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Postural Stability and Flexibility in Young Adults

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Abstract: The components of postural stability and flexibility are considered essential to overall physical fitness and well-being. Previous researchers have evaluated the relationship between these factors in the elderly; however studies addressing the younger population in relation to implications of gender difference have been largely inconclusive. The purpose of this study was to assess the strength of the correlation between stability and flexibility in young adults as well as to evaluate ways in which the anthropometrical differences between men and women dictate flexibility performance. The present quantitative clinical study tested 20 young adults between 20 and 29 years in age, a convenience sample recruited from recreational facilities, classrooms, and the university's campus. The force plate was utilized to measure anterior- posterior center of pressure (COP-AP) in terms of static and dynamic stability, as well as mediolateral center of pressure (COP-ML) in relation to dynamic stability with the purpose of detecting any sway in the orthogonal x, y, or z axes. Flexibility measures were taken with a manual goniometer and a sit-and-reach box (SRB). The goniometer quantified joint angles of the hip and ankle. The modified SRB evaluation assessed lower back and hamstring flexibility of each participant. We hypothesized that a strong correlation between stability and flexibility would be apparent in each subject, and that females would express a greater range of motion (ROM) than males. Significant and non-significant relationships were detected.

Keywords: *postural stability, static stability, dynamic stability, balance, flexibility, young adults, force plate, goniometer, sit and reach box*

Professionals in sports medicine are constantly modifying what exactly constitutes fitness. Currently, the five identified components of health related fitness are as follows: cardiorespiratory endurance, musculoskeletal fitness, body weight and composition, flexibility, and balance (Heyward, 2010). Conscious integration of each element into one's lifestyle is considered a critical ingredient for a healthy and active individual. Two of these components are largely neglected in applications concerning fitness health: balance and flexibility. In many instances, these factors are simultaneously addressed in exercise regimens, (e.g. yoga, tai chi, and pilates) and therefore highlights a negligence that appears to have a correlation in sports settings. What is the statistical significance of the relationship between these factors? Recent awareness of this deficiency in postural stability and flexibility has caught public attention, and exercise forms that promote these elements have gained considerable popularity in Western civilization and have even been applied to forms of allopathic medicine in order to optimize physical health and well-being (Massey, 2007).

Previously considered a performance-based measure in athletic parameters, postural stability, or balance, is the most recent addition to physical fitness criteria (Heyward, 2010). Little is known of postural stability's relationship to the other preceding components of functional fitness. However, an exception is a large amount research concerning the integrity of postural stability in the elderly demographic. These studies concerning postural stability have received a considerable amount of attention, and this accumulation of knowledge is largely concerned with the increasing risk of serious falls with old age. These researchers have concluded that higher instability in the elderly increases this risk, therefore making them more prone to serious injury from a fall in comparison to younger age groups. Balance is the most recently accepted component of health related fitness, and research lacks critical information concerning its importance in the physical well-being in the younger population. Implications concerning methods to integrate activities addressing postural stability in young people have the potential to reduce the instances of serious falls in the elderly in future generations.

Like postural stability, maintenance of flexibility is underrated in the scope of physical well-being. However, it is often included in health-related fitness batteries, and it has since been accepted that an absence of flexibility impacts musculoskeletal health (Heyward, 2010). In addition to postural stability evaluations, the majority of flexibility measures have been assessed predominantly in the elderly. Cross-sectional studies comparing young and older populations have suggested that range of motion (ROM), or the full movement potential of a joint, becomes limited with an increase in age. Similar to postural stability, it is difficult to locate studies that omit the variable of old age. In addition to a relative absence of research targeting the younger population, the majority of studies fail to address the difference between males and females. Therefore, we were interested in the implications of gender in flexibility.

Significance of the correlation between postural stability and flexibility requires further clarification in young people. Ideally, the following results will promote greater understanding of the significance of balance and flexibility in physical fitness, as well as the influence of gender on ROM. Each component was addressed in hopes of providing a framework in which studies can be understood and applied to further research.

LITERATURE REVIEW

The following literature review is separated into categories that address critical components of the study concerning postural stability and flexibility. Subcategories under postural stability include differences between age groups and its relationship with physical activity. Differences in age groups, gender differences, and the connection with physical activity are topics of flexibility research addressing this study.

Postural Stability

Differences between age groups

The maintenance of whole body stability lessens as an individual reaches old age. The neuromuscular system is directly linked to postural stability performance, with biomechanical and anatomical elements serving as determinants of physiological integrity. Further components of postural stability include sensory systems, musculoskeletal structure, and the peripheral and sensory nervous systems. These body subsystems are compromised as an individual ages, ultimately leading to a decline in overall balance. Current posturography research has accepted that the sensory system weakens in older adults to the extent that balance is directly impacted (Choy, Brauer, & Nitz, 2003). Clinical studies have attributed the diminished functions of visual, vestibular, and somatosensory systems to be the primary factors leading to the decrease in postural stability of the elderly (Woollacott, Shymway-Cook, & Nasher, 1986; Teasdale, Stelmach, & Breunig, 1991). Elevated instances in acquired hearing loss in the elderly are directly related to a loss in body equilibrium and proprioception, which are essential to the integrity of balance performance. Compromised visual acuity also decreases coordination and joint angle awareness (Teasdale et al., 1991). Age-related diseases such as osteoporosis and arthritis contribute to limitations in postural balance, and instances of muscle wasting are not uncommon in the elderly demographic, especially in those who lead sedentary lifestyles (Todd & Skelton, 2004). The majority of clinical findings indicate that a larger frequency and amplitude of postural sway is more prevalent in the elderly during stance. This has been attributed to the limited sensation of vibration throughout the lower extremities. Sihvonen (2004) noted that peak values in static and dynamic stability are obtained in young adulthood and maintain full potential through the average age of 55, but states that physiological decline occurs near the age of 65. However, Sihovonen (2004) included both men and women in his study while Choy et al. (2003) utilized data from a female participant pool. This indicates that gender differences in studies concerning posturography have the potential to skew data, making it difficult to draw comparisons and conclusions based on the isolated variable of age and its effect on postural stability. Research that targets the body balance of young adults, with the exception of elite athletes, is largely absent.

Physical Activity and Postural Stability

In terms of postural stability, exercise has been attributed to both the correction of displacement and the perception of displacement. The correction of displacement indicates stronger muscles, better balance, and an increased sense of proprioception. Perception of displacement pertains to reduced edema and an increased ROM at the site of the ankle joint. (Skelton, 2001). Skelton (2001) concluded that in order to improve these factors as well as modify certain risk factors for falling, moderate physical activity is appropriate. Researchers have suggested that as level of athleticism improves, static and dynamic abilities in stance are enhanced with training. This indicates a positive correlation between exercise and integrity of body stability. These findings are strongly correlated with those in the study of Paillard et al. (2006) whom assessed the differences in postural stability between athletes who compete at regional and national levels. Paillard et al. (2006) found that balance performances were significantly superior in the national athletes in comparison to the regional players. He attributed this discrepancy to the national level athletes' greater sensitivity of sensory receptors as well as their heightened level of information integration. Clinical studies have indicated that postural stability performance varies throughout the wide spectrum of sport activity types. In their study assessing balance diversities between female athletes in basketball, soccer, and gymnastics, Bressel, Yonker, Kras, & Heath (2007) found significant differences in static and dynamic performances when comparing the sport-specific populations. Their results expressed that female basketball players demonstrated inferior static balance compared with gymnasts and inferior dynamic balance compared with soccer players. When comparing the static and dynamic balances between gymnasts and soccer players, no differences were found. Bressel et al. (2007) concluded that rather than participation in general sport activity, specific sensorimotor challenges appear to serve as the predominant factor in developing optimal balance. These evaluations demonstrate that postural stability integrity cannot be predicted by mere activity level, but by specificity of certain muscles and joints most commonly trained in that particular activity. Research concerning postural stability performance of active individuals outside of high level sports training requires further clarification.

Flexibility

Differences between age groups

Trends indicate a decrease in flexibility with aging (Chapman, 1971), which is largely attributed to a loss in elasticity in the connective tissues surrounding the muscles. In general, these muscles throughout the body endure a natural shortening process as a result of decreased frequencies of physical activity (Kravitz and Heyward). In addition to a deterioration in the musculature, as much as a 50% decreases in ROM in certain joints have been attributed to age. This is especially apparent in sites that are subject to overuse and wear, such as the knees and ankles. In a study utilizing a female population, Brown and Miller (1998) demonstrated that ROM quantified with the SRB decreased approximately 30% for women between 20 and 70+ years of age. Buckwalter (1997) suggested that a gradual deterioration of cell function within cartilage, ligaments, tendons, and muscles is the mechanism for this loss of ROM as the aging process continues. Raab, Agre, McAdam, & Smith (1988) proposed that because the elderly suffer a significant loss in joint ROM, this usually results in limited daily activities. However, regular exercise, including stretching exercises to enhance flexibility, has the ability to minimize the effect of this age-related decrease in ROM, as indicated by Bassey, Morgan, Dallosso, & Ebrahim (1989) in comparing shoulder abductions between young and elderly populations. Therefore, this decline in ROM potential as one becomes older is age related, but not age dependent. Performance levels of flexibility in the younger demographic are also critical in understanding flexibility as a component of physical well-being.

Differences in gender

Although men and women are structurally similar, they demonstrate slight variations in connective-tissue anatomy and joint structures throughout the body. The most significant of these variations is found at the level of the pelvis. The female pelvis is accommodated for gestation, and is therefore proportionately wider than that of their male counterparts. As the pelvic region is wider, the acetabula are further apart, maximizing the distance between the greater trochanters and consequently the width of the hips. In addition to a narrower hip anatomy, men generally have longer bones and a greater structural height than women. The average male also distributes the majority of body mass in his upper extremities and trunk. The sum of these components increases the space between the center of gravity and the base of support. In contrast to men, women are more prone to exhibiting a “pear shape,” or carrying the majority of their weight in their hips and upper thighs (Heyward, 2010). Given these differences in skeletal anatomy and musculature, it is possible that there is a direct correlation between gender and ROM performance.

Holland (1968) suggested that females tend to demonstrate greater ROM than males throughout life, and that this difference is largely attributed to anatomical variations in joint structures and anthropometric make-up. Flexibility assessments addressing gender have indicated that the ROM of a woman is marginally greater than that of a man, such as in the study of Bell and Hoshizaki (1981). The research team measured 17 joint actions in eight specific joints from a sample of 190 male and female participants between 18 and 88 years. They found that as a population, females expressed greater degrees of flexibility than males. Alter (2004) also explained that anthropometric factors such as hip structure influence ROM, but that this is also affected by hormonal differences between men and women. Fluctuations in hormones are directly related to joint laxity, and such changes can be detected throughout a woman’s lifetime. In cases of female athletes, pubertal status is related to joint laxity, specifically at the sites of the acetabula and tibiofemoral joint. Although joint laxity increases ROM, it can also be detrimental if this laxity compromises support at the joint sites. In a study addressing the instance of ACL tears in female athletes, Hewett, Zazulak, and Myer (2007) investigated the effect of the menstrual cycle at the site of the tibiofemoral joint. They found that female athletes in the preovulatory period of their menstrual cycle are more prone to non-contact injury than when they are in the postovulatory stage in their cycle. This is largely attributed to fluctuations in estrogen levels, which in turn has an impact on the central nervous system, resulting in muscle lengthening and joint laxity. Hormones prevalent during pregnancy also contribute to variations in laxness found at female joints. Relaxin, a polypeptide hormone similar to insulin, is produced by the corpus luteum (Manarch et al., 2003), which has the most significant impact on joint laxity in the third trimester of pregnancy. In comparison to females, males demonstrate elevated levels of testosterone, which lead to muscle growth and shortening. This may ultimately impact ROM performance that males can achieve in specific movements.

Physical Activity and Flexibility

Healthcare practitioners assess flexibility through joint ROM and by quantifying the pliability of specific target areas. Regular exercise that utilizes full ROM generally augments flexibility. In contrast, one who leads a sedentary lifestyle is more susceptible to diminished flexibility (Beaulieu, 1980). Just as periodic exercise reinforces joint ROM, enhanced flexibility through stretching is also beneficial to the actual act of exercise. Sport specificity also implies the importance of flexibility as one of the factors of physical fitness. De Vries (1963) demonstrated that while stretching enhanced static ROM in sprinters, it resulted in no deviations in speed or energy cost in comparison to non-stretching performance. Andersen (2005) highlighted the importance of stretching prior to a bout of exercise or athletic event. A warm up targeting the cardiorespiratory system should be performed before stretching begins for the greatest performance potential and in order to reduce risk of injury (Safran, Garrett, Seaber, Glisson, & Ribbeck, 1988). Warm-up exercises of aerobics, stationary cycling, walking and jogging of an average of a five minute duration is sufficient in increasing blood flow to active skeletal muscle. This increase in blood flow carries nutrients and oxygen to targeted muscles, nourishing these active sites and preparing the individual for a bout of exercise. An active warm-up also serves to raise body temperature, eliciting a physiological reaction resulting in increased joint lubrication and therefore greater ROM potential. The chosen method of stretching has an impact on exercise performance as well. Stretching can be categorized into four main components: passive, ballistic, static, and proprioceptive neuromuscular facilitation (PNF) (Spernoga, Uhl, Arnold & Gansneder, 2001).

In addition to stretching, simple exercise also serves in enhancing ROM performance. Misner, Massey, Bemben, Going, & Patrick (1992) in a longitudinal study evaluating 12 females aged 50-71 years, demonstrated that regular exercise (15-30 minutes of stretching and 30-60 minutes of walking or water aerobics) 3 times per week for a duration of 5 years increased shoulder and hip ROM significantly (3%-22% in various joint actions). ACSM (2006) recommends that preventative and rehabilitative exercise programs should include activities that promote the maintenance of flexibility. While habitual exercise is critical in prolonging full ROM throughout one’s life, flexibility itself is essential to active individuals in order to perform daily activities with fluidity and ease.

Purpose of Study

The objective of this study was to evaluate the relationship between balance and flexibility in active young adults and to assess differences in flexibility between men and women. A major relevance of this study to current research is that postural stability has only been considered a fitness component in recent years. To demonstrate its importance in training and preventative regimens our goal was to test the strength of the correlation between flexibility and both static and dynamic stability. An additional motive in conducting this study was that the majority of research concerning balance and flexibility targets the elderly and is constructed around fall prevention. Lastly, the majority of clinical studies concerning ROM differences between men and women target the elderly demographic. Data supporting these differences are largely inconclusive in the young population. Therefore, we chose to utilize a young, active population on which to perform postural stability and ROM assessments.

Hypotheses

H_o1 Flexibility is not related to static stability

H_o2 Flexibility is not related to dynamic stability

H_o3 There is no difference in ROM between females and males

H1 Flexibility is related to static stability

H2 Flexibility is related to dynamic stability

H3 Females have a greater ROM than males

METHODS

Participants

Twenty young, active, healthy adults volunteered for this study. A convenience sample of participants was recruited from campus, recreational facilities, community health clubs, and from SES classes. These locations have been specifically chosen to increase the probability that the subjects will be those who lead a healthy and active lifestyle. We tested subjects that fell within the age range of 20-29 years and who were free of any existing skeletal or neuromuscular conditions that could potentially limit their participation in the study (mean age, with SD; mean body mass, with SD; mean body height, with SD).

Participants attended one testing session. Initially, the experimental protocol was explained and all participants offered their consent to participate in accordance with the university’s

Institutional Review Board. Demographic and anthropometric data were then collected. Each person completed a form that inquired about age, an estimation of weekly physical activity, and a self-assessment of current fitness level. All participants were asked to record any physical activity performed in a typical week (e.g., if they are involved in a sport). Then flexibility of lower extremity joints was assessed, followed by static and dynamic stability assessments.

Instruments

Flexibility

The primary device used to assess flexibility was a manual goniometer, shown in Figure 1. A goniometer is an instrument that measures an angle or quantifies an individual's range of motion at an anatomical joint. The flexibility assessments of the hip and ankle required placement of the goniometer's axis over the joint axis of rotation. One arm of the goniometer was aligned along a proximal segment, while the other was aligned along the distal segment. An angle was then recorded at these joints for all participants. To further evaluate flexibility, we used the modified version of the standard sit-and-reach (SR) test. The modified SR assessment evaluated lower back and hamstring flexibility. Participants were seated on the floor, with their backs against the wall, and the SR instrument was placed against their feet and then zeroed while the person comfortably reached forward with both hands. Centimeters were the choice unit of length for the modified SR test. In the bent knee assessment of talocrural dorsiflexion, a rolled towel of approximately 5 in. diameter was used to support the tibiofemoral joint.

Figure 1. Manual Goniometer

Postural (Dynamic/Static) Stability

An AMTI force plate was used to quantify stability. A force plate is an instrument that records ground reaction force (GRF) generated by a body standing or moving across the device to quantify balance, gait, and other parameters of biomechanics. Balance and jump plates have 3 force components about the x, y, and z axes and 3 moment components along the x, y, and z axes for a total of 6 outputs. For the present study, Fx and Fy were used to assess dynamic stability and the coordinates of the center of pressure (COP) were used to assess static stability. Although not a part of the 6 primary outputs, COP coordinates were calculated by the data collection software.

Procedures

At the testing session, participants were provided with a 10-15 minute warm-up period in which they walked, stretched or performed another low intensity exercise of their choice. The order of testing was consistent across participants to ensure that one subject was not physically taxed before the others during their protocols.

For the static stability assessments, each participant stood as still as possible on one leg, while looking forward (gaze fixed at a target on the wall). Hands were placed on their waist. Four conditions were tested: standing on right leg on a hard surface; standing on left leg on a hard surface; standing on right leg on a soft surface; and standing on left leg on a soft surface. For the soft surface conditions, a foam mat was placed on the surface of the force plate. Force data were collected for 20 s at a sampling rate of 100 Hz.

The dynamic stability assessments required participants to hop onto the force plate, land one-footed, and become as still as possible. Four conditions were tested: a forward landing following a step-step-hop approach (landing on right foot and left foot); and a side landing after a short hop sideways (completed for right and left foot landings). Again, force data were collected for 20 s at a sampling rate of 100 Hz.

Flexibility Assessment

Thomas Test (Hip flexion)

Prior to the evaluation we located the greater trochanter which served as the axis of the goniometer. We then had the subject lie supine on the bench with both legs extended and ensuring the entire body was on the bench. Arms were held out to the side. The participant lifted one leg with the help of the evaluator in an active-assisted stretch to its full ROM while maintaining a locked knee. The proximal arm of the goniometer was placed parallel to the midaxillary line and the distal arm was parallel to the femur. Three trials were performed with each leg.

Hip Extension

The subject started at the end of the bench with the edge resting at midthigh level. From this position the subject was assisted into the supine position and then pulled the opposite of the target leg into hip flexion, with the knee flexed. We then quantified the angle of hip extension and the angle of the knee joint (ipsilateral). Three trials for each leg were recorded.

Talocrural Dorsiflexion (Knee Straight)

The participant lied prone with their knee extended and with the ankle positioned so that it extended beyond the length of the bench. The tibia was supported against the bench surface by the assessor. Once the subject flexed their foot proximally to its full ROM into an active assisted stretch, the goniometer axis was positioned at the lateral malleolus. The proximal arm of the goniometer axis was parallel to the long axis of the fibula and pointed towards the fibular head, and the distal arm aligned with the long axis of the 5th metatarsal. A total of three trials were conducted for each leg.

Talocrural Dorsiflexion (Bent Knee)

The participant lied prone with their knee extended and will the ankle positioned so that it extended beyond the length of the bench. A bolster was slid under the knee so that it was in passive flexion. Once the patient flexed their foot proximally to its full ROM in an active-assisted stretch, the goniometer axis was positioned at the lateral malleolus. The proximal arm of the goniometer was placed parallel to the long axis of the fibula and pointed toward the fibular head, and the distal arm aligned with the long axis of the 5th metatarsal. A total of three trials were conducted for each leg.

Modified Sit and Reach

The subject sat against a wall while maintaining a flat back. They sat on the floor with the SRB and completely extended both legs in a way that the sole of the foot was flat against one side of the box. The participant then held their arms out with one hand placed on top of the other (with palms down and one hand on top of the other in a way that the middle fingers were aligned). The SR was then adjusted to the individual’s arm length. Keeping the knees as straight as possible, the subject slowly reached forward and slid their hands along the adjustable arm. Measurements were from zero (initial arm length point) to the final displacement. The evaluation was conducted for three trials.

DATA ANALYSIS

Data collected from the force plate during static and dynamic stability assessments were low-pass filtered (15 Hz cut-off frequency) with a

Butterworth digital filter. COP coordinates were then calculated within the Motus motion analysis software dependent variables for stability assessments were then calculated with custom MATLAB software. For static stability, COP motion was quantified by calculating the mean, anterior-posterior COP velocity during the 20 s trial (Prieto, Myklebust, Hoffman, Lovett, & Myklebust, 1996). Lower velocities are indicative of good stability. For dynamic stability trials, medial-lateral and anterior-posterior stability indices were calculated in accordance with Wikstrom, Tillman, Schenker, & Borsa (2008). These indices assess the fluctuations of the horizontal forces around zero, by calculating a mean square deviation over the first 3 s after landing. Lower indices are indicative of a person becoming stable more quickly.

Each participant was coded chronologically (1-20) upon entry into the system as well as with a letter (M/F) to indicate gender. Pearson-product correlations tested the strength of relation between flexibility and both assessments of stability. A one-tailed t-test was used to test the difference in flexibility between men and women. Resulting p-values exceeding 0.05 were not considered statistically significant.

RESULTS

Mean values for all range of motion measurements are presented in Table 1. Measurements were made from the anatomical position. Larger values, therefore, indicate greater range of motion for that joint in a particular direction (e.g., flexion, extension). It should be noted that minimum angles for HEL and HER in Table 1 are from one person who was unable reach the anatomical position for that specific evaluation.

Table 1
Overall Mean Flexibility Measures

Test	*M*	*SD*	*Max*	*Min*
HFL	82.5	13.1	110	58
HFR	85.2	12.5	105	62
HEL	16.7	7.6	27	-6
HER	16.0	9.2	32	-13
ADFL	7.4	4.7	16	1
ADFR	7.4	5.0	19	2
ADFTL	9.6	5.0	20	3
ADFTR	10.7	5.1	23	4
SAR	38.9	6.9	44.5	32.5

Note. All values except Sit-and-Reach (SAR) have the unit of degrees. SAR is cm. HFL = hip flexion left; HFR = hip flexion right; HEL = hip extension left; HER = hip extension right; ADFL = ankle dorsiflexion, with knee fully extended, left; ADFR = ankle dorsiflexion, with knee fully extended, right; ADFTL = ankle dorsiflexion, with towel under knee for slight flexion, left; ADFTR = ankle dorsiflexion, with towel under knee for slight flexion, right

Although not a component of the primary hypotheses of the present study, static stability was compromised when participants were required to stand on a soft surface (i.e., mean velocity is higher for both right and left limbs, as shown in Table 2).

Correlation coefficients between all flexibility measures and static stability measures are shown in Table 3. Scatterplots for statistically significant correlations are then shown in Figures 2-5.

Table 2
Mean anterior-posterior COP velocity for all surface-foot conditions

Condition	*M*	*SD*
Hard-Left	26.77	10.02
Soft-Left	34.17	11.43
Hard-Right	27.82	10.38
Soft-Right	38.30	14.71

Note. units are mm/s

Table 3
Correlation Coefficients between Flexibility and Static Stability

Test	SL	HL	SR	HR
HFL	-0.34	-0.51*		
HFR			-0.23	-0.47*
HEL	-0.11	-0.17		
HER			0.03	-0.25
ADFL	0.48*	0.09		
ADFR			0.20	0.26
ADFTL	0.45*	0.03		
ADFTR			0.09	0.09
SAR	0.18	0.00	-0.10	-0.08

Note. SL = soft-left condition; HL = hard-left condition; SR = soft-right condition; HR = hard-right condition; HFL = hip flexion left; HFR = hip flexion right; HEL = hip extension left; HER = hip extension right; ADFL = ankle dorsiflexion, with knee fully extended, left; ADFR = ankle dorsiflexion, with knee fully extended, right; ADFTL = ankle dorsiflexion, with towel under knee for slight flexion, left; ADFTR = ankle dorsiflexion, with towel under knee for slight flexion, right; SAR = sit-and-reach.
*p < .05

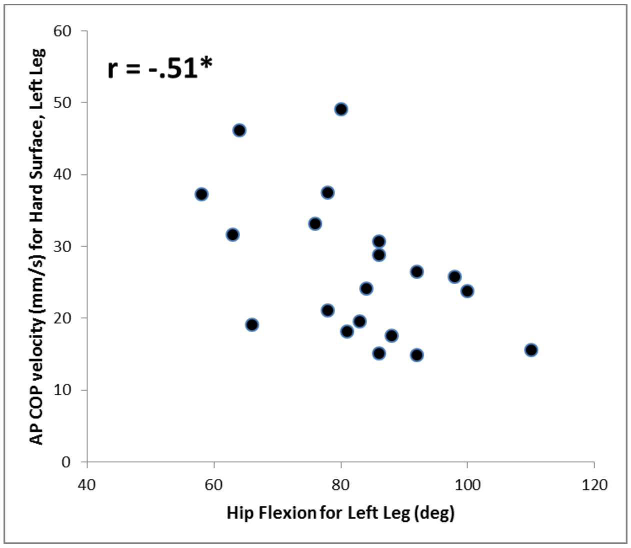

Figure 2. Scatterplot for left hip flexibility (flexion) and static stability (hard surface, left leg)

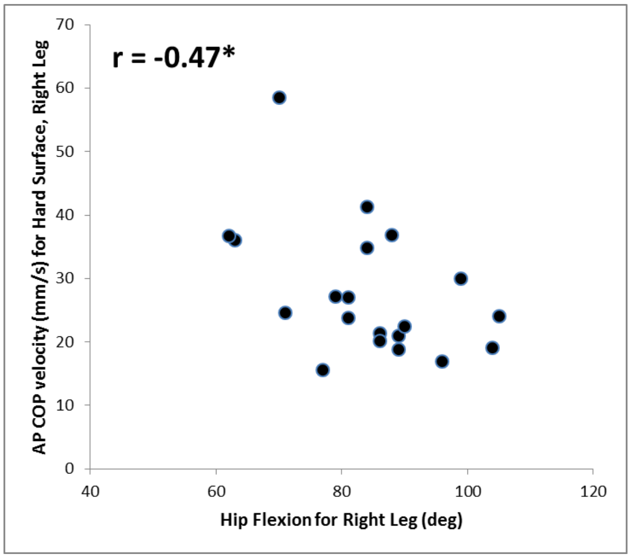

Figure 3. Scatterplot for right hip flexibility (flexion) and static stability (hard surface, right leg)

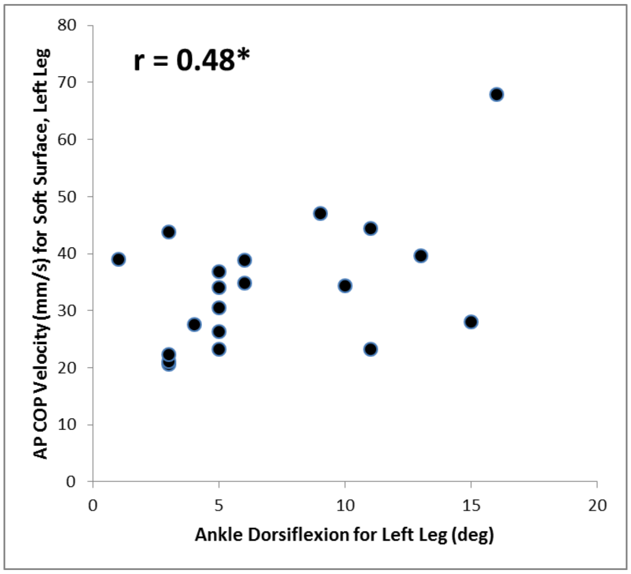

Figure 4. Scatterplot for left ankle flexibility (dorsiflexion) and static stability (soft surface, left leg).

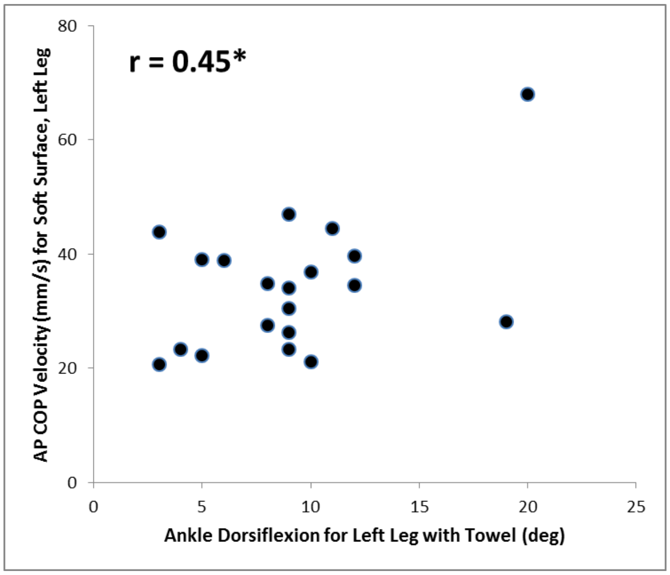

Figure 5. Scatterplot for left ankle flexibility (dorsiflexion) and static stability (soft surface, left leg)

Dynamic stability indices are influenced by the landing direction. As shown in Table 4, the anterior-posterior index is higher for landings from a forward hop, whereas the mediolateral indices are higher for the landings from a side hop. This is consistent with data collected previously in our lab.

As with static stability, the correlation coefficients between all flexibility measures and dynamic stability measures are shown in Tables 5 and 6. A scatterplot for the one statistically significant correlation is then shown in Figures 5.

Table 4

Mean anterior-posterior and medial-lateral stability indices for all landing-foot conditions

Condition	*Map*	*SDap*	*Mml*	*SDml*
Forward-Left	76.86	20.74	18.35	13.93
Side-Left	15.79	3.24	41.66	6.60
Forward-Right	81.83	14.84	13.07	3.17
Side-Right	16.85	6.51	36.43	8.33

Note: ap = anterior-posterior; ml = medial-lateral

Table 5
Correlation Coefficients between Flexibility and Anterior-Posterior Dynamic Stability

Test	FL	SL	FR	SR
HFL	-0.02	0.08		
HFR			0.21	-0.03
HEL	-0.30	0.06		
HER			-0.22	-0.18
ADFL	0.10	0.12		
ADFR			-0.04	-0.14
ADFTL	-0.02	0.13		
ADFTR			0.04	-0.19
SAR	0.02	0.05	0.06	0.04

Note. SL = soft-left condition; HL = hard-left condition; SR = soft-right condition; HR = hard-right condition; HFL = hip flexion left; HFR = hip flexion right; HEL = hip extension left; HER = hip extension right; ADFL = ankle dorsiflexion, with knee fully extended, left; ADFR = ankle dorsiflexion, with knee fully extended, right; ADFTL = ankle dorsiflexion, with towel under knee for slight flexion, left; ADFTR = ankle dorsiflexion, with towel under knee for slight flexion, right; SAR = sit-and-reach

Table 6
Correlation Coefficients between Flexibility and Mediolateral Dynamic Stability

Test	FL	SL	FR	SR
HFL	-0.02	0.00		
HFR			0.09	-0.05
HEL	-0.20	-0.24		
HER			-0.54*	-0.15
ADFL	0.40	0.24		
ADFR			-0.06	0.10
ADFTL	0.42	0.17		
ADFTR			-0.19	0.11
SAR	0.13	-0.04	0.13	-0.04

Note. SL = soft-left condition; HL = hard-left condition; SR = soft-right condition; HR = hard-right condition; HFL = hip flexion le5t; HFR = hip flexion right; HEL = hip extension left; HER = hip extension right; ADFL = ankle dorsiflexion, with knee fully extended, left; ADFR = ankle dorsiflexion, with knee fully extended, right; ADFTL = ankle dorsiflexion, with towel under knee for slight flexion, left; ADFTR = ankle dorsiflexion, with towel under knee for slight flexion, right; SAR = sit-and-reach
*p < .05

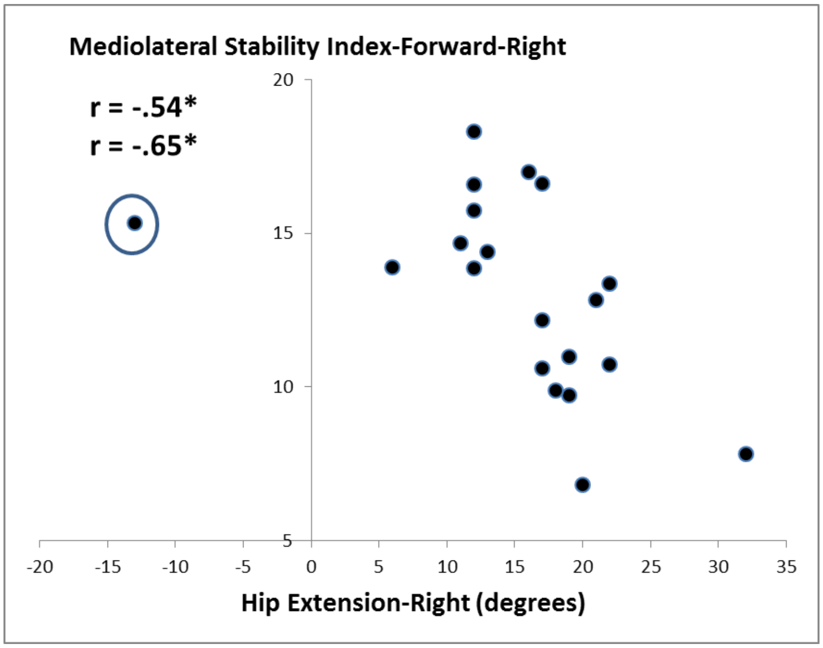

Figure 5. Scatterplot for right hip flexibility (extension) and dynamic stability (mediolateral forward, right). Top correlation coefficient is for all data points and bottom correlation coefficient is for sample without circled data point. *p < .05

Finally, the flexibility between men and women showed some slight contradictions. Women were significantly more flexible than men in the instances of HEL (p= 0.002) and HER (p= 0.006), supporting the hypothesis that women would demonstrate greater flexibility than men. However, this same hypothesis was contradicted with the measurements of ADFL (p=0.043), ADFR (p=0.039), ADFTL (p=0.027), indicating that men had greater ROM in these ankle measurements.

Table 7
Mean flexibility values of men and women

Test	*Mw*	*SDw*	*Mm*	*SDm*
HFL	82.5	7.35	82.38	15.50
HFR	84.08	6.73	84.38	14.15
HEL	19.33*	4.96	11.50	6.67
HER	18.42*	5.45	10.50	8.50
ADFL	5.83	3.49	8.63*	4.11
ADFR	5.67	2.06	8.50*	4.90
ADFTL	7.75	3.22	11.00*	4.47
ADFTR	9.17	2.89	11.50	4.73
SAR	41.42*	4.26	35.19	6.90

Note: w = women; *m* = men; HFL = hip flexion left; HFR = hip flexion right; HEL = hip extension left; HER = hip extension right; ADFL = ankle dorsiflexion, with knee fully extended, left; ADFR = ankle dorsiflexion, with knee fully extended, right; ADFTL = ankle dorsiflexion, with towel under knee for slight flexion, left; ADFTR = ankle dorsiflexion, with towel under knee for slight flexion, right; SAR = sit-and-reach.
*p> .05

DISCUSSION

The aim of the present study was to identify any relationships that exist between postural stability and flexibility and also to evaluate differences in ROM between genders. Few flexibility measures were significantly related to stability measures. However, the correlations found at the hip level demonstrated a moderate relationship between hip flexion and hard surface static conditions. Another apparent relationship was detected between soft surface static conditions and the left ankle dorsiflexion measurements. Dynamic stability and flexibility resulted in only one significant correlation, which was that of the mediolateral movement of the forward hop dynamic test and hip extension of the right leg. Secondly, women were found to be more flexible than men in the instances of hip extension, which is consistent with the stated research hypothesis.

Unlike the study conducted by Kettunen et al. (2000), the present study recorded hip flexion measurements in relation to the angle made with the midaxillary axis of the body and the line parallel to the femur, and resulted in an average of 85.35 deg. (averaged between the right and left extremities). Therefore greater values indicated a decreased range of motion, while higher angles indicated greater flexibility. In the compared study of Kettunen et al. (2000), the complementary angle was considered, resulting in values greater values that represented greater flexibility and expressed a mean of 139.4 – 140.6 deg. In the instances of hip extension, however, the reported means ranged from 15.8 - 18 deg., a value consistent with the data gleaned in the present study (16.35; the averaged value of right and left extremities). Similar to the present study, the clinical assessments of Mecagni, Smith, Roberts, & O’Sullivan (2000) demonstrated both comparable methods in evaluating ankle dorsiflexion values and similarities in the gathered results. Mecagni et al. (2000) evaluated ankle dorsiflexion in an active-assisted manner with conditions of the knee fully extended and slightly bent. Mean results were 10.9 degrees for a flexed knee, and 8.45 degrees for a fully extended knee. This was fairly consistent with data gathered from the present study, which reported 10.15 deg. for a flexed knee and 7.4 deg. for a fully extended knee, These values were derived from averaging the mean values of the right and left extremities. The study of Zapartidis et al. (2011) reported the modified SAR values as 36.67 cm for females and 32.42 cm for males. This was fairly consistent with our gleaned values, which reported an average of 41.42 cm for females and 35.19 cm for males. However, this study reported the best performance of three trials while the present study averaged the three trials for a final value.

Static stability indices in the anterior-posterior direction in our study were considerably higher than those reported by Cote, Brunett II, Gansneder, and Shultz (2005), demonstrating a range of 15.06- 68.18. In the study of Cote et al. (2005), the SI measurements did not exceed the value of 1.0.

The dynamic stability indices for anterior-posterior and mediolateral were considerably higher than those reported by Wikstrom, (2008). They reported values less than 1.0 for all stability indices and all directions of jump landings. Although their jump-landing protocol was different than the present study, this alone would not explain the large differences in values. In the present study, the relative difference between AP and ML index scores for the different directions of landings make intuitive sense. In other words, the AP index was higher than the ML index for forward-directed landings, whereas the opposite was true for side-directed landings (Table 5 and Table 6).

Implications of Correlations

Of the statistically significant correlations, the static postural stability conditions demonstrated a negative relationship in relation to hip flexion measurements. This indicates a situation where as flexibility angle increased (reduced ROM), static AP COP velocity decreased, indicating an increased situation of stability (Figure 2 and Figure 3). This demonstrates that the less flexibility an individual shows, the more stable properties they express in relation to flexion at the hip joint. This may be attributed to the condition of the rectus femoris in each participant, the major muscle which crosses the hip and is the primary knee extender of the leg.

In the instances at the ankle joint, AP COP velocity increased (static stability decreased) as ankle angles increased. The measurements at the ankle demonstrated a tendency of a higher amount of static whole body stability being correlated to a less flexible ankle joint. However, an outlier was present in each of these correlations, exaggerating the positive relationship between AP COP velocity and ROM (Figure 4 and Figure 5).

One statistically significant correlation was detected when addressing the relationship between dynamic postural stability and flexibility, which expressed a negative correlation concerning the mediolateral SI of the dynamic forward right condition and hip extension of the right leg. This demonstrated that as the stability index decreased (stability increased), hip extension of the right leg also increased.

Data comparing the flexibility performances between men and women indicated several statistically significant relationships. However, the flexibility at the ankle joint was significantly higher in men (again, largely contributed to the outlier present in the data), than in women. This not only failed to support our hypotheses, but opposed our initial predictions.

LIMITATIONS AND FUTURE RESEARCH

Although weekly exercise of each participant was self-estimated, our research team did not monitor the activity of the participants immediately prior to the testing session. It is possible that some engaged in physical activity while others did not. Those who participated in physical activity would have exhibited higher body temperature at active muscle sites, resulting in an increased ROM and reduced stiffness in the joint areas. Instructions to omit any major exercise in a certain timeframe prior to the investigation would maintain consistency. Another limitation of the present study was that instances of previous injury at the hip, knee, or ankle joint was not included in the intake form and was not a primary consideration when evaluating postural stability and flexibility performances. However, certain participants noted occurrences of previous injury at the ankle, although it was not discussed with all subjects nor was it included as a major component of the present study. Finally, a larger sample would have resulted in greater statistical power, thus allowing real differences to be more clearly identified. Further research would include a longitudinal study tracking hormonal fluctuations in women and how this impacts ROM. Another longitudinal study would be to test the benefits of exercises incorporating balance and flexibility and their importance as preventative and rehabilitative fitness batteries.

In conclusion, it is critical to consider postural stability and flexibility as key components of health related physical fitness. Through this awareness, we have the potential to optimize athletic performance as well as body integrity when performing daily activities. While evaluating ways in which to improve balance and flexibility in the elderly is essential, we must consider the implications of incorporating these regimens at a younger age in order to reduce the instance of serious falls in addition to other physical impairments in those of mature age.

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