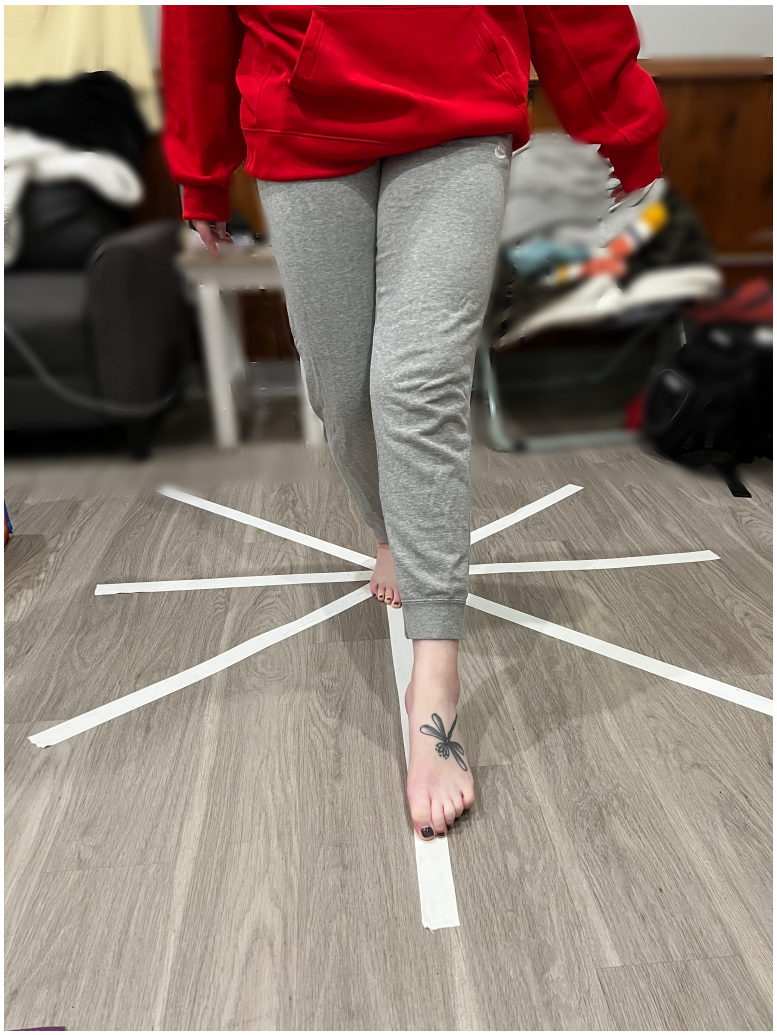
I _____ have read the description of the project for which this consent is requested, I understand my rights, and I hereby consent to participate in this study.

_____ _____

Signature Date

Appendix C – Experimental Setup

Weight Bearing Lunge Test



Star Excursion Balance Test

Appendix D – Sample Data

Participant ID	Age	Height (in)	Weight (kg)	Leg length (in)	WBLT 1	WBLT 2	WBLT 3	ANT 1	ANT 2	ANT 3	PL 1	PL 2	PL 3	PM 1	PM 2	PM 3
101	19	64	56.7	34.5	6.9	7	7.4	61.3	63.1	66.4	91.4	92.5	97.8	85.5	86.9	92.6
102	19	64	58.97	34	4.4	6	6.7	56.5	57.8	58.5	84.5	85.9	91.5	83.8	89.8	91.4
103	20	66	58.1	35	12.8	13.8	14.2	63.5	64.1	68.5	128.1	126	124.4	109	122.5	129.5

Participant ID	Age	Gymnastics Experience	Height (in)	Weight (kg)	Leg length (cm)	WBLT	ANT (%)	PL (%)	PM (%)	TOTEX (Romberg)	TOTEX ML (Romberg)	TOTEX AP (Romberg)
101	19	11	64	56.7	87.6	7.1	72.6	107.2	100.8	2.452	1.786	2.909
102	19	9	64	58.97	86.4	5.7	66.7	101	102.2	2.711	2.828	2.601
103	20	13	66	58.1	88.9	13.6	64.8	98.2	99.4	1.896	1.756	1.970